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DE LOS FINES Y PROPÓSITOS DE EDUWEB, REVISTA DE TECNOLOGÍA DE INFORMACIÓN Y COMUNICACIÓN EN EDUCACIÓN

Eduweb, la revista de Tecnología de Información y Comunicación en Educación, es una publicación de carácter nacional e internacional de divulgación del conocimiento, del uso, aplicación y experiencias de las Tecnologías de la Información y Comunicación (TIC) en ambientes educativos. Con la revista se pretende divulgar las innovaciones que en materia de TIC están siendo implementadas y ensayadas en los diferentes niveles y modalidades del sistema educativo venezolano e iberoamericano. De igual manera contribuir a proyectar las experiencias de estudiantes de pre y postgrado, docentes, investigadores y especialistas en TIC en educación en la Universidad de Carabobo y en otras universidades de Venezuela y de otros países de Iberoamérica. Es una revista arbitrada e indexada adscrita al programa de la especialización en Tecnología de la Computación en Educación, de la Facultad de Ciencias de la Educación de la Universidad de Carabobo, registrada bajo el ISSN 1856-7576. Editada en formato impreso y digital.

Visión

Ser un espacio académico-científico de difusión y divulgación de las distintas tendencias del pensamiento universal ubicadas en el área de TIC en ambientes educativos, con altos niveles de calidad académica.

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Promover y facilitar la difusión y divulgación de los productos de las investigaciones y experiencias de los docentes e investigadores de la Universidad de Carabobo y otras universidades del país y del mundo en el área de TIC en ambientes educativos; motivar la participación en redes comunes de información y publicación nacional e internacional; coordinar esfuerzos y velar por la calidad de las publicaciones a fin de procurar elevar el nivel académico del personal docente y de investigación mediante el desarrollo de trabajos de investigación como función esencial en su crecimiento académico.

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Servir como órgano de divulgación de las TIC y su influencia en ambientes educativos. Estimular la producción intelectual no solo en los docentes e investigadores de la Universidad de Carabobo, sino también en otros centros de educación e investigación nacional e internacional.

Propiciar el intercambio cultural, académico, científico y tecnológico con otros centros de educación superior en Venezuela y el mundo.

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Original Article

Editorial

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En este número de la *Revista Eduweb*, dedicado a IA y nuevos escenarios educativos, planteamos una reflexión profunda sobre cómo estas tecnologías están transformando la experiencia formativa. Se trata de incorporar herramientas digitales y de comprender los cambios epistemológicos, éticos y pedagógicos que acompañan a la inteligencia artificial en su expansión hacia los ámbitos de la vida académica.

Durante este año, la conversación global sobre educación ha estado marcada por tres fenómenos que atraviesan nuestras instituciones con una intensidad inédita: la automatización de tareas cognitivas, la emergencia de entornos de aprendizaje aumentados, y la necesidad urgente de fortalecer la alfabetización digital crítica. Estos fenómenos constituyen el tejido mismo de la educación contemporánea y exigen una mirada lúcida, capaz de distinguir la promesa del riesgo, la eficiencia de la responsabilidad y la innovación de la ética.

En este contexto, resulta imprescindible observar hacia dónde se dirige la inteligencia artificial en el ámbito de la investigación. Una de las iniciativas más significativas es LeapSpace™, la plataforma de IA académica desarrollada por Elsevier. Aunque su acceso está restringido a instituciones suscritas, LeapSpace representa un modelo de IA confiable, transparente y trazable, construido exclusivamente sobre literatura científica verificada. Su valor para este editorial no radica en su disponibilidad, sino en lo que simboliza: una nueva generación de IA responsable, diseñada para acompañar procesos de lectura profunda, análisis conceptual, verificación de afirmaciones y escritura académica.

LeapSpace muestra cómo la IA puede integrarse en la investigación sin sustituir al investigador, ya que potencia su capacidad de pensar, argumentar y conectar ideas con evidencia sólida. Es un ejemplo de hacia dónde se mueve la IA cuando se orienta por principios de rigor, transparencia y ética. Para quienes deseen conocer más, la información oficial está disponible en https://www.elsevier.com/

Sin embargo, la mayoría de nuestros lectores, docentes, estudiantes, investigadores independientes, no cuentan con acceso institucional a plataformas de este tipo. ¿Qué sentido tiene entonces hablar de LeapSpace? El sentido es pedagógico y estratégico, es decir, comprender el estándar que debería guiar el uso de IA en educación y en investigación.

La alfabetización digital crítica consiste en desarrollar la capacidad de:

- Evaluar la confiabilidad de una IA
- Distinguir entre evidencia y contenido inventado
- Verificar fuentes

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- Comprender sesgos algorítmicos
- Adoptar prácticas responsables de producción académica

En un entorno caracterizado por la información automatizada, esta alfabetización se convierte en una competencia esencial para la formación universitaria. La IA amplía nuestras capacidades y exige nuevas formas de discernimiento, nuevas preguntas y responsabilidades. Por ello, este editorial propone que, más allá de las plataformas específicas, los lectores adopten principios que sí están a su alcance, tales como el uso de ORCID, la verificación de DOI, la consulta de bases abiertas, la lectura crítica de metadatos, la comprobación de afirmaciones y la integración de herramientas gratuitas que permiten navegar conceptos, organizar literatura y fortalecer argumentos. LeapSpace funciona como referente conceptual, pues nos ayuda a visualizar el horizonte hacia el cual deben evolucionar las herramientas abiertas y las prácticas cotidianas de investigación.

Por su parte, los artículos reunidos en este volumen exploran cómo la inteligencia artificial está transformando la docencia, la evaluación, la interacción en las aulas virtuales, la producción de materiales educativos y la construcción del pensamiento crítico. Cada contribución amplía el mosaico del cambio educativo contemporáneo y ofrece claves para comprender un presente que avanza con rapidez, pero que exige profundidad. La incorporación de la IA en los espacios educativos no constituye únicamente una cuestión tecnológica. Su presencia plantea nuevas preguntas sobre distintos aspectos, tales como las formas de enseñar y aprender, el papel de docentes y estudiantes, así como las decisiones que orientan los procesos formativos. En este escenario, innovar implica también revisar prácticas, reconocer desafíos y asumir con responsabilidad las oportunidades que ofrecen estas herramientas.

La presente edición muestra, desde distintas perspectivas, que la inteligencia artificial puede contribuir a enriquecer las experiencias educativas, favorecer nuevas formas de interacción y ampliar las posibilidades para la creación y circulación del conocimiento. Al mismo tiempo, pone de relieve la necesidad de abordar críticamente sus usos, considerando aspectos como la autonomía, la ética, la inclusión, la calidad de la información y el desarrollo de competencias que permitan desenvolverse de manera consciente en entornos digitales.

Este número de la *Revista Eduweb* es una invitación a pensar críticamente la IA, a explorar sus posibilidades y a reconocer sus límites. Que sus páginas contribuyan al diálogo entre innovación y responsabilidad y nos permitan imaginar escenarios educativos capaces de responder ante la complejidad del mundo digital que habitamos, sin perder de vista aquello que da sentido a la educación: la capacidad humana de aprender, crear, cuestionar y construir nuevos escenarios.

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Original Article

Mediación instrumental con Inteligencia Artificial en la promoción del pensamiento crítico de estudiantes universitarios

The instrumental mediation of Artificial Intelligence in fostering critical thinking in higher education students

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Resumen

El propósito del presente artículo se centra en valorar el significado de la mediación instrumental con Inteligencia Artificial en la promoción del pensamiento crítico de estudiantes universitarios de la Facultad de Ciencias de la Educación de la Universidad de Carabobo. La rapidez con la que se desarrollan las tecnologías emergentes y la manera como se integran en la vida de los ciudadanos contemporáneos, hacen pensar en la necesidad de abordar el tema de la inteligencia artificial en el contexto de la formación universitaria. La metodología considerada en esta investigación fue de tipo cualitativo enmarcada en el paradigma interpretativo. Se asumió un diseño fenomenológico hermenéutico. Se utilizó como técnica la observación a partir de registros realizados en el contexto de un aula universitaria con diez estudiantes del área de Castellano en la Facultad de Ciencias de la Educación de la Universidad de Carabobo. El abordaje cualitativo se desarrolló a partir de procesos de categorización, estructuración y triangulación de fuentes y teóricas que se evidencia en las interpretaciones de los abordajes cualitativos. Se concluye que la visión tradicional con la que se concibe la inteligencia artificial como herramienta instrumental debe trascender a una perspectiva de mediación didáctica integradora que permita a los estudiantes desarrollar competencias vinculadas al pensamiento crítico y a la reflexión de lo que leen y producen en las aulas universitarias.

Palabras clave: Mediación; inteligencia artificial; promoción; pensamiento crítico; universidad.

Abstract

The purpose of this article is to assess the significance of instrumental mediation with Artificial Intelligence in fostering critical thinking among university students at the Faculty of Education Sciences of the University of Carabobo. The rapid development of emerging technologies and their increasing integration into everyday life highlight the need to examine the role of artificial intelligence in university education. The study adopted a qualitative approach within the interpretive paradigm and followed a hermeneutic phenomenological design. Non-participant observation was conducted through field diaries over five weeks of activities involving ten students in the Spanish Language area. Data analysis included coding, categorization, structuring, and the establishment of relationships among categories, supported by Atlas.ti. The interpretation of the findings was strengthened through theoretical triangulation by contrasting the categories emerging from the observation records with conceptual frameworks and previous studies related to educational mediation, artificial intelligence, and critical thinking. The findings suggest that a merely instrumental use of artificial intelligence may encourage passive responses, whereas intentional didactic mediation promotes processes of comparison, reflection, information

assessment, and integrative written production. It is concluded that artificial intelligence can contribute to the development of critical thinking when its integration is articulated with mediation strategies that foster students' cognitive autonomy.

Keywords: didactic mediation; artificial intelligence; critical thinking; higher education; university.

Introducción

Las estrategias andragógicas constituyen una base significativa en el quehacer del estudiante universitario por cuanto el desarrollo de competencias y la consolidación de los aprendizajes pasan a ser responsabilidades compartidas entre un mediador que promueve situaciones y experiencias, elementos de mediación formal dentro de los contextos formales de educación universitaria y la actitud de los aprendices, quienes deben ser capaces de trascender en los saberes que se proponen como finalidades ulteriores de los procesos formativos.

En relación con lo expuesto, Guaicha Soriano et al. (2026) abordan la trascendencia de la pedagogía a la andragogía convierte al sujeto de aprendizaje en un ser "protagonista, activo, crítico y autodirigido" (p. 4) Esta visión transformadora que se da en el ámbito universitario exige del profesorado una actitud y un rol trascendente que va más allá de la perspectiva tradicional de enseñanza y que, en la contemporaneidad, se ve impulsada por las tecnologías emergentes como las herramientas de Inteligencia Artificial.

En este contexto de cambios abruptos y brechas emergentes entre el conocimiento, su producción y la consolidación de competencias cognoscitivas esenciales como el desarrollo del pensamiento crítico y la evaluación del contenido que se divulga en formatos digitales vertiginosamente, queda suspendida una pregunta ¿Cómo integrar las herramientas de Inteligencia Artificial de manera que influyan en favor del desarrollo integral del estudiante, específicamente en la autonomía de su pensamiento? La visión propuesta por Vendrell et al. (2026), quienes conjugan políticas educativas, organismos gubernamentales, "centros de investigación, universidades, profesorado y estudiantado" (p. 22) como los promotores del pensamiento crítico concebido como un eje transversal en el contexto de la educación universitaria. Se evidencia una necesidad en los aportes de Miranda y Chamorro-Mera (2026), quienes exponen que se sabe poco de la percepción de los actores académicos sobre las tecnologías como la Inteligencia Artificial.

Considerando los aportes de los mencionados autores y las necesidades que develan, se ha estructurado esta investigación cuyo propósito es valorar el significado de la mediación instrumental con Inteligencia Artificial en la promoción del pensamiento crítico de estudiantes universitarios, inscritos en el primer semestre de la Facultad de Ciencias de la Educación de la Universidad de Carabobo. En este contexto, el sujeto aprendiz se encuentra en transición de concepciones hebegógicas del aprendizaje a perspectivas andragógicas para el desarrollo de sus competencias, ya en el contexto de la formación profesional. Al respecto, Ravelo Díaz (2022) asegura que la hebegogía es "un período intermedio" (p. 79), que garantiza condiciones para el posterior desarrollo de estrategias andragógicas. La autonomía que exige el aprendizaje en los adultos demanda la integración del profesorado como elementos de mediación social que son capaces de elegir una batería de mediadores instrumentales que, en la Universidad del Siglo XXI, son de naturaleza tecnológica y digital.

Al valorar las perspectivas sobre la Inteligencia Artificial en el contexto de la formación de los sujetos que aprenden, Fernández-Prados et al. (2025) proponen “transformar las percepciones negativas en actitudes proactivas” (p. 122). Por ello, esta investigación se justifica desde una perspectiva andragógica, criterios axiológicos y puntos de vista sociales. También se consideran la novedad, la pertinencia y la relevancia contextual.

Referentes teóricos o revisión de literatura

El proceso de revisión de la literatura en este artículo de investigación, emerge con el panorama de los estudios previos desde los contextos internacionales hasta aquellos estudios que reflejan la realidad dentro de la República Bolivariana de Venezuela. En el contexto internacional, el tema de la inteligencia artificial como herramienta vinculada con los procesos de mediación para la consolidación del pensamiento crítico en la Universidad, ha sido de interés para la comunidad científica global y, entre los trabajos más significativos relacionados con estos tópicos, pueden mencionarse los siguientes:

Con miras a develar perspectivas contextualizadas, Rodríguez-Torres y Boillos-Pereira (2025), desarrollaron una investigación que fue titulada La inteligencia artificial desde la mirada de los estudiantes universitarios, en ella se aborda el impacto de la inteligencia artificial en los estilos de aprendizaje y el riesgo de pérdida de competencias básicas como el pensamiento crítico por causa de la influencia de la tecnología. El objetivo general del estudio se centró en conocer los riesgos y beneficios que identifican los estudiantes en la inclusión de la IA en su formación universitaria. La visión epistemológica permite el esbozo de temas como la alfabetización digital, la educación adaptativa y la importancia de la mediación pedagógica en el proceso formativo humanizado.

El tipo de investigación propuesto fue cualitativo, que se desarrolló a partir del trabajo con grupos focales con estudiantes de Pedagogía; en este contexto, se aplicaron los principios del análisis del discurso. Los resultados reflejan los beneficios en la formación personalizada, y se expone la dependencia tecnológica como un tema preocupante. Se concluye que la mediación es fundamental para que la IA actúe como herramienta de apoyo y no sustitutiva. Este estudio se relaciona con la presente investigación porque, a través de la percepción de los sujetos aprendices sobre el riesgo que corre el pensamiento crítico ante el uso de la IA, se busca dar valor a la mediación instrumental y a la promoción de la autonomía cognoscitiva de los estudiantes.

En el mismo orden de ideas, Guaman-Eras (2026) propuso un estudio formal denominado Ética y Complejidad en Educación Superior: Mediación Constructivista de la Inteligencia Artificial. Esta investigación enfrenta un problema de integridad académica y los límites de la supervisión tradicional. Se planteó como objetivo analizar la transición paradigmática desde un enfoque punitivo hacia una mediación constructivista. El sustento epistemológico permitió considerar la Teoría de la Complejidad en el contexto de la inteligencia artificial como parte de un andamiaje cognoscitivo y socioafectivo.

Se realizó el análisis sistemático de 31 documentos científicos. Entre los resultados se destacan los límites de la visión tradicional punitiva ante la evolución de los modelos de lenguaje y las tecnologías emergentes. Se propone un rediseño evaluativo centrado en los procesos y la alfabetización ética. Se evidencian vínculos entre el trabajo reseñado y el presente estudio en forma directa porque, en ambos, se fundamenta la necesidad de una mediación instrumental que trascienda el

control y potencie la autonomía del pensamiento crítico del estudiante para su desenvolvimiento como futuro profesional.

Al vincular la herramienta de la inteligencia artificial con el desarrollo del potencial cognoscitivo de los estudiantes, Bautista Uday (2026), en su artículo Impacto de la Inteligencia Artificial en la Alfabetización Digital y el Pensamiento Crítico Universitario, considera como tema esencial la aceptación de información automatizada sin visión crítica y con un pensamiento superficial. Esta investigación fue desarrollada con el objetivo de analizar el impacto de la inteligencia artificial en la alfabetización digital y el pensamiento crítico de estudiantes universitarios. Las bases teóricas incluyen la redefinición de la alfabetización digital como un elemento formativo para reconocer sesgos y evaluar éticamente el uso de la inteligencia artificial.

Para el desarrollo del estudio, se consideró la metodología de revisión bibliográfica narrativa con alcance descriptivo y analítico de literatura indexada entre 2021 y 2025. Se concluye que la inteligencia artificial favorece el razonamiento analítico únicamente en el contexto del desarrollo de estrategias pedagógicas críticas; también se afirma que el impacto educativo del uso de esta herramienta depende de la mediación pedagógica y la formación ética. Este trabajo se vincula con la investigación en curso porque evalúa objetivamente el uso de la inteligencia artificial como una herramienta que puede potenciar o debilitar el pensamiento crítico de acuerdo con la forma como se promueva su utilización con fines didácticos o andragógicos.

Entre el conjunto de antecedentes significativos desarrollados en el contexto nacional, figura, primeramente, la investigación propuesta por Arcila Franceschi y Medina (2026), quienes desarrollaron un artículo científico titulado Redefinición de la investigación y el aprendizaje universitario mediante la incorporación de la inteligencia artificial generativa, en el que se analiza la transformación de la gestión del conocimiento del modelo analógico a una estructura digital y la crisis de soberanía cognoscitiva. La investigación se trazó como objetivo general indagar los significados en la trama de las experiencias surgidas en el intercambio con herramientas de inteligencia artificial generativa. Teóricamente, se apoya en la fenomenología hermenéutica, el humanismo de la UNESCO y los principios éticos aplicados a la inteligencia artificial.

Para el desarrollo de la investigación se consideró un método vinculado con los principios filosóficos de heideggerianos. Se realizaron entrevistas semiestructuradas a docentes, estudiantes y egresados de la Universidad de Carabobo. Los resultados revelan que, por una parte, la inteligencia artificial motiva el aprendizaje, pero, por la otra, puede generar baja retención y pérdida de habilidades de redacción. Las investigadoras realizan una propuesta de redefinición que prioriza la calidad de los prompts y el uso crítico de la herramienta.

Este antecedente es vital porque fue realizado en el mismo contexto institucional de la Universidad de Carabobo, donde también se contextualiza también el presente estudio, para explorar los significados de la interacción con la inteligencia artificial en función del desarrollo del pensamiento crítico de los estudiantes que se forman como profesionales en las aulas universitarias.

Otro antecedente de importancia que se ha considerado en el contexto de la sustentación epistemológica del presente artículo ha sido la investigación desarrollada por Morfes et al. (2026), quienes investigaron sobre el tema de las

Tecnologías emergentes: Concepciones, retos educativos en el mundo global transcomplejo. En su trabajo, plantean como problema el neocolonialismo digital cognoscitivo y la pedagogía pasiva en instituciones tradicionales. Plantearon el objetivo de reflexionar sobre el papel estratégico del desarrollo tecnológico para generar escenarios educativos que fortalezcan el aprendizaje. Como sustento epistemológico consideraron la transcomplejidad y la transdisciplinariedad, con miras a cuestionar críticamente los mitos relacionados con la inteligencia artificial.

El desarrollo de la investigación fue realizado a partir de un enfoque cualitativo e interpretativo, con apoyo de una revisión documental crítica. Concluyen con la necesidad de un modelo educativo irreverente que armonice la tecnología con valores humanos; reflexionan sobre la urgencia de una praxis educativa emancipada que fomente la creatividad y el juicio propio. Este trabajo se relaciona con el estudio actual al ofrecer una mirada crítica sobre cómo la mediación tecnológica debe servir para la liberación del pensamiento y no para su condicionamiento, relación esencial que se busca consolidar en el presente estudio. Otro aporte esencial para esta investigación es el estudio propuesto por Bolaños Gómez et al. (2026), quienes estudiaron la Inteligencia artificial en educación superior: ¿Sustituto o complemento del pensamiento crítico? A través de su investigación, los autores abordaron la incertidumbre sobre el fortalecimiento o el reemplazo de los procesos cognoscitivos activos del estudiante. El análisis de la relación entre el uso de la inteligencia artificial y el desarrollo del pensamiento crítico en la educación superior fue el objetivo general de la investigación. Las bases teóricas permitieron considerar la alfabetización algorítmica, la vigilancia epistemológica y la autorregulación.

Se realizó una revisión sistemática cualitativa, incluyendo 28 estudios. Los resultados demostraron que la inteligencia artificial actúa como catalizador de habilidades de análisis y evaluación solo bajo una mediación formativa; por ello, el desafío es fundamentalmente pedagógico y estratégico. Este estudio se vincula con la presente investigación porque propone que la mediación instrumental con inteligencia artificial requiere de un encuadre pedagógico intencional para promover efectivamente el pensamiento crítico, concepciones que coinciden con la esencia de la investigación propuesta. Seguidamente, se ofrece la explicación de los núcleos epistemológicos centrales del estudio: mediación y orientación educativa en el contexto de la inteligencia artifiial, promoción del pensamiento crítico en la universidad y la importancia del uso adecuado de la inteligencia artificial en la educación universitaria para generar la autonomía cognoscitiva.

Metodología

El estudio se desarrolló sobre la base de los principios del paradigma interpretativo, parafraseando los aportes de Vergara-Calderón y Rey-Sánchez (2025) esta forma de interpretar el mundo se centra en la subjetividad. Se ha seleccionado el tipo de investigación cualitativa que, de acuerdo con la perspectiva de Garay Rivera y Navea Olivares (2026), “ ha alcanzado un notable grado de sofisticación epistemológica y metodológica” (p. 15). Este tipo de investigación parte de las categorías de la realidad que la subjetividad del investigador es capaz de estructurar en un todo global con estructura teórica.

Se ha considerado un diseño de investigación fenomenológico y hermenéutico al valorar los aportes de Ortega (2026) para quien “La fenomenología hermenéutica permite una comprensión profunda de la experiencia educativa a partir de los significados vividos” (p. 28); en este contexto, se seleccionó un grupo de diez estudiantes universitarios cursantes del primer semestre en una signatura vinculada

con el área de Castellano. Durante un período de cinco semanas, el docente promovió actividades vinculadas con el uso de la Inteligencia Artificial y el pensamiento crítico. En cada sesión de dos horas semanales, el investigador registró, mediante diarios de campo, las interacciones y rasgos significativos en la dinámica de las estrategias desarrolladas por el docente a través de un proceso de observación no participante. Los criterios de excelencia de la investigación cualitativa expuestos por Ruiz Olabuénaga (2012) hacen pensar que “la capacidad de observación del investigador, aún siendo correcta, es limitada y debe ser completada y contrastada con otras observaciones” (p. 71). En consecuencia, la diversidad y la variedad de situaciones observadas aportan calidad a la investigación cualitativa.

El procesamiento de la información cualitativa fue realizado a partir de los principios de la teoría fundamentada de Glaser y Strauss (1967), utilizada en su propuesta original a partir de la cual el individuo selecciona categorías, estructuración, saturación y generación de la teoría como una estrategia de organización de la información a partir de las ideas de Creswell et al. (2023), quienes integran estas posiciones en dos fases, una de interpretación de significados o vivencias y otra de narrativas interpretadas para la construcción de una teoría sustantiva. En este sentido, una vez recolectada la información se realizó la categorización y la red de relaciones con el apoyo del Programa Atlas.ti. que fue utilizado como plataforma tecnológica para la organización de categorías. A través de su función de codificación se realizó un proceso de categorización abierta; también permitió la jerarquización de significados a través de la función de grupos de códigos, a través de la cual se establecieron familias y subfamilias de categorías para desencadenar la creación de una red de relaciones entre los códigos identificados. El programa Atlas.ti es valorado por Martínez (2004) como uno de los más completos para la organización de información de tipo cualitativo. Los resultados de este proceso cualitativo se presentan en los párrafos subsiguientes.

Resultados y discusión

Una vez desarrollado el proceso de observación en el contexto del aula y, específicamente, a partir de la acción didáctica del docente con el apoyo de la Inteligencia Artificial como elemento de mediación instrumental, se procedió al abordaje cualitativo de la información y a su categorización. En la figura 1 se presenta el proceso de categorización de los registros de campo obtenidos durante tres momentos didácticos, cada uno articulado con una estrategia específica de mediación mediante Inteligencia Artificial. Estos registros permitieron identificar categorías y relaciones asociadas con las formas de interacción de los estudiantes con la herramienta y con los procesos de reflexión vinculados al pensamiento crítico. De acuerdo con De la Barra Cadíma (2026), “los paradigmas de investigación constituyen marcos conceptuales fundamentales que orientan de manera decisiva la producción de conocimiento” (p. 34). Sobre esta base, se presenta seguidamente el proceso de categorización de la información.

En el manejo de la IA como herramienta para el desarrollo del pensamiento crítico de los estudiantes estriba en que a la hora de consultar a alguna de las opciones que existen en la red de inteligencia artificial, éstos se quedan únicamente con lo que sugiere o responde la IA. No hay un proceso de análisis o reflexión de lo propuesto por la aplicación. Una estrategia que se desarrolla en el contexto del aula es la siguiente: Sugerir a los estudiantes un texto determinado, luego proponer una seria de preguntas, donde los estudiantes reflexionen sobre algunos aspectos del texto leído, luego, se les invita a realizar las mismas preguntas a la IA, entonces se les propone comparar ambas respuestas. Que los estudiantes visualicen qué aspectos desarrollan ellos y cuáles la IA, el enfoque de las respuestas en ambos, qué les faltó por analizar. Posteriormente, se les propondría redactar una respuesta que contemple su visión personal complementada con la de la IA.

Otra estrategia desarrollada se centra en proponer un texto seleccionado, indicar unas preguntas para su reflexión y que investiguen las respuestas con ayuda de la IA, luego se les sugerirá responde las mismas preguntas desde un enfoque contrario al de la IA, de esta forma se genera en los estudiantes un proceso reflexivo y de análisis, en primer lugar, y desarrollo de la redacción en segundo lugar.

Una tercera estrategia consiste en proponer un tema de discusión, motivándolos a redactar un texto de su preferencia (narrativo, argumentativo, expositivo) donde los estudiantes expongan los aspectos más importantes para ellos sobre la temática abordad, luego se les invita a que propongan la elaboración del texto a una IA, según los parámetros establecidos para la actividad. Después compararían dichos textos en cuanto a el enfoque de cada texto, los aspectos abordados y cómo se abordan en cada texto. Se les sugiere al final elaborar otro texto con los aspectos más interesantes de ambos textos.



Figura 1. Selección de segmentos para el proceso de categorización.
Fuente: El autor.

La significación de la aplicación de la inteligencia artificial en el ámbito universitario se presenta en este artículo en medio de una tensión dialéctica entre el riesgo de la inercia cognoscitiva del estudiante y la posibilidad de convertirla, a través de la mediación, en una herramienta activa dentro del aula. La evidencia permite inferir que cuando el uso de la inteligencia artificial se limita solamente a la consulta y la copia literal de las ideas que esta tecnología genera, pues indudablemente el estudiante asume un rol pasivo sin posibilidad de promoción de pensamiento crítico y simplemente asume los resultados de un algoritmo como una respuesta posible a un reto de aprendizaje o a una actividad didáctica dentro o fuera del aula. Según Bermeo Berrú et al. (2026), “un contexto marcado por la incertidumbre y un mercado laboral en constante transformación, exige que los estudiantes adquieran competencias que les permitan enfrentar estos cambios de manera activa” (p. 2). La visión de los mencionados autores exige la trascendencia hacia un nivel de pensamiento superior que supere la tradicional concepción instrumental de la tecnología.

El estudio muestra indicios de que esta dinámica instrumental anula la significación del proceso cognoscitivo resultante de la reflexión y el análisis de la información; como consecuencia, neutraliza, por supuesto, cualquier posibilidad emergente de pensamiento crítico. Para transformar esta visión pasiva del estudiante universitario frente al desarrollo de su propio criterio, es preciso que se establezca un contraste dialéctico entre el andamiaje de la relectura donde el estudiante no busca validar la respuesta de la herramienta tecnológica sino interrogar, contrastar con sus propias preguntas, hacer una valoración de enfoques y, al final, llegar a su propia conclusión con una capacidad de discernimiento de las diferencias entre un pensamiento realmente humano y el procesamiento algorítmico de la inteligencia artificial.

Por lo tanto, este contraste de perspectivas permite que el estudiante supere el sesgo de la automatización y promueva la investigación profunda. Estos hallazgos permiten comprender que también existe la posibilidad de una co-construcción temática que se equilibra entre la producción original del estudiante y los aportes de la inteligencia artificial, pero siempre con la posibilidad de evaluación de la información y la validación de la misma por parte del aprendiz. La dinámica de esta explicación que surge de la categorización, se refleja en la red de relaciones semánticas que integran categorías generales y subcategorías.

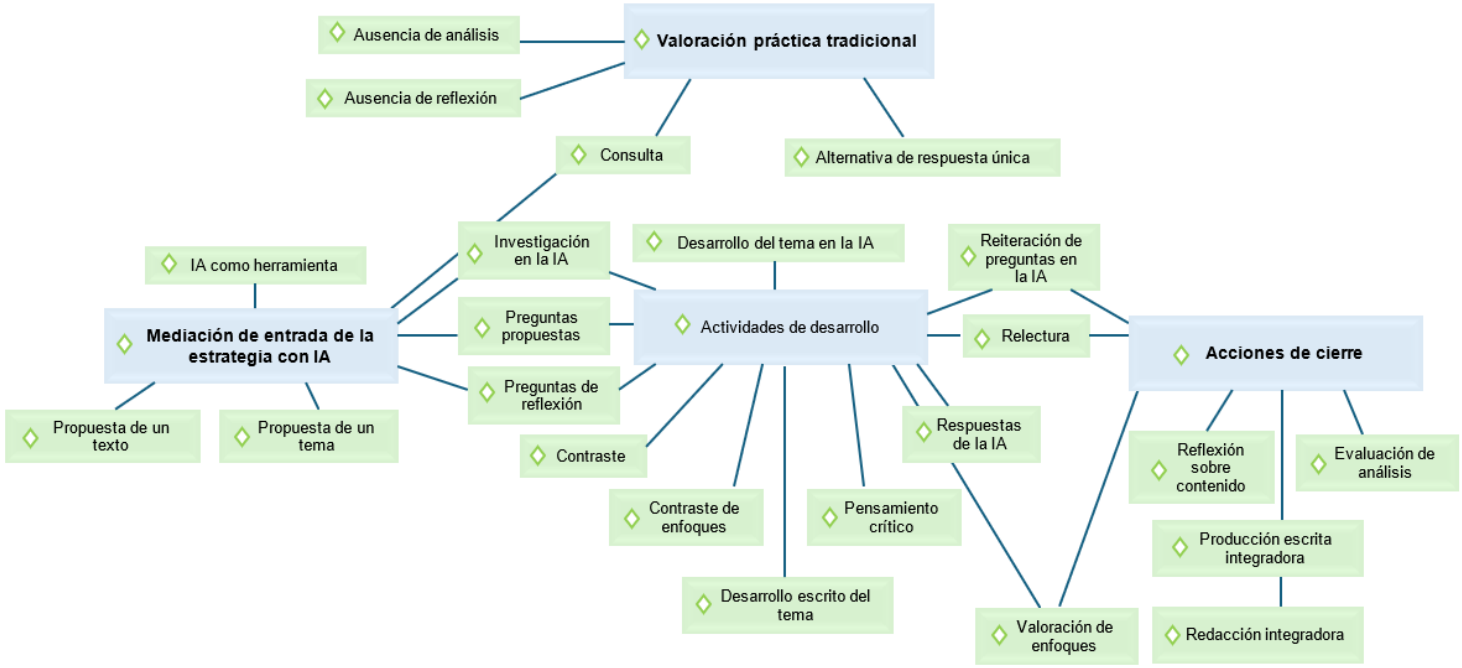


Figura 2. Red de relaciones entre categorías.
Fuente: El autor

El desarrollo de la red semántica, que se presenta en la Figura 1, parte de una valoración de la práctica tradicional donde actúa en una contraparte la innovación de la inteligencia artificial directamente opuesta con la ausencia de análisis y la ausencia de reflexión en un primer momento didáctico para reflejar un posible proceso de aprendizaje pasivo. Este enfoque tradicional de interacción pedagógica se limita a la consulta y a una respuesta posible de la inteligencia artificial donde el cuestionamiento y la visión crítica evidencian su ausencia.

Con la mediación de las estrategias de inteligencia artificial dentro del aula como herramienta, se introduce de manera instrumental la estructura de esta tecnología y se vincula positivamente con las posibilidades de trabajo productivo con esta herramienta. Existe una propuesta temática, un conflicto cognoscitivo y unas preguntas que pueden cuestionar o no la respuesta que ofrece la inteligencia artificial. El núcleo dinámico de la mediación e incubación del pensamiento crítico se concentra en las actividades de desarrollo.

En esta fase mucho más productiva, el estudiante universitario debe actuar de manera interactiva y profunda con la tecnología, pero el análisis de las respuestas y las conclusiones a las que llega deben ser parte de su propio pensamiento a partir de preguntas de reflexión, contraste, de su propio enfoque y del desarrollo escrito del tema que parte de sus ideas originales.

Es precisamente en este entramado de interacciones donde se sitúa el nodo pensamiento crítico, para demostrar que éste no surge de la mera exposición de la Inteligencia Artificial, sino a través de la mediación activa del docente y sus pares, así como del cuestionamiento metodológico de los productos que ésta ofrece. En los procesos didácticos de consolidación y cierre, se observa un bloque orientado a la metacognición, la síntesis y la evaluación del aprendizaje.

En una dimensión que se conecta con la fase anterior, mediante la relectura y la reintegración de preguntas, emerge un proceso cíclico de refinamiento de la información. La consolidación del pensamiento crítico se materializa, entonces, en resultados tangibles como la valoración de enfoque, la reflexión sobre el contenido, la producción escrita integradora y la redacción global que permite culminar con la evaluación del texto, para cerrar un ciclo pedagógico de mediación, concebido como lo proponen Fernández Fernández y Manzano Díaz (2026) “una mediación que permita la atención a las necesidades de los estudiantes en la capacidad de criticar, interpretar, cuestionar y resignificar los datos adquiridos” (p. 272), donde la inteligencia artificial no es el centro sino una herramienta más con posibilidades de promocionar el pensamiento crítico en el estudiante universitario.

Conclusiones

Una vez desarrollado el abordaje cualitativo correspondiente, puede afirmarse que existe un elemento epistemológico que permite evidenciar que la mediación instrumental llevada en un contexto didáctico genera una verdadera producción escrita integradora. El pensamiento crítico del estudiante se manifiesta cuando en un contexto formal o informal puede redactar un texto que no se limita a copiar de la IA, pero tampoco a ignorarla.

A través de la mediación, sencillamente conglomera, complementa y da su propia visión crítica de los aportes estructurados que la herramienta pudiera ofrecerle. Este ciclo de mediación asegura que la tecnología actúe como un catalizador del aprendizaje, pero no como un sustituto del pensamiento crítico, porque es el sujeto quien deberá procesar la información, verificarla, evaluarla y llegar a una conclusión propia a través de su particular y único proceso de pensamiento crítico.

Entonces, sobre la base de los argumentos expuestos, no debe concebirse el uso de la Inteligencia Artificial como un evento aislado sino como una trayectoria tecnopedagógica planificada para activar el pensamiento crítico; igualmente, debe integrarse en una estrategia para desplazar esa posibilidad de respuesta única de la enseñanza tradicional, mediante un proceso de entrada orientada a la investigación, una fase de desarrollo basado en contraste dialéctico y el establecimiento consciente de una reflexión frente a la inteligencia artificial con un cierre centrado en la producción escrita integradora y la metacognición del estudiante para el verdadero pensamiento crítico. De esta manera se dará un paso significativo para la integración de las tecnologías emergentes y la didáctica para la formación de sujetos autónomos con pensamiento trascendental en la Universidad contemporánea.

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Original Article

La historieta como estrategia didáctica para la resolución de un caso forense

The comic strip as a didactic strategy for solving a forensic case

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Resumen

En el ámbito forense, el cómic policíaco permite al lector enfrentar el esclarecimiento de crímenes como un reto analítico. Este trabajo describe y evalúa una estrategia didáctica para fomentar el aprendizaje crítico en 31 estudiantes de la Licenciatura en Ciencias Forenses de la Universidad de Carabobo, 2025. La actividad consistió en resolver un caso criminal mediante una historieta diseñada con Inteligencia Artificial, integrando contenidos técnicos de la asignatura. La evaluación se realizó analizando las respuestas al caso y una encuesta autoadministrada sobre la percepción de la estrategia. Los resultados muestran una coincidencia superior al 90% en la resolución del caso, destacando la capacidad de los estudiantes para identificar elementos faltantes y sustentar argumentos científicos. Los participantes valoraron la actividad como útil, lúdica e innovadora. Se concluye que la historieta facilita la exploración transdisciplinaria de la investigación forense, demostrando que los estudiantes pueden aplicar conocimientos de forma racional y pertinente. Esta metodología activa minimiza la presión evaluativa y potencia el análisis crítico de evidencias, aunque se identificó la necesidad de mayor precisión técnica en las imágenes generadas por IA.

Palabras clave: Aprendizaje activo; Ciencias forenses; Historieta; Inteligencia artificial; Pensamiento crítico.

Abstract

In the forensic field, the crime comic allows the reader to face the clarification of crimes as an analytical challenge. This work describes and evaluates a didactic strategy to promote critical learning in 31 students of the Bachelor's Degree in Forensic Sciences at the University of Carabobo, 2025. The activity consisted of solving a criminal case through a comic strip designed with Artificial Intelligence, integrating technical contents of the subject. The evaluation was carried out by analyzing the responses to the case and a self-administered survey on the perception of the strategy. The results show a coincidence of over 90% in the resolution of the case, highlighting the students' ability to identify missing elements and sustain scientific arguments. Participants valued the activity as useful, playful, and innovative. It is concluded that the comic strip facilitates the transdisciplinary exploration of forensic investigation, demonstrating that students can apply knowledge rationally and pertinently. This active methodology minimizes evaluative pressure and enhances the critical analysis of evidence, although the need for greater technical precision in the images generated by AI was identified.

Keywords: Active learning; Forensic science; Comic strip; Artificial intelligence; Critical thinking.

Introducción

Partiendo de la definición de ciencias forenses por Roux (como se citó en Ross et al., 2025, p. 8) “es un esfuerzo científico y orientado a la investigación basada en casos para estudiar rastros, los restos de actividades pasadas (presencia y las acciones de un individuo), a través de su detección, reconocimiento, recuperación, examen e interpretación para comprender eventos…”. Desde el punto de vista práctico, las ciencias forenses se fundamentan en la aplicación de los conocimientos y técnicas de cada ciencia al sistema de justicia, aportando conclusiones relevantes sobre la persona, objeto o cosa que se evalúa, información que al triangularse servirá posteriormente como elementos probatorios concluyentes para el esclarecimiento de un hecho, bien sea civil, laboral o penal (Núñez Rodríguez, 2022).

En el ámbito penal, se han utilizado diversas estrategias didácticas para la enseñanza y aprendizaje de las ciencias forenses, por ejemplo, el debate de ideas (Romano et al., 2017; Sebastiany, 2013), la simulación y experimentación (Gavilán García & López Santiago, 2020; Núñez, 2015; Sánchez et al., 2017; Sanches Santos & Gonzalez Ribeiro, 2020), el aprendizaje basado en juegos o problemas (Cruz et al., 2016; Fernández-Laso et al., 2023; Pérez de Urbina, 2013), el uso de las herramientas tecnológicas (dos Santos & Barin, 2015; Núñez Rodríguez, 2020), el aprendizaje basado en el estudio de un caso o en la integración de casos (Eraña-Rojas et al., 2019; Núñez Rodríguez & Rodríguez Rangel, 2020; Ruiz Zapata et al., 2008; Romo Guadarrama et al., 2017; Sosa Reyes, 2017), entre otras.

No obstante, la irrupción de la Inteligencia Artificial (IA) generativa ha planteado un nuevo paradigma en el diseño de estos escenarios. Según Mollick y Mollick (2024), la capacidad de estas herramientas para actuar como "innovadores instruccionales" permite a los docentes crear materiales personalizados de alta complejidad de forma acelerada. Sin embargo, en el campo forense existe un vacío de información sobre cómo la generación de historietas mediante IA afecta la percepción del estudiante y la precisión técnica del caso, lo que justifica la necesidad de explorar esta herramienta como un puente entre la tecnología emergente y la resolución de problemas criminalísticos.

Por tales razones, la presente investigación tuvo como objetivo descubrir la tendencia con base en la opinión de los estudiantes sobre el uso de la historieta como estrategia didáctica para la resolución de un caso forense, analizando sus ventajas y desventajas. Hallazgos que contribuyen con la didáctica de las ciencias forenses y las mejores prácticas educativas con base en la evidencia.

Referentes teóricos o revisión de literatura

En tal sentido, el aprendizaje es el proceso a través del cual, los estudiantes, adquieren, modifican o mejoran sus habilidades, conocimientos, conductas y valores, a través de metodologías activas que los involucran (Copari Romero, 2014; Gross, 2012). Al respecto, Morelato et al. (2023) consideran que las estrategias de aprendizaje se deben centrar en los procesos de inferencia que implican la deducción de conclusiones a partir de información existente o de patrones aprendidos, así como el pensamiento crítico al ser una forma de razonamiento, con esto se refieren al uso de casos forenses como material didáctico estructurado y transversal que permitan la reflexión de la praxis forense, poniendo a los estudiantes en situaciones más cercanas a las reales, porque se obtienen

resultados de aprendizajes duraderos. Justamente, el caso se puede presentar de diversas maneras, siendo una de ellas la historieta.

Por lo tanto, la historieta es una metodología activa para el aprendizaje, donde el uso de dibujos y textos cuentan una historia, los estudiantes la interpretan y analizan su contenido para formular conclusiones (Ayala García, 2016; Córdoba-Baldrich & Maturana, 2022). La historieta no debe ser subestimada como un recurso meramente recreativo; por el contrario, representa una herramienta de alta demanda cognitiva. Al respecto, Syma y Weiner (2013) sostienen que el arte secuencial en el aula constituye un proceso de decodificación dual donde el estudiante debe procesar simultáneamente información visual y textual. Esta interacción entre imagen y palabra obliga al cerebro a realizar inferencias constantes, lo que transforma la lectura en un ejercicio de pensamiento crítico avanzado, esencial para la interpretación de contextos complejos como el de la criminalística. Por lo anteriormente mencionado, las historietas se han utilizado como estrategias de enseñanza y aprendizaje de la literatura e idiomas (Huerta Rosales & Ortega Villadeza, 2021; Villa-Castro et al., 2020), historia (Ochoa Perdomo, 2024), ciencias naturales (Hernandez de la Cruz et al., 2024; Romá-Mateo et al., 2022; Romero & Tarquino, 2023), matemáticas (Andrade dos Santos & Santiago de Assis, 2024; Guacán Tandayamo et al., 2023), entre otras áreas que develan su versatilidad práctica en el campo de la educación.

En el caso forense existe un género de acción que narra una investigación criminal, llamado cómics policíacos o historietas de crímenes. Al respecto, McCloud (1994) explica que el lector se coloca en el lugar del investigador y se relaciona con él, a través de una historia que permite comprender una serie de eventos para esclarecer el hecho; donde se desarrolla la aptitud investigadora del lector implicando habilidades como el pensamiento crítico, la capacidad de comunicación, la organización y la curiosidad por aprender mientras resuelve el caso (Shukla, 2021). En este orden de ideas, una historieta o cómic es una forma de contar una historia a través de viñetas, que puede incluir texto e imágenes de manera lúdica y creativa, mediante encuadre y planos para dinamizar la secuencia (Muro Munilla, 2022).

El diseño de una historieta actualmente utiliza herramientas digitales e inteligencia artificial donde se agiliza la creación del texto de la historia y las imágenes personalizadas (Córdoba-Baldrich & Maturana, 2022; Villa-Castro et al., 2020). Desde el punto de vista educativo la historieta puede ser diseñada por los estudiantes, o puede ser suministrada por el docente y analizada por el estudiante (Moreno-Vera et al., 2021). En ambos casos, favorece la comprensión de los conceptos y el desarrollo de argumentos basados en la reflexión (da Silva & Vieira, 2022; Matuk et al., 2021; Moretti et al., 2025). Desde el punto de vista de la formación de los científicos forenses, la tendencia es prestar atención a competencias como el pensamiento crítico y la educación científica basada en la evidencia (Ross et al., 2025). Por último, dentro de las desventajas se ha reportado que la extensión de la misma puede ser un factor clave para que el lector pierda el interés (Ibarra-Rius & Ballester-Roca, 2022).

Metodología

Se abordó desde el enfoque cualitativo, a través del análisis de contenido como método (López Noguero, 2002), para identificar patrones, temas y significados relevantes durante la resolución de un caso forense mediante el uso de documentos o textos. La actividad buscaba la integración de la información obtenida tras la aplicación de una historieta para el desarrollo del pensamiento crítico y la capacidad argumentativa de los estudiantes cursantes de la asignatura Ciencias Forenses III

perteneciente al plan de estudios de la Licenciatura en Ciencias Forenses, Facultad de Ciencias Jurídicas y Políticas - Universidad de Carabobo, Venezuela. La población estuvo conformada por 31 estudiantes (20 mujeres y 11 hombres) cursantes del cuarto año de la carrera en el periodo académico 2025.

Diseño de la historieta y asignación de la actividad

Trama narrativa: Mediante el uso de las palabras clave “criminalística”, “sangre”, “homicidio”, “toxicología”, “cocaína”, “patología”, “herida”, “arma de fuego”, “entomología” y “larvas” se introdujeron en el generador de historias con inteligencia artificial Summarizer, donde se establecieron los parámetros de una historia original y creativa, dirigida a un grupo de edad entre 21-35 años y con una duración larga. La trama narrativa obtenida fue revisada, fraccionada y ajustada al contenido impartido en la asignatura, específicamente darle un carácter técnico científico a la información con base en la evidencia forense, finalizando con un guion en términos narrativos con diversos elementos aportados por las ciencias forenses.

Imágenes y diagramación: La información obtenida en el paso anterior se introdujo en la plataforma AI Comic Factory - Hugging Face, donde se generaron siete imágenes con un estilo americano moderno. Se diseñó un prompt específico para cada imagen según el guion (contexto, trasfondo, datos del personaje y escena). Es importante acotar que el proceso de prompting enfrentó limitaciones técnicas inherentes a la herramienta de IA, la cual presentó restricciones para recrear detalles criminalísticos de alta especificidad (como patrones de manchas de sangre detallados o estadios entomológicos precisos), debido a sus políticas de contenido y capacidades de resolución. Esta limitación se consideró un factor de control para evaluar la capacidad de los estudiantes de detectar vacíos de información.

La incorporación de herramientas como Summarizer (s.f.) y AI Comic Factory (Bilcke, s.f.) responde a las nuevas corrientes de innovación educativa. Bajo este enfoque, el rol del docente evoluciona a un “curador” y “diseñador de prompts”. Como señalan Mollick y Mollick (2024), el uso de la IA Generativa en el aula permite a los instructores actuar como innovadores instruccionales, utilizando la tecnología para crear materiales didácticos personalizados y simulaciones de casos que optimizan el diseño pedagógico. Posteriormente, estas imágenes se diagramaron sobre una plantilla con fondo negro anexando recuadros narrativos para contextualizar la historia y los resultados de las experticias forenses (Figura 1).

Asignación de la actividad: Una vez finalizada la historieta se les envió a los estudiantes por el grupo de Whatsapp de la asignatura, con un plazo de una semana para responder las interrogantes: ¿Qué sucedió?, ¿Quién?, ¿Dónde?, ¿Cuándo?, ¿Cómo?, ¿Con qué?, ¿Por qué?, ¿Qué falta por investigar? y la postulación de su hipótesis. Las respuestas se recibieron individualmente vía correo electrónico en formato Word.

Evaluación de la estrategia por parte de los estudiantes: Tras la entrega, el docente remitió la retroalimentación y una entrevista autoadministrada por correo electrónico. Dicho instrumento fue sometido a una validación por juicio de expertos, integrada por el equipo docente del área de ciencias forenses de la facultad, quienes verificaron la pertinencia, claridad y coherencia de las preguntas respecto a los objetivos pedagógicos. El cuestionario incluyó: 1) ¿Cuál es tu opinión sobre el uso de la historieta como estrategia didáctica?, 2) ¿Cuáles son las ventajas? y 3) ¿Cuáles son las desventajas?

Unidades de análisis y procesamiento de la información

La unidad de análisis estuvo constituida por las 31 tareas entregadas por los estudiantes, codificadas como estudiante (E) del 1 al 31, y por las respuestas a la entrevista autoadministrada. Cada tarea fue tratada como unidad hermenéutica independiente, preservando la autoría y el contexto de producción. Se trabajó con la categorización emergente, cuantificando su frecuencia y proporción respecto al total, complementando el análisis cualitativo desde lo interpretativo.

Criterios de categorización emergente: El análisis de contenido siguió las fases propuestas por Bardin (1996) y Krippendorff (2018): (a) preanálisis, (b) codificación, (c) categorización y (d) interpretación. La codificación se realizó de forma abierta, identificando unidades de significado en las respuestas de los estudiantes. Posteriormente, se aplicó una codificación selectiva para integrar las categorías en torno a los ejes de análisis. Los criterios para la definición de categorías fueron: (1) exclusividad mutua, una unidad de significado no podía pertenecer simultáneamente a dos categorías; (2) homogeneidad interna, las unidades agrupadas en una misma categoría compartían un mismo núcleo semántico; y (3) pertinencia, la categoría debía responder a los objetivos del estudio y a las preguntas de la actividad. La saturación teórica (Glaser & Strauss, 1967) se evaluó de forma continua durante el análisis, considerándose alcanzada cuando las nuevas respuestas no aportaban unidades de significado novedosas a las categorías emergentes.

Posteriormente, para los resultados de la entrevista se aplicó la técnica de nubes de palabras mediante la herramienta wordcloud.online. Para garantizar el rigor del análisis de contenido, se realizó un proceso previo de limpieza de datos que incluyó la eliminación de stopwords (conectores, preposiciones y artículos) y la exclusión manual de términos redundantes vinculados a la asignatura y de las interrogantes formuladas (ej. “forense”, “historieta”), permitiendo que la visualización reflejara únicamente las tendencias de opinión y categorías emergentes de los participantes. La herramienta permitió lematizar las palabras a su forma gramatical inicial para facilitar la agrupación y frecuencia visual, donde el tamaño de la palabra indica su relevancia en el discurso estudiantil.

Procesamiento de nubes de palabras: El procedimiento se realizó en cinco fases: (1) transcripción y normalización, las respuestas se transcribieron literalmente en un archivo de texto plano, preservando la ortografía original y unificando el uso de mayúsculas y minúsculas; (2) limpieza de datos, se eliminaron stopwords del español y se excluyeron manualmente términos redundantes vinculados a la asignatura y de las interrogantes formuladas; (3) lematización, la herramienta agrupó las palabras a su forma gramatical inicial (lema), unificando variantes flexivas (plurales, géneros, conjugaciones); (4) generación de la nube, la herramienta procesó la totalidad de las palabras de las 31 tareas y, para el reporte, se seleccionaron las palabras de mayor frecuencia, entendida como el número de tareas en las que apareció cada palabra (por ejemplo, “ayudar” apareció en 25 de las 31 tareas); y (5) interpretación, la nube se interpretó de forma complementaria al análisis de contenido categorial, contrastando las palabras de mayor tamaño con las categorías emergentes para verificar coherencia entre ambos niveles de análisis.

Criterios de rigor cualitativo: Para asegurar la calidad del análisis se aplicaron los criterios de Lincoln y Guba (1985): credibilidad (triangulación de fuentes, tareas y entrevistas), transferibilidad (descripción densa del contexto y participantes), dependencia (auditoría del proceso de codificación) y confirmabilidad (reflexividad del investigador).



Figura 1. Historieta utilizada en la estrategia
Nota. Elaboración propia

Resultados y discusión

La muestra del estudio estuvo conformada por 31 estudiantes (n=31) pertenecientes al cuarto año de la Licenciatura en Ciencias Forenses, con una distribución de género de 20 mujeres (64,5%) y 11 hombres (35,5%). Todos los participantes completaron la actividad de resolución del caso y la posterior entrevista autoadministrada, lo que permitió una saturación de datos suficiente para el análisis de contenido y la identificación de tendencias sobre la efectividad de la

historieta como recurso didáctico.

Las respuestas de los estudiantes sobre el caso se presentan en la Tabla 1, donde se tabulan las preguntas y respuestas con sus respectivos porcentajes. Se observa que la mayoría de las respuestas tienen una coincidencia mayor al 90%; sin embargo, esa discrepancia se justifica por la falta de elementos de interés criminalístico que no se presentan en la historieta analizada, lo cual genera una duda razonable durante la interpretación del caso, obligándolos a una evaluación cuidadosa para evitar un sesgo del investigador.

Al respecto, Nilendu (2024) considera que la educación basada en la evidencia forense debe ser incorporada en las estrategias de aprendizaje para garantizar la aplicabilidad de las buenas prácticas y la comprensión de metodologías científicas ajustadas a las normativas vigentes. En el mismo orden de ideas, Marohl et al. (2023) hacen énfasis en la eficacia que debe tener la pedagogía en este campo, al ser un área en rápido desarrollo que requiere una mejor interpretación de la evidencia para avalar la inocencia o culpabilidad en un hecho.

Tabla 1.
Respuesta de los estudiantes a las interrogantes del caso

Preguntas	Respuestas	Argumentos
¿Qué sucedió?	Presuntamente un homicidio (100%)	Por la ausencia del arma de fuego en el sitio del suceso.
¿Quién?	Víctima: Sr Riz (100%). Victimario: Presuntamente el Sr Pérez (96,7%)	El 100% de los estudiantes indican que faltan análisis para determinar la culpabilidad del sospechoso (E1-31). Pero, el 96,7% presumen que se trata del Sr Pérez. Con base en el testimonio de la Sra. García, se menciona a un viejo amigo del Sr. Riz cuyo apellido es Pérez, tal parece que estos tenían últimamente problemas relacionados con apuestas de caballos y dinero, esto haría que el Sr. Pérez sea el principal sospechoso de este caso.
¿Dónde?	Domicilio del Sr Riz (100%) Sitio del suceso primario: Cocina (90,3%) Sitio del suceso secundario: Sala (54,8%)	El 90,3% de los estudiantes afirman que el hecho ocurrió en la cocina por la "presencia de manchas secas de presunta naturaleza hemática" (E15). "Ausencia de sangre alrededor del cadáver en la sala, indicando que se trataría de un sitio del suceso secundario" (E21). "Utilizar luminol para reactivar la presencia de presunta sangre en caso de haber sido limpiada" (E29).
¿Cuándo?	Aproximadamente 48 horas antes del hallazgo del cuerpo (28 de marzo) (100%)	El hecho ocurrió poco después de que la Sra García viera con vida al Sr Riz a las 10 am del 28 de marzo. Según el detective Gil el cadáver se encontraba en la fase cromática (habían transcurrido 48 horas), tiempo reforzado por la patóloga forense con los hallazgos durante la autopsia (E1-31). Además, "las larvas de *C. megacephala* colectadas en el orificio de entrada presentan aproximadamente 2 días de desarrollo a 22°C con base en los resultados de la entomóloga forense" (E3).
¿Cómo?	Herida por impacto de un proyectil percutido por un	El disparo se encontraba ubicado en la región del parietal derecho, se observa claramente el "signo de boca de mina de Hoffman indicando que el disparo fue de contacto (0-2 cm de distancia)"

	arma de fuego (100%). Causa de la muerte: Shock hipovolémico (100%).	(E11), el victimario “se encontraba a la derecha, este empleó un arma de fuego tipo pistola de calibre 9mm esto confirmado por la bala obtenida del cadáver. Causando la muerte debido a un shock hipovolémico” (E23).
¿Con qué?	Arma de fuego 9 mm (100%)	Con base en la información obtenida del proyectil recuperado de la cabeza del Sr. Riz. También se encontraron rastros de Plomo, Bario y Antimonio en las larvas analizadas, lo que confirma la presencia de residuos de disparo en la escena, reforzando la hipótesis del uso de un arma de fuego (E1-31). Pudiendo tratarse de una Glock G19, Sig Sauer P226, Smith & Wesson M&P, entre otras (E4,5,9,17).
¿Por qué?	Disputa económica (apuestas) o conflicto personal (100%).	Con base en el testimonio de la Sra. García (E1-31).

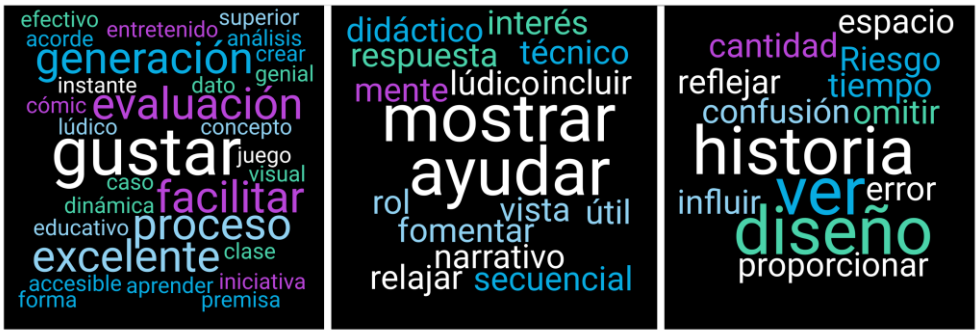
Fuente: Datos de la investigación.

Por esta razón, en la interrogante ¿Qué falta por investigar?, los estudiantes consideraron que se debe determinar: la pertenencia de las huellas dactilares en los vasos (100%), realizar levantamiento planimétrico (3,2%), verificar cámaras de seguridad (70,9%), analizar restos de comida y bebida (6,4%), determinar la procedencia de la sangre (38,7%), búsqueda del arma homicida (90,3%), establecer la relación víctima-victimario (48,3%), analizar historial de consumo de drogas del Sr. Riz (67,7%), investigación financiera (19,3%), entrevistas a allegados (12,9%), cronotanatodiagnóstico de la herida (29%), trayectoria intraorgánica (3,2%), ubicar e interrogar al Sr. Pérez (100%), evaluación médico forense del sospechoso (3,2%) y determinar posibles encubrimientos (6,4%).

Al analizar la distribución de estas interrogantes adicionales, se observa una tendencia marcada a priorizar elementos de identificación directa e inmediata (huellas e interrogatorios al 100%), mientras que aquellas técnicas de mayor especificidad técnica, como la planimetría o trayectoria (3,2%), fueron mencionadas por una minoría. Esta asimetría valida la intención pedagógica declarada en la metodología: la limitación visual de la historieta generada por IA actuó como un reactivo que activó el pensamiento crítico al detectar vacíos necesarios para la validez judicial. Este hallazgo demuestra una transición exitosa hacia un pensamiento científico integral y sistémico, alineado con la postura de Nilendu (2024) sobre priorizar la evaluación holística de la evidencia por encima de la simple ejecución de técnicas aisladas.

Por otro lado, al analizar la opinión de los estudiantes sobre el uso de la historieta como estrategia didáctica para la resolución de un caso forense en la Figura 2.1 se observa la nube de palabras generada, donde aquellas palabras con mayor ocurrencia fueron “gustar” (28), “excelente” (22), “facilitar” (21), “generación” (21), “evaluación” (21) y “proceso” (21), excluyendo aquellas palabras clave como “historieta”, “estrategia”, “didáctica”, “aprendizaje” y “forense”. La prominencia del término “facilitar” sugiere que la historieta, como recurso multimodal, logró reducir la carga cognitiva percibida por los estudiantes al enfrentar conceptos forenses complejos, actuando como un andamiaje pedagógico que permite una transición más fluida entre la teoría y la práctica. En este sentido, Córdoba-Baldrich y Maturana (2022) encontraron que la historieta como estrategia facilita la identificación, adquisición y fortalecimiento de competencias en el proceso de aprendizaje, en este caso en particular de las ciencias forenses, un estudiante

argumentó “me gustó, llama la atención” (E3); es decir, la estrategia invitó al estudiante a resolver un caso de manera lúdica.



2.1) Opinión **2.2) Ventajas** **2.3) Desventajas**

Figura 2. Nube de palabras para las preguntas formuladas sobre la estrategia didáctica utilizada
Fuente: Datos de la investigación.

Entonces, ¿Cuáles fueron las ventajas y desventajas reportadas por los estudiantes? En la Figura 2.2 se observa la nube de palabras generada, encontrando la mayor ocurrencia de las palabras “mostrar” (25), “ayudar” (25), “didáctico” (20), “secuencial” (20), “lúdico” (20), “fomentar” (20), “interés” (20), “relajar” (20), “útil” (20) y “mente” (20). Esta recurrencia de términos como “relajar” y “lúdico” revela una dimensión afectiva crucial; al disminuir la ansiedad evaluativa, la historieta fomenta un entorno de seguridad psicológica que potencia el rigor analítico, demostrando que la pedagogía del juego optimiza la disposición mental para el procesamiento de información crítica. Por ejemplo, como parte de las ventajas un estudiante argumentó “no existe una presión en la evaluación, permite relajarme” (E15). Opiniones similares fueron reportadas por Linares González et al. (2016) donde los conceptos vistos en la asignatura y la historieta al tener una relación, favorecen que el estudiante aplique los conocimientos de una manera crítica, pero creativa, esto último contribuye con un estado de relajación mental.

Mientras que en las desventajas las palabras con mayor ocurrencia fueron “historia” (29), “diseño” (29), “ver” (29), “proporcionar” (13), “cantidad” (13), “tiempo” (13), “influir” (13), “error” (13), “riesgo” (13), “confusión” (13) y “omitir” (13), excluyendo en este último caso las palabras clave “desventajas”, “didáctica”, “aprendizaje”, “educación”, “forense” e “información” (Figura 2.3). La frecuencia de las palabras “omitir” y “confusión” pone de manifiesto la importancia de la fidelidad técnica en la creación de materiales con IA, advirtiendo que el docente debe ejercer una curaduría técnica exhaustiva para evitar que la abstracción visual genere sesgos en la interpretación pericial. Por otro lado, las desventajas se centraron en el diseño e imágenes, “debería reflejar más el sitio del suceso para analizarlo con detalle” (E6), “limita detalles técnicos por la presencia de ciertos colores, etc” (E11) y “se requieren imágenes más específicas de los resultados y no solo la imagen de las expertas forenses” (E20). De la opinión de los estudiantes se desprende que el error y la omisión de información pudieran influir en las respuestas generadas, y la confusión en la interpretación de la imagen, siendo necesario el buen diseño de la misma, con imágenes que reflejen el resultado de las conclusiones de las expertas en el caso planteado.

Del análisis de contenido de las opiniones estudiantiles sobre el uso de la historieta emergieron cinco categorías, que se presentan en la Tabla 2 con sus definiciones operacionales, frecuencias y ejemplos representativos.

Tabla 2.
Categorías emergentes del análisis de las opiniones estudiantiles

Categoría	Definición operacional	Frecuencia (n/31)	Porcentaje	Ejemplo representativo
Calidad de la información	Valoraciones sobre la suficiencia, claridad y precisión de la información presentada en la historieta	6	19,4%	"Debería reflejar más el sitio del suceso para analizarlo con detalle" (E6)
Calidad de las imágenes	Valoraciones sobre la fidelidad técnica y el nivel de detalle de las imágenes generadas por IA	12	38,7%	"Limita detalles técnicos por la presencia de ciertos colores" (E11)
Limitaciones técnicas de la IA	Reconocimiento de restricciones propias de la herramienta para recrear contenido forense específico	8	25,8%	"Se requieren imágenes más específicas de los resultados y no solo la imagen de las expertas forenses" (E20)
Diseño y diagramación	Opiniones sobre la organización visual, secuencialidad y presentación de la historieta	15	48,4%	Palabras "diseño", "secuencial", "ver" en la nube
Confusión interpretativa	Dificultades para interpretar la información visual por abstracción o ambigüedad	4	12,9%	Palabras "confusión", "error", "omitir" en la nube

Nota: La frecuencia corresponde al número de estudiantes (n=31) que mencionaron cada categoría en sus respuestas.
Fuente: Datos de la investigación.

Los resultados de la Tabla 2 muestran una distribución desigual de las categorías emergentes. La categoría más frecuente fue "Diseño y diagramación" (48,4%), seguida de "Calidad de las imágenes" (38,7%), lo que indica que los estudiantes prestaron mayor atención a los aspectos visuales y estructurales de la historieta que a la calidad de la información (19,4%). Esta asimetría sugiere que la dimensión visual del recurso didáctico tuvo peso cognitivo en la experiencia de aprendizaje, lo cual es coherente con lo reportado por Torres Zúñiga (2025), quien evidenció que las imágenes generadas por IA presentan sesgos y limitaciones sistemáticas que los usuarios tienden a detectar cuando se les expone a un análisis crítico.

Esta preocupación por la fidelidad visual no es exclusiva de la IA educativa. En el ámbito forense, Sufiyan (2024) señala que la fotografía de casos de ahogamiento

requiere iluminación correcta, ángulos precisos y múltiples puntos de vista para evitar interpretaciones erróneas de los hallazgos postmortem. La coincidencia entre ambas preocupaciones refuerza la importancia de la precisión visual en cualquier recurso que pretenda representar evidencia forense, ya sea en la práctica profesional o en la formación de científicos forenses.

La imperfección visual de la IA generativa no es un defecto a corregir, sino un recurso didáctico a diseñar. En este sentido, puede entenderse como un andamiaje cognitivo invertido. A diferencia del andamiaje tradicional descrito por Wood et al. (1976), en el que el experto ofrece apoyo temporal al novato, aquí es la ausencia de información visual la que obliga al estudiante a construir activamente los elementos faltantes. Esta inversión del andamiaje desplaza la carga del aprendizaje desde la recepción pasiva hacia la construcción activa de inferencias periciales, convirtiendo al estudiante en un detective de la información faltante.

Esta ausencia actúa como un desafío productivo (Kapur, 2008) que activa el pensamiento crítico, entendido por Facione (1990) como la capacidad de juzgar la calidad de la información disponible y detectar sus vacíos. En el ámbito forense, esa capacidad se traduce en la detección de vacíos periciales, entendida como la identificación de información faltante que debe ser completada mediante análisis adicionales para sostener una hipótesis criminalística con validez judicial (Nilendu, 2024). Los resultados de este estudio respaldan esta interpretación, los estudiantes no solo resolvieron el caso con una coincidencia superior al 90% en preguntas clave, sino que identificaron de forma mayoritaria la necesidad de análisis adicionales (huellas dactilares, búsqueda del arma, interrogatorio del sospechoso), demostrando que la imperfección controlada de la IA, lejos de ser una falla, puede convertirse en un recurso didáctico deliberado para fomentar el pensamiento crítico y la detección de vacíos periciales en la formación de científicos forenses.

No obstante, resulta contrastante que, a pesar de que los estudiantes identificaron confusiones en el diseño técnico-visual (Figura 2.3), esto no afectó la precisión en la resolución criminalística del caso (Tabla 1), donde la mayoría alcanzó consensos superiores al 90% en preguntas clave como la causa de muerte o el arma utilizada. Esto sugiere que la “confusión” reportada no actuó como un obstáculo para el aprendizaje, sino como un motor de desafío que activó un pensamiento crítico más profundo para compensar los vacíos de la IA.

La imperfección visual de la IA ha sido documentada empíricamente. Torres Zúñiga (2025), al analizar 600 imágenes de profesionales forenses generadas por IA, encontró que el 90,2% representaba hombres, el 72,8% tez caucásica, y que el programa mostraba una limitación sistemática para representar el cuerpo completo, optando por planos medios y omitiendo símbolos asociados a la administración de justicia (96,8%). Estas restricciones coinciden con las reportadas por Peche et al. (2025), quienes señalan que la IA forense aún enfrenta limitaciones vinculadas con la calidad de los datos, la explicabilidad de los algoritmos y la falta de estandarización de datasets.

En el contexto educativo, Tarttelin Hernández et al. (2026) demuestran que los estudiantes de ciencias forenses no adoptan la IA de forma acrítica, sino que la posicionan como un apoyo condicional, reservando el juicio profesional para sí mismos. En nuestro estudio, esta misma tendencia se manifestó cuando los estudiantes, lejos de aceptar pasivamente las imágenes incompletas, identificaron activamente los vacíos periciales (¿Qué falta por investigar?) y los convirtieron en objeto de análisis crítico.

Sin embargo, la ausencia de los detalles específicos de las pruebas forenses y sus resultados en las imágenes obtenidas con la inteligencia artificial generativa son limitaciones inherentes de estas herramientas, las cuales arrojan una imagen con base en el prompt diseñado, pero que requieren un entrenamiento para ir perfeccionando sus resultados. En este sentido, la educación forense exige trascender el uso de una IA generalista hacia un prompt engineering especializado; el docente debe actuar como un diseñador instruccional de alta precisión para evitar sesgos visuales o abstracciones gráficas que puedan confundir al estudiante en la interpretación de evidencias críticas. Ahora bien, Eldridge et al. (2021) consideran que existen beneficios de los errores durante la formación o entrenamiento de los estudiantes, porque es una manera para desafiarlos al desarrollo del pensamiento crítico, mejorando la comprensión de sus actos, basados en la retroalimentación de estas estrategias por parte del docente, esto tendría un impacto positivo al minimizar la falta de habilidad, conocimientos, sabiduría y experiencia en la praxis forenses, logrando reducir errores en el campo laboral.

En relación con lo anterior, Gavaldón et al. (2020) reafirman que no solo el sesgo de información de la historieta puede ser un sesgo, sino también la falta de retroalimentación por parte del docente favorece las dudas en los estudiantes, llevándolos a una interpretación errónea o incompleta. Por el contrario, Reyes et al. (como se citó en Romero & Tarquino, 2023), consideran que la historieta como estrategia le resulta familiar a los estudiantes, porque les da la libertad de experimentar, indagar, preguntar, discutir e innovar, dando paso al pensamiento como investigadores forenses al interpretar la información disponible (tanto en imagen como en texto), y la ausencia de información los obliga a plantear aquellos elementos que son necesarios analizar para lograr la formulación de una hipótesis del caso; lo cual se compensó con la interrogante ¿Qué falta por investigar? para identificar esos elementos que no ofrecía la historieta, pero que son claves en el caso.

En líneas generales, la historieta resulta ser una estrategia útil y lúdica, logrando respuestas desde lo técnico y científico, centrándose en las fortalezas que posee el estudiante como investigador, todo se traduce en blindar el caso con argumentos probatorios con base en las evidencias disponibles; incluso fomenta la búsqueda de información para fundamentar sus argumentos. Mosquera Echeverry (2021) afirma que la historieta es una estrategia propicia para inspirar y empoderar a los estudiantes; por su parte Romá-Mateo et al. (2022) explican que la estrategia utilizada se transforma en un reto para el estudiante que da lugar al debate y reflexiones durante el análisis del caso, porque es una manera de aplicar los conocimientos. Todo esto se traduce en un aprendizaje significativo, es decir, útil y duradero (Huerta Rosales & Ortega Villadeza, 2021). Incluso, la historieta es una forma de facilitar la internalización de normas y valores profesionales, así como el ensayo de comportamientos profesionales adecuados (Moretti et al., 2025).

Lo anterior se debe a que las nuevas generaciones son más visuales y observadoras, se identifican con la historia y los personajes, resaltando la importancia del componente lúdico para la formación de ciudadanos críticos, al desarrollar posturas críticas mediante aspectos simbólicos, pero sin dejar a un lado el texto (Paredes-Bonilla et al., 2024); porque un informe pericial emanado de algunos de los científicos forenses se trata de textos con sus respectivas descripciones y conclusiones que vienen respaldados con imágenes de sus resultados. Siendo necesario el análisis de la información plasmada en dicho informe pericial.

Del mismo modo, Ochoa Perdomo (2024) resalta la importancia de aplicar lo aprendido tanto en la asignatura como en su carrera, porque es necesario integrar la información, que fue fragmentada en cada unidad curricular y que al final deberá ser unida para evitar la pérdida de una visión global del caso. Para Daeid (como se citó en Nilendu, 2024) se debe integrar la mejor evidencia científica disponible basada en la combinación de las conclusiones de los expertos forenses e investigadores, para tomar las decisiones informadas e impartir justicia con mayor eficacia. Por esta razón, la educación basada en la evidencia científica promueve la enseñanza y el aprendizaje efectivo en la educación forense, al permitir la comprensión del contexto más amplio de las ciencias forenses.

Por último, Guleria et al. (2024) concluyen que el pensamiento crítico, la pericia y la experiencia práctica pueden proporcionar la información y las competencias necesarias en los ámbitos de las ciencias forenses. Entendiendo, que debemos seguir desarrollando las competencias de los futuros científicos forenses con base en metodologías activas; considerando lo expresado por Araújo et al. (2024) no existe una única estrategia que garantice el desarrollo de las competencias, debido a la complejidad de fomentar el pensamiento crítico en la educación. En este sentido se deben utilizar y combinar diferentes prácticas de alto impacto pedagógico a lo largo del tiempo en las ciencias forenses (Bracewell & Jones, 2022).

En definitiva, la triangulación de estos hallazgos demuestra que la historieta, potenciada por la IA generativa, trasciende lo lúdico para convertirse en un instrumento de evaluación auténtica. Como se planteó en la metodología, la "imperfección" técnica o los vacíos en las imágenes generadas actuaron como un catalizador del pensamiento crítico. Esto obligó al estudiante a no ser un mero espectador, sino un investigador activo que cuestiona, indaga y fundamenta sus hipótesis ante la duda razonable, validando la estrategia como un puente eficaz entre la innovación tecnológica y el rigor científico-forense.

Conclusiones

La historieta como estrategia de aprendizaje permite explorar la investigación forense desde cualquier ciencia, a través del uso de imágenes y una historia, las cuales aportan información sobre el caso objeto a analizar. Estrategia que se interpreta como una alternativa lúdica del aprender haciendo, donde el pensamiento crítico da paso a la argumentación con base en la evidencia disponible, tratando de minimizar la duda razonable. Es decir, proporcionar evidencia científica sólida, basada en la correcta aplicación de procedimientos investigativos y la transparencia en la presentación de pruebas.

La efectividad de esta propuesta se confirma mediante la triangulación de los hallazgos: la consistencia en las resoluciones técnicas (Tabla 1) y la valoración positiva de los estudiantes sobre la utilidad y dinamismo del recurso (Nubes de palabras). Esta convergencia demuestra que la historieta no solo es una herramienta lúdica que favorece el compromiso del estudiante, sino que es un recurso didáctico eficaz para la resolución técnica de problemas, validando su carácter transdisciplinario en la enseñanza de las ciencias forenses.

Por último, la tendencia con base en la opinión de los estudiantes sobre el uso de la historieta como estrategia didáctica para la resolución de un caso forense, trae ventajas prácticas al aplicar los conocimientos en el caso, donde el dominio de conceptos y el razonamiento de ¿cómo aplicarlos? demuestran esa capacidad de análisis para su uso racional, eficiente y pertinente en la resolución del hecho.

Aunque el objetivo de la investigación no fue evaluar la calidad de la historia e imágenes generadas con la inteligencia artificial, es importante considerar para futuras actividades e investigaciones el diseño del prompt y la necesidad de ofrecer detalles en el campo forense sobre las experticias realizadas y sus resultados. Esto debido, a las múltiples ciencias que prestan sus conocimientos al sistema de justicia, aportando información valiosa para que los investigadores forenses puedan sustentar el caso. Sin embargo, el objetivo de la estrategia se cumplió al obtener una veracidad interna de los resultados tras el análisis de contenido, debido a la recurrencia de las palabras y argumentos presentados.

Lo anterior evidencia la necesidad de avanzar hacia el diseño de directrices y prompts especializados para la IA educativa para las ciencias forenses. En primer lugar, resulta necesario establecer lineamientos pedagógicos que orienten la integración de IA generativa en la formación forense, considerando las particularidades técnicas y éticas de la disciplina, tales como la fidelidad de las representaciones visuales, la protección de datos sensibles y la trazabilidad de las decisiones asistidas por IA. En segundo lugar, se requiere avanzar en el diseño de prompts especializados que incorporen terminología forense precisa (por ejemplo, patrones de manchas hemáticas, estadios entomológicos, signos de disparo a contacto) y que permitan a los docentes generar materiales didácticos con mayor rigor científico.

En tercer lugar, futuras investigaciones podrían explorar el impacto de estos prompts especializados en el desarrollo de competencias forenses específicas, como la detección de vacíos periciales, la formulación de hipótesis criminalísticas y la argumentación basada en evidencia. Finalmente, se recomienda desarrollar estudios longitudinales y comparativos que evalúen la efectividad de diferentes estrategias de IA educativa en ciencias forenses, así como investigaciones que aborden las implicaciones éticas y legales del uso de IA generativa en la formación de futuros científicos forenses. Estas líneas de investigación contribuirían a consolidar un marco pedagógico sólido para la integración responsable y efectiva de la IA en la educación forense.

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Original Article

Estrategias educativas mediadas por avatares de IA para fortalecer la comprensión auditiva y la expresión oral en la educación superior

Educational strategies mediated by AI avatars to strengthen listening and speaking in higher education

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Resumen

El artículo explora el papel de los avatares digitales como herramienta para aumentar la efectividad del aprendizaje de lenguas extranjeras entre los estudiantes y describe estrategias educativas efectivas para su integración. El estudio se realizó sobre la base de un diseño empírico cuantitativo con elementos de un cuasi-experimento. Un grupo experimental (n = 80) que estudió utilizando avatares digitales y un grupo de control (n = 80) que estudió utilizando métodos tradicionales se utilizaron para la comparación. La muestra incluyó estudiantes que estudiaban inglés (n = 84) y alemán (n = 76). Los resultados mostraron una ventaja estadísticamente significativa del grupo experimental en términos del nivel de competencia comunicativa ($p < 0,001$; $d = 0,68$). También se demostró un efecto principal significativo del uso de avatares ($\eta^2 = 0,11$) sin interacción con la lengua de instrucción. La intensidad del uso de avatares tuvo un efecto positivo en los aspectos de la motivación ($r = 0,42$) y el compromiso ($r = 0,38$). Se observó que el uso de avatares fue un predictor de competencia ($\beta = 0,31$). Los resultados resumieron que los efectos más pronunciados se observaron en la escucha y el habla.

Palabras clave: avatares digitales; competencia comunicativa; educación superior; lengua extranjera; motivación.

Abstract

The article explores the role of digital avatars as a tool to enhance the effectiveness of foreign language learning among university students and outlines effective educational strategies for their integration. The quantitative empirical design with elements of a quasi-experiment was used. An experimental group (n = 80) that studied using digital avatars and a control group (n = 80) that studied using traditional methods were used for comparison. The sample included students studying English (n = 84) and German (n = 76). The findings showed a significant advantage for the experimental group in communicative competence in a foreign language ($p < 0.001$; $d = 0.68$). A significant main effect of the use of avatars ($\eta^2 = 0.11$) without interaction with the language of instruction was also demonstrated. The intensity of the use of avatars had a positive effect on the aspects of motivation ($r = 0.42$) and engagement ($r = 0.38$). It was noted that the use of avatars was a predictor of competence ($\beta = 0.31$). The findings summarized that the most pronounced effects were found for listening and speaking.

Keywords: foreign language; communicative competence; digital avatars; higher education; motivation.

Introduction

The development of higher education has led to an active search for innovative tools to increase the effectiveness of foreign language learning by students. One such tool is digital avatars, which act as interactive virtual agents that allow simulating speech and social interaction. Accordingly, they are used in educational platforms, virtual simulations, and blended learning environments. In the language education system, digital avatars are used to model communicative situations, develop oral and listening skills, and form intercultural communication. At the same time, an important pedagogical explanation for the effectiveness of digital avatars is the concept of social presence in a digital learning environment. In particular, it has been proven that digital avatars can create the illusion of interpersonal interaction, but do not provide for a direct evaluative reaction from the teacher or other students. This format of interaction helps to reduce the affective filter and reduces speech anxiety and fear of making mistakes. Thus, it has been proven that students can get the opportunity to repeatedly practice speaking in a safe and controlled environment, experiment with language constructions, and participate more actively in communicative situations. This creates favorable conditions for the development of foreign language forein communicative competence and learning autonomy. Therefore, the relevance of this study is that despite the increasing number of practical examples of the use of digital avatars in foreign language learning, their real impact on students' academic performance remains insufficiently quantified. At the same time, most of the available studies were descriptive or experimentally limited in nature and did not provide a specific idea of the role of digital avatars in the development of language skills (Laurens-Arredondo, 2024).

The scientific value of this work lies in establishing the relationship between the use of digital avatars and key indicators of the effectiveness of foreign language learning in higher education institutions. In addition, the study is aimed at bridging the gap between the technological capabilities of digital avatars and the evidence base of their pedagogical effectiveness (Canto & Jauregi-Ondarra, 2021; Jauregi-Ondarra & Canto, 2022). The scientific problem of the study is the lack of empirically confirmed data on which aspects of language learning (foreign language communicative competence, motivation, autonomy of learning, reduction of speech anxiety) most depend on the use of digital avatars. Thus, the purpose of the study is to determine the impact of the use of digital avatars on the results of foreign language learning by students and to indicate effective educational strategies for their integration into the learning process.

To achieve the goal, the following tasks have been defined:

1. To assess the impact of the use of digital avatars on the level of foreign language communicative competence of students.
2. To determine the relationship between the use of digital avatars and students' learning motivation and involvement in the process of learning a foreign language.
3. To analyze the effectiveness of educational strategies for integrating digital avatars into the learning process based on a comparison of the results of students who study using digital avatars and students who study using traditional methods.

Research hypotheses

H1. The using of avatars has a positive impact on the level of foreign language communicative competence of students compared to traditional teaching methods.
H2. There is a positive and statistically significant relationship between the intensity of the use of digital avatars and the level of students' learning motivation and involvement in learning a foreign language.
H3. Educational strategies that involve the interactive use of digital avatars are more effective in terms of students' learning outcomes.

Literature Review

Digital avatars in foreign language teaching in modern research are considered as a tool that combines the visual “embodiment” of a participant (student or teacher) with the capabilities of digital environments for communication, situation modeling, and personalized feedback (Marín Rodriguez et al., 2023). In the existing scientific discourse, “digital avatars” most often appeared within two interrelated approaches: (1) avatars as a form of user presence in VR systems; (2) avatars as a shell for virtual or embodied conversational agents that imitated the interlocutor/mentor and supported language interaction. It is this terminological framework that became productive for further scientific research, as it made it possible to connect the “avatar” phenomenon with established research areas.

In general, the authors proved that digital avatars play the role of important virtual characters (2D or 3D), which are based on artificial intelligence or software algorithms. In language education, they can be used as virtual interlocutors (Torija & Torija, 2024).

As a rule, the authors indicated that digital avatars integrate several technologies: speech recognition: the system understands what the student says, analysis of the content of the response (Gu et al., 2023). In addition, there are special animated models that can create the effect of a real conversation.
Accordingly, in modern systems, avatars can support a dialogue in real time and correct grammatical and phonetic errors

Avatar VR environments as a space for communicative practice

During 2021–2025, many researchers focused on the extent to which social VR has changed the conditions of language practice. In particular, there was a process of increasing tangible presence, increased interaction, which made it possible to reproduce communicative situations in the format of role-playing scenarios. It was especially evident to what extent VR research considered opportunities as an “environment” or “gamification” (Alam & Mohanty, 2022; Wang & Zou, 2025). At the same time, scientists drew attention to avatars as a space for the formation of interactional competence (the ability to interact in real dialogue - to initiate a conversation, respond, clarify, maintain social roles and politeness) (Torija & Torija, 2024). Highly immersive VR sessions in training demonstrated that avatar interaction supported the development of precisely this “pragmatic-interactional” component of language training, which was often poorly formed in traditional classroom formats.

In parallel, a line of research developed where social VR was used in virtual exchange (VE) models as a form of intercultural interaction (Hensen, 2023). Such works emphasized that the virtual space with avatars changed the communicative dynamics compared to video communication: participants demonstrated a different

level of social involvement, built joint activities differently and more often moved to spontaneous interactions, which is valuable for the development of oral speech and intercultural competence (Barráez-Herrera, 2022; Chen, 2021). Thus, avatar practices were associated with the transition from “reproductive” approaches (exercise performance) to strategies where learning took place through interaction, cooperation and joint solving of communicative tasks. It is important that researchers used systematic syntheses to substantiate the effectiveness of digital avatars (González Vallejo, 2024; Laura-De La Cruz et al., 2023). PRISMA reviews or analysis of empirical studies summarized the existing experience of using immersive VR in foreign language teaching (Peixoto et al., 2021). This showed that positive effects were most often recorded in the areas of motivation, engagement and satisfaction with learning, as well as in creating conditions for communicative practice. At the same time, the review highlighted typical methodological limitations (Peredo-Alarcon, 2025): small samples, diverse measurement tools, and different VR usage scenarios, which make more detailed comparisons difficult.

Avatars as “virtual agents”: personalization and pedagogical support in learning

A separate direction of modern research has formed the idea of digital avatars as embodied conversational agents. They acted as active participants in the learning process, were visual representations of users. Such studies analyzed how avatars interacted with students in the format of dialogue, role-playing or instruction, modeling communicative situations and supporting learning interaction (Taguchi & Hanks, 2025). Scoping reviews have shown that studies of this type focus not only on the final learning outcomes, but also on intermediate mechanisms, in particular the quality of interaction between the student and the agent, types of prompts and feedback, levels of engagement, trust in the digital interlocutor and reduction of speech anxiety (Gu et al., 2023). Besides, the authors emphasized the importance of further systematic research aimed at analyzing the learning process itself, comparing "before" and "after" indicators, using comparable and methodologically consistent assessment tools (Gu et al., 2023).

In the context of the formation of new educational strategies, this approach made it possible to consider a digital avatar as a multifunctional pedagogical tool that can simultaneously perform the role of a virtual interlocutor for training dialogical speech, support repetition and consolidation of material, accompany the performance of tasks through explanation of instructions and structuring the scenario, provide adaptive feedback in the form of prompts, corrections and recommendations (Muñoz-Arteaga, 2020; Thrasher et al., 2024). In a broader perspective, avatar technologies fit into the general trend of personalization and automated pedagogical support, which has become particularly relevant in the conditions of mass higher education, large study groups and limited opportunities for individual feedback with teachers (Vazquez-Calvo et al., 2020; Yang et al., 2025).

Research gaps

Despite the increase in the number of publications, several important gaps have been demonstrated in the literature. First, studies often differed in the level of immersion (desktop VR vs HMD), the type of avatar interaction (peer-to-peer vs agent-learner), and the task scenarios, making it difficult to directly compare results. Second, studies with a strong focus on VR often focused on motivational and subjective metrics (satisfaction, engagement), while language outcomes required more robust measurement tools.

Methodology

Research design

The study was conducted using a quantitative empirical design with elements of a quasi-experimental approach. This design made it possible to indicate the influence of digital avatars on the results of foreign language learning by students based on the comparison of educational indicators between the experimental and control groups, as well as taking into account the language factor.

The independent variable was the use of digital avatars in the learning process (experimental / control group). At the same time, the main dependent variables were the level of foreign language communicative competence, learning motivation and student involvement. An additional factor variable was the study of a specific foreign language (English or German). This, in turn, affected the consideration of possible differences between language groups. The control variables were the course of study and the initial level of foreign language proficiency.

Participants and sample

160 students of higher education institutions who studied a foreign language within the framework of their educational programs participated in the study. The sample was formed on the principle of accessible sampling, taking into account the comparability of the learning environment.
Participants were divided into two groups:

experimental group - 80 students, whose training was carried out using digital avatars;
control group - 80 students who studied using traditional methods.
By language component, the sample included:
students who studied English (n = 84);
students who studied German (n = 76).

In general, the distribution of students by language was proportionally represented in both groups. All participants participated in the study on a voluntary basis, observing the ethical principles of scientific research and ensuring data anonymity (See Table 1).

Table 1.
Demographic characteristics of the sample

Variable	Category	n	%
Gender	Female	98	61.3
	Male	62	38.7
Age	18–19 years	46	28.8
	20–21 years	72	45.0
	22–23 years	42	26.2
Year of study	1st year	44	27.5
	2nd year	58	36.3
	3rd year	38	23.7
	4th year	20	12.5
Language studied	English	84	52.5
	German	76	47.5
Group type	Experimental (digital avatars)	80	50.0
	Control (traditional instruction)	80	50.0

As shown in Table 1, the sample was dominated by women (61.3%). The majority of respondents were students aged 20–21 (45.0%). These data correspond to the typical age profile of bachelor's degree applicants.

By year of study, the most represented were 2nd year students (36.3%), followed by 1st year students (27.5%), 3rd year students (23.7%) and 4th year students (12.5%). By language, the sample was almost evenly distributed among students. The experimental and control groups were quantitatively balanced (80 people each).

It should be noted that the sampling procedure was based on availability (convenience sampling), which may limit the generalizability of the results to the broader population of higher education students. Participants were recruited from institutions that agreed to participate in the study and had access to the technological infrastructure. Therefore, the results should be interpreted primarily in the context of similar educational settings. Future studies could expand the sample and use randomized or multi-institutional sampling strategies to increase external validity.

Instruments and procedure

The work used various tools aimed at measuring students' foreign language communicative competence, their learning motivation, engagement and features of using digital avatars.

The level of foreign language communicative competence was measured on the basis of standardized final testing adapted to the language of instruction (English or German). The test included three structural components:

listening;
speaking;
lexical and grammatical correctness.

The content of the test tasks was aligned with the CEFR levels (A2–B2) and the curricula of the relevant courses. To ensure validity, the tool was expertly evaluated by foreign language teachers (n = 3). They checked the correspondence of the tasks to the learning objectives and the level of complexity.

The reliability of the test was checked by calculating the internal consistency coefficient (Cronbach's α). Accordingly, the indicator α = 0.82 was obtained - good reliability of the tool.

Students' learning motivation and engagement were determined using a structured questionnaire, which was compiled on the basis of previous empirical research in the field of language education and adapted to the goals of this study. The questionnaire consisted of 18 statements grouped into two scales:

motivation to learn a foreign language;
learning engagement.

Moreover, responses were recorded on a five-point scale. To check the construct validity, an exploratory factor analysis with varimax rotation was conducted, the results of which confirmed the two-factor structure of the questionnaire. Overall, the internal consistency indicators were high for motivation, in particular: α = 0.85; engagement: α = 0.83.

At the same time, the intensity of use of digital avatars was measured based on students' self-assessment (frequency and duration of interaction) and data from educational platforms (number of sessions, types of completed tasks, interaction time).

Based on these indicators, an index of intensity of use of digital avatars was formed, which was used in correlation and regression analysis.

The study was conducted during an 8-week educational cycle in the usual conditions of the educational process. At the initial stage, participants were informed about the purpose of the study, the principles of voluntary participation, and data confidentiality.

The experimental group implemented the integration of digital avatars into language classes.

Avatars were created based on the use of artificial intelligence and natural language processing technologies.

The digital avatars were implemented using an AI-based conversational engine based on the Large Language Model (LLM) architecture combined with natural language processing (NLP) technologies. The system integrated automatic speech recognition (ASR) to process students' spoken input and text-to-speech (TTS) synthesis to generate natural-sounding avatar responses.

The dialogue system operated through an intent recognition engine. This enabled the avatar to respond to students' questions and statements within predefined communicative scenarios. The platform also consisted of adaptive language modules that adjusted lexical and grammatical complexity according to the learner's level of language proficiency. Interaction logs (number of sessions, duration of interaction, tasks completed) were automatically recorded by the learning platform and used as indicators of the intensity of avatar use.

Digital avatars were used for:

modeling typical communicative situations (everyday communication, educational and professional contexts);
training oral speech through dialogic scenarios;
practicing lexical and grammatical structures in context;
developing listening skills and speech response.

Avatars had a human-like visual image, synthesized speech and the ability to adapt language complexity according to the student's level. For students studying English and German, appropriate language modules with authentic pronunciation samples were used.

Interaction with digital avatars took place during regular classes and within the framework of independent work. Students in the experimental group performed tasks with avatars at least 2 times a week, each session lasted an average of 10–15 minutes.

The control group was trained using traditional methods without the use of digital avatars.

Later, after the end of the training period, all participants took a final test in a foreign language and filled out a questionnaire on motivation and involvement. Data collection was carried out in an online format with subsequent statistical processing of the results.

To increase internal validity, the same learning conditions, course duration, and learning material were provided for both groups. External validity was supported by including students who studied different foreign languages (English and German).

The reliability of the results was ensured by using standardized instruments, checking the internal consistency of the scales, and applying several data collection methods. In particular, the content validity index (CVI) was calculated based on the results of the expert assessment. For the foreign language communicative competence test: CVI = 0.89;
for the motivation and engagement questionnaire: CVI = 0.91 (recommended threshold 0.80).

To determine the construct validity of the motivation and engagement questionnaire, an exploratory factor analysis (EFA) with varimax rotation was conducted. The Kaiser–Meyer–Olkin (KMO) index was 0.86, indicating a high adequacy of the sample. Bartlett's test of sphericity was statistically significant ($\chi^2 = 742.36$, $p < 0.001$).

Data Analysis

The empirical data analysis was carried out in stages using descriptive and inferential statistics. Statistical data processing was carried out on the basis of SPSS.

At the first stage, data cleaning and completeness checking were carried out. Cases with missing values did not exceed 5% of the total sample. Next, descriptive statistics of the main study variables were carried out, in particular, average values, standard deviations and minimum and maximum indicators were calculated. At the same time, for hypothesis H1 regarding the impact of the use of digital avatars on the level of foreign language communicative competence, a t-test for independent samples was applied.

In order to take into account the language factor (English / German), a two-factor analysis of variance (ANOVA) was additionally conducted, which allowed to evaluate the effect of the use of digital avatars.

The effect size was determined using the indicators η^2 (eta squared) and Cohen's d.

To test hypothesis H2, a correlation analysis was conducted between the intensity of digital avatar use and indicators of students' learning motivation and engagement.

To test hypothesis H3 and assess the contribution of digital avatar use to the formation of foreign language communicative competence, a multivariate linear regression analysis was applied.

The regression model included:

intensity of digital avatar use;

learning motivation;
learning engagement;
language of instruction (dichotomous variable);
initial level of foreign language proficiency (control variable).

Before building the models, the absence of multicollinearity was checked using VIF (Variance Inflation Factor) indicators, the values of which did not exceed the permissible threshold.

Results and Discussion

The results indicated that students in the experimental group who were trained using digital avatars had higher average communicative competence in a foreign language compared to students in the control group who were trained using traditional methods. Students who studied with digital avatars (M = 78.42, SD = 8.15) had higher scores compared to those who studied with traditional methods (M = 72.36, SD = 9.04 (see Table 2).

Table 2.
Comparison of foreign language communicative competence between groups

Group	N	Mean	SD	t	p	Cohen's d
Experimental (digital avatars)	80	78.42	8.15			
Control (traditional instruction)	80	72.36	9.04	4.29	< 0.001	0.68

The results of the ANOVA revealed a statistically significant main effect of the use of digital avatars, $F(1, 156) = 18.47$, $p < 0.001$, $\eta^2 = 0.11$. Therefore, regardless of the language of instruction, students who studied using digital avatars had a higher level of language communicative competence compared to students in the control group.

Analysis of the interaction of the factors "digital avatars × language of instruction" also did not reveal a statistically significant effect, $F(1, 156) = 0.84$, $p = 0.361$.

Table 3.
Two-way ANOVA data for foreign language communicative competence

Source	SS	df	MS	F	p	η^2
Digital avatars (yes/no)	1184.32	1	1184.32	18.47	< 0.001	0.11
Language (English/German)	123.06	1	123.06	1.92	0.168	0.01
Avatars × Language	53.84	1	53.84	0.84	0.361	0.01
Error	9995.20	156	64.07			
Total	11356.42	159				

Besides, the main effect of the language of instruction (English / German) was statistically insignificant, $F(1, 156) = 1.92$, $p = 0.168$. Therefore, there were no significant differences in the level of foreign language communicative competence between students.

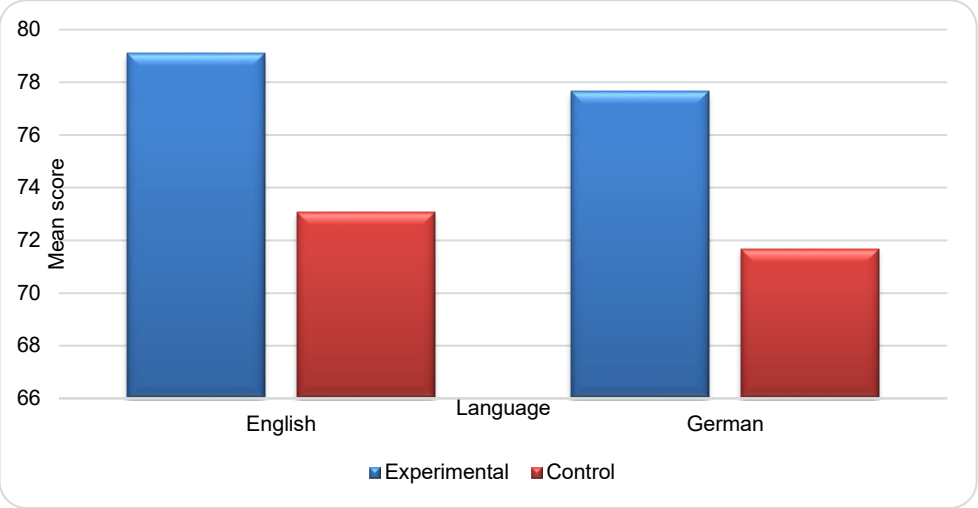


Figure 1. Mean Scores of Foreign language communicative competence

The digital avatar intensity index was calculated for students in the experimental group (N = 80) based on aggregated avatar interaction logs over an 8-week study period. Two indicators were included in the calculation of the index: the total number of interaction sessions and the total time of interaction with avatars (See Appendix 1).

To ensure comparability of the indicators, each of them was standardized (z-transformed), and then integrated into a single index according to the formula:

Avatar Use Intensity Index=2z(Total sessions)+z(Total minutes)

Thus, the digital avatar intensity index indicated that the average index value in the experimental group was equal to SD = 0.96, which is the expected result of standardization of indicators. The index values ranged from −1.46 to 1.67, which indicates the presence of significant interindividual variability. In addition, the study also conducted a Pearson correlation analysis. The results of the analysis showed a positive relationship between the intensity of digital avatar use and the level of students' academic motivation ($r = 0.42$, $p < 0.001$), as well as between the intensity of digital avatar use and the level of academic engagement ($r = 0.38$, $p < 0.001$).

Table 4.
Correlations between digital avatar use intensity, learning motivation, and engagement

Variable	1	2	3
1. Digital avatar use intensity	1		
2. Learning motivation	0.42***	1	
3. Learning engagement	0.38***	0.51***	1

***p < 0.001*

The last stage of the study involved conducting a multivariate linear regression analysis. It was aimed at determining the contribution of the use of digital avatars to the formation of foreign language communicative competence of students, considering motivation, involvement and language factors.

In particular, the main dependent variable in the model was the level of foreign language communicative competence, while the independent variables were the index of the intensity of use of digital avatars; learning motivation; learning involvement; language of instruction (English / German, dichotomous variable). Before building the regression model, the linear regression assumptions were checked. Multicollinearity analysis did not reveal critical violations (all VIF values < 2.0). Therefore, the data from the regression analysis indicated that the model is statistically significant ($F(4, 155) = 19.36$, $p < 0.001$) and explained 42% of the variation in the level of foreign language communicative competence of students ($R^2 = 0.42$).

The index of intensity of use of digital avatars turned out to be a significant positive predictor of foreign language communicative competence ($\beta = 0.31$). Also, learning motivation ($\beta = 0.29$, $p < 0.001$) and learning engagement ($\beta = 0.21$, $p = 0.004$) made significant contributions to the model (See Table 5).

Table 5.
Multiple Regression Predicting Foreign language communicative competence

Predictor	B	SE	β	t	p
Digital avatars use intensity index	3.12	0.74	0.31	4.22	< 0.001
Learning motivation	2.45	0.68	0.29	3.60	< 0.001
Learning engagement	1.87	0.63	0.21	2.91	0.004
Language (English = 1, German = 0)	0.84	0.59	0.06	1.42	0.158

$R^2 = 0.42$, Adjusted $R^2 = 0.40$, $F(4, 155) = 19.36$, $p < 0.001$

Thus, the data from the regression analysis indicated that the use of digital avatars has an independent and significant impact on the level of foreign language communicative competence of students even after controlling for motivational and learning factors.

At the same time, to determine the mechanisms of influence of digital avatars on foreign language communicative competence of students, the results were analyzed by individual language skills.

The data indicated that the most pronounced influence of digital avatars is observed in listening and speaking skills. Students in the experimental group had statistically significantly higher results in listening ($p < 0.001$) and speaking ($p < 0.001$) compared to students in the control group (See Figure 2).

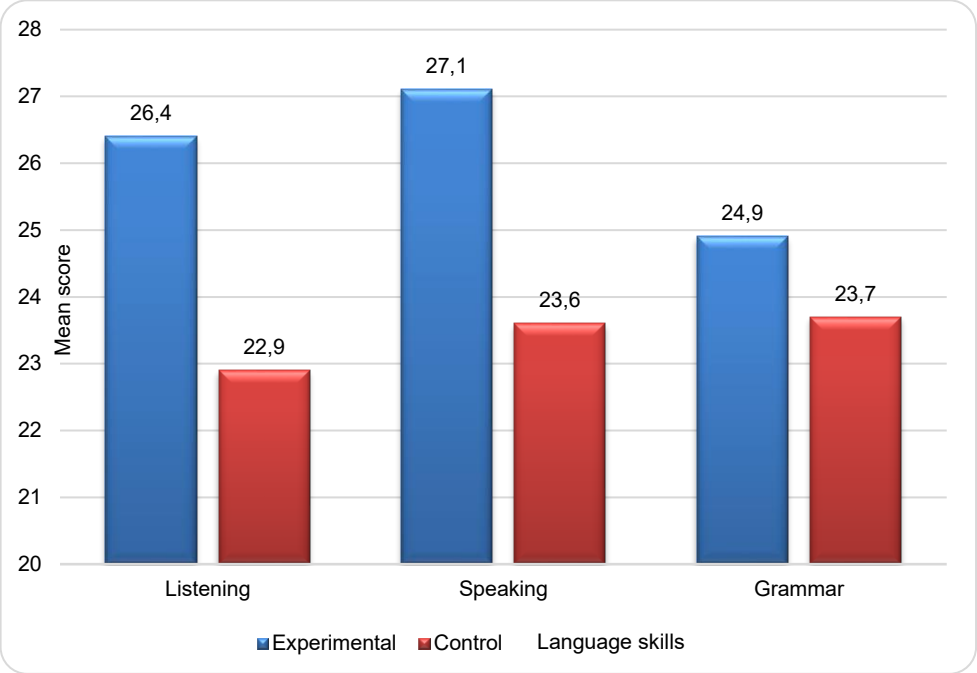


Figure 2. Effects of avatars on skills

In contrast, for lexical and grammatical correctness, only moderate differences were recorded between the groups, which did not have a statistical significance level ($p > 0.05$). Therefore, digital avatars had a greater influence on communicative and receptive skills than on formal and structural aspects of foreign language communicative competence (See Table 6).

At the same time, the study indicated an improvement in grammatical correctness ($p = 0.062$), which requires a separate explanation. This is probably due to the different nature of the formation of communicative and formal language skills. Digital avatars primarily formed an environment for interactive speech practice, which stimulated the development of receptive and productive oral skills - listening and speaking. In such conditions, students focused on conveying content and maintaining a dialogue. This, in turn, contributes to the development of communicative competence in foreign language, but does not always involve focused work on grammatical accuracy. In addition, grammatical correctness is usually formed through another type of learning activity, which consists of systematic exercises in the analysis of language structures and written practice (Aliyeva et al., 2023). In the study, the use of avatars was primarily aimed at modeling communicative situations and developing spontaneous speech. Accordingly, this could reduce the emphasis on formal grammar control. Therefore, the results indicated that digital avatars are particularly effective for developing communicative skills; however, increasing grammatical accuracy may require additional pedagogical strategies focused on explicit grammar instruction.

Table 6.
Comparison of skill scores

Skill	Group	Mean	SD	t	p	Cohen's d
Listening	Experimental (digital avatars)	26.4	3.2			
	Control (traditional instruction)	22.9	3.8	4.89	< 0.001	0.78
Speaking	Experimental (digital avatars)	27.1	3.5			
	Control (traditional instruction)	23.6	3.9	4.52	< 0.001	0.72
Grammar	Experimental (digital avatars)	24.9	3.6			
	Control (traditional instruction)	23.7	3.4	1.88	0.062	0.30

This study aimed to determine the role of digital avatars in foreign language learning by students. The data obtained made it possible to explain the impact of digital avatars through three analytical blocks that corresponded to the formulated tasks and hypotheses (H1–H3).

The first task was to assess the impact of digital avatars on the level of language communicative competence of students. In particular, the data obtained from the t-test and two-factor ANOVA confirmed H1, that students in the experimental group had statistically significantly higher foreign language communicative competence compared to the control group. At the same time, the main effect of using avatars was significant even when taking into account the language factor. The absence of a significant interaction of "avatars × language (English/German)" indicated the presence of a positive effect that was relatively universal and not limited to the specifics of a particular language.

Compared with previous studies in the field of language learning technologies, the obtained data agreed with the positions of scientists (Bohomaz et al., 2023; Harbord et al., 2021; Kaplan-Rakowski & Gruber, 2023). In particular, scientists have indicated that digital interlocutors (virtual agents/avatars) have increased the effectiveness of learning based on technologies of interactivity, imitation of communicative situations (Anacona Ortiz et al., 2022). Others have also pointed out the importance of the digital environment for language practice. It is especially important that avatars indicated the conditions for repeated repetition of communicative actions without social pressure. Our results added an empirical argument to this discussion. In particular, the effect of avatars was not reduced to an "interesting tool" (Gruber et al., 2023). It was manifested in a measurable improvement in competence.

At the same time, it is worth emphasizing that the growth of foreign language communicative competence in the case of using avatars may be associated with technology and with the pedagogical organization of interaction. In particular, this is associated with the regularity of practice, scenario-based construction of dialogues, adaptation of complexity and the presence of feedback (Jerez-Rodríguez & Díaz-Borja, 2023; Li et al., 2021).

The second task involved determining the relationship between the use of digital avatars and learning motivation and engagement. The positive correlations found between the intensity of digital avatar use and motivation/engagement confirmed H2. This was consistent with studies that consider digital interactive agents as an important factor in modern language education (Silveira et al., 2025; Turchyn et al., 2023). In particular, the authors indicated that they supported learning autonomy, a sense of control over the pace of learning. Other authors indicated that they influenced the personalization of practice and increased engagement. Importantly, in our case, the effect appeared to be a relationship, that is, the more

intense the interaction, the higher the motivation and engagement" (Marenco Domínguez & Marín Juanías, 2024; Tarouco et al., 2024). However, these results should be interpreted with caution given the possibility of a bidirectional relationship. For example, more motivated students could use digital avatars more often. Therefore, further studies should strengthen the evidence by experimentally controlling intensity.

The third task was aimed at assessing the effectiveness of educational strategies with digital avatars. Thus, the regression data confirmed H3. Thus, the intensity of the use of digital avatars was a significant predictor of foreign language communicative competence even after controlling for motivation, engagement, and language factors. This is an important contribution to the discussion on whether the effect of digital technologies is mediated only by motivational mechanisms or has an independent "educational" contribution (Peña Arcila, 2020; Ribeiro et al., 2024). Moreover, when compared with other studies, it becomes clear that the results of this study support the "pragmatic" approach (Guerra-Tamez, 2025). In particular, the digital avatar works as a practice environment that increased the number and quality of communicative attempts, and this is what explained the increase in competence. At the same time, motivation and engagement also remain significant predictors. Such data are consistent with other works (Antón-Sancho et al., 2023; Cabrera-Duffaut et al., 2024). Thus, in our model, digital avatars interacted with motivation.

Thus, the integration of digital avatars into the learning process led to improved academic performance of students. One possible explanation for this effect is the increased level of interactivity and personalization of learning. Thus, unlike traditional learning environments, avatar environments created an important effect of social presence and imitation of interpersonal interaction. As a result, this had a positive effect on motivation and cognitive activity.

Additional analysis by individual skills showed that digital avatars have the most pronounced impact on listening and speaking. This result is consistent with the research logic of using digital technologies (Bucchiarone, 2022; Jauregi-Ondarra et al., 2022). In particular, the authors indicated that they form live communication situations, train the speed of speech reaction, and listening comprehension. In contrast, grammatical accuracy often requires specially designed exercises with an explicit focus on form (Boichenko et al., 2023). Thus, avatars have become the most effective for developing foreign language communicative competence. However, despite the results obtained, the study has certain limitations. First, the sample was formed on the principle of accessibility and included students of only two foreign languages. This may limit the generalizability of the results. On the other hand, some indicators are based on self-reported data. In addition, the duration of the intervention was limited in time. This did not allow assessing the long-term impact of digital avatars.

Therefore, further research should be directed towards the use of long-term experimental designs, the inclusion of objective logs of interaction with digital avatars, and the expansion of the spectrum of languages and educational contexts.

Conclusions

The results of the proposed study established the effectiveness of digital avatars as a tool for supporting and developing foreign language training of students. It was shown that the use of digital avatars significantly increased the level of foreign

language communicative competence, which confirmed the main hypothesis of the study. The influence of avatars became stable regardless of the language of instruction, which indicated the universal educational potential of this approach.

It was also found that the intensity of interaction with digital avatars was positively correlated with students' learning motivation and involvement. This indicated that digital avatars strengthened communicative practice, created a favorable psychological environment for active participation in the educational process.

The proposed results of the regression analysis confirmed that the intensity of avatar use was an independent predictor of foreign language communicative competence even after controlling for motivational and educational factors. This indicated the existence of a real pedagogical effect of the use of digital avatars, which goes beyond simply increasing interest or emotional involvement.

Additional analysis of individual language skills showed that the greatest increase was observed in the field of listening and speaking, while the impact on lexical and grammatical correctness became less pronounced. Thus, digital avatars became effective in the development of communicative aspects of speech activity.

In summary, the study confirmed the feasibility of integrating digital avatars into foreign language courses in higher education institutions. Their use contributed to increasing the efficiency of the educational process, the formation of positive learning strategies and the creation of an innovative educational environment.

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Appendix 1.

Student ID	Sessions Per week	Avg. minutes per session	Total sessions	Total minutes	Sessions z	Minutes z	Avatar Use Intensity Index
1	3	14	24	336	0,310776	0,318399	0,314588
2	4	19	32	608	1,198708	2,137823	1,668266
3	1	15	8	120	-1,46509	-1,12644	-1,29576
4	3	10	24	240	0,310776	-0,32375	-0,00649
5	3	8	24	192	0,310776	-0,64483	-0,16702
6	4	11	32	352	1,198708	0,425424	0,812066
7	1	9	8	72	-1,46509	-1,44751	-1,4563
8	1	15	8	120	-1,46509	-1,12644	-1,29576
9	3	11	24	264	0,310776	-0,16321	0,073782
10	2	9	16	144	-0,57716	-0,9659	-0,77153
11	3	13	24	312	0,310776	0,157862	0,234319
12	3	13	24	312	0,310776	0,157862	0,234319
13	3	17	24	408	0,310776	0,800011	0,555394
14	3	11	24	264	0,310776	-0,16321	0,073782
15	4	13	32	416	1,198708	0,853524	1,026116
16	1	9	8	72	-1,46509	-1,44751	-1,4563
17	4	17	32	544	1,198708	1,709723	1,454216
18	4	19	32	608	1,198708	2,137823	1,668266
19	4	9	32	288	1,198708	-0,00268	0,598016
20	3	17	24	408	0,310776	0,800011	0,555394
21	2	11	16	176	-0,57716	-0,75185	-0,6645
22	1	15	8	120	-1,46509	-1,12644	-1,29576
23	2	14	16	224	-0,57716	-0,43078	-0,50397
24	4	19	32	608	1,198708	2,137823	1,668266
25	4	16	32	512	1,198708	1,495674	1,347191
26	2	15	16	240	-0,57716	-0,32375	-0,45045
27	2	12	16	192	-0,57716	-0,64483	-0,61099
28	2	9	16	144	-0,57716	-0,9659	-0,77153
29	4	12	32	384	1,198708	0,639474	0,919091
30	4	15	32	480	1,198708	1,281624	1,240166
31	1	17	8	136	-1,46509	-1,01941	-1,24225
32	1	16	8	128	-1,46509	-1,07293	-1,26901
33	4	19	32	608	1,198708	2,137823	1,668266
34	2	19	16	304	-0,57716	0,104349	-0,2364
35	2	19	16	304	-0,57716	0,104349	-0,2364
36	1	16	8	128	-1,46509	-1,07293	-1,26901
37	4	8	32	256	1,198708	-0,21673	0,490991
38	1	16	8	128	-1,46509	-1,07293	-1,26901
39	1	14	8	112	-1,46509	-1,17995	-1,32252
40	3	16	24	384	0,310776	0,639474	0,475125
41	3	15	24	360	0,310776	0,478937	0,394856
42	3	8	24	192	0,310776	-0,64483	-0,16702
43	2	19	16	304	-0,57716	0,104349	-0,2364
44	4	15	32	480	1,198708	1,281624	1,240166
45	4	15	32	480	1,198708	1,281624	1,240166
46	4	18	32	576	1,198708	1,923773	1,561241
47	4	10	32	320	1,198708	0,211374	0,705041
48	3	8	24	192	0,310776	-0,64483	-0,16702
49	2	15	16	240	-0,57716	-0,32375	-0,45045
50	2	10	16	160	-0,57716	-0,85888	-0,71802
51	3	10	24	240	0,310776	-0,32375	-0,00649
52	2	8	16	128	-0,57716	-1,07293	-0,82504
53	3	18	24	432	0,310776	0,960549	0,635663
54	4	12	32	384	1,198708	0,639474	0,919091
55	3	17	24	408	0,310776	0,800011	0,555394
56	4	14	32	448	1,198708	1,067574	1,133141
57	4	17	32	544	1,198708	1,709723	1,454216
58	1	16	8	128	-1,46509	-1,07293	-1,26901
59	3	19	24	456	0,310776	1,121086	0,715931

60	1	14	8	112	-1,46509	-1,17995	-1,32252
61	3	16	24	384	0,310776	0,639474	0,475125
62	3	15	24	360	0,310776	0,478937	0,394856
63	1	19	8	152	-1,46509	-0,91239	-1,18874
64	1	9	8	72	-1,46509	-1,44751	-1,4563
65	3	8	24	192	0,310776	-0,64483	-0,16702
66	2	14	16	224	-0,57716	-0,43078	-0,50397
67	4	14	32	448	1,198708	1,067574	1,133141
68	1	15	8	120	-1,46509	-1,12644	-1,29576
69	4	12	32	384	1,198708	0,639474	0,919091
70	2	10	16	160	-0,57716	-0,85888	-0,71802
71	2	19	16	304	-0,57716	0,104349	-0,2364
72	2	15	16	240	-0,57716	-0,32375	-0,45045
73	1	13	8	104	-1,46509	-1,23346	-1,34928
74	2	18	16	288	-0,57716	-0,00268	-0,28992
75	1	10	8	80	-1,46509	-1,394	-1,42954
76	2	8	16	128	-0,57716	-1,07293	-0,82504
77	4	10	32	320	1,198708	0,211374	0,705041
78	4	12	32	384	1,198708	0,639474	0,919091
79	3	10	24	240	0,310776	-0,32375	-0,00649
80	4	8	32	256	1,198708	-0,21673	0,490991

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Original Article

Un estudio cuasiexperimental sobre la preparación para el aprendizaje autodirigido en entornos digitales mejorados con STEAM (Ciencia, tecnología, ingeniería, arte y matemáticas)

A quasi-experimental study on self-directed learning readiness in STEAM-enhanced digital environments

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Resumen

El artículo investiga el desarrollo de la preparación de los futuros docentes para el aprendizaje profesional autodirigido en un entorno digital innovador de educación superior. El estudio se centra en la implementación de condiciones pedagógicas que apoyan el aprendizaje autónomo mediante tecnologías de Internet integradas, la digitalización del proceso educativo y la creación de un entorno de aprendizaje orientado a STEAM. Se aplicó un diseño de investigación cuasiexperimental con mediciones pre-test y post-test para evaluar la efectividad de la intervención pedagógica propuesta. El estudio involucró a 162 futuros docentes de universidades pedagógicas de Ucrania, incluyendo 82 estudiantes en el grupo experimental y 80 en el grupo de control. La preparación para el aprendizaje profesional autodirigido se evaluó a través de tres componentes: motivacional-valorativo, cognitivo-operacional y reflexivo-activo. El análisis estadístico se realizó utilizando estadística descriptiva y la prueba de chi-cuadrado de Pearson (χ^2) para determinar la significancia de las diferencias entre los grupos. Los resultados del post-test demostraron una mejora sustancial en el grupo experimental después de la implementación del modelo pedagógico. La proporción de estudiantes con un alto nivel de preparación aumentó del 7,1 % al 38,2 % (una mejora de 31,1 puntos porcentuales), mientras que la proporción con un nivel bajo disminuyó del 48,2 % al 8,9 %. En contraste, el grupo de control mostró cambios mínimos. Los resultados confirman la eficacia de las condiciones pedagógicas propuestas para mejorar la preparación de los estudiantes para el aprendizaje profesional autodirigido en entornos digitales de educación superior.

Palabras clave: aprendizaje profesional autodirigido; futuros docentes; entornos innovadores en la educación superior; tecnologías de Internet integradas; digitalización.

Abstract

The article investigates the development of pre-service teachers' readiness for self-directed professional learning in an innovative digital higher education environment. The study focuses on the implementation of pedagogical conditions that support autonomous learning through integrated Internet technologies, digitalization of the educational process, and the creation of a STEAM-oriented learning environment. A quasi-experimental research design with pre-test and post-test measurements was applied to evaluate the effectiveness of the proposed pedagogical intervention. The study involved 162 pre-service teachers from pedagogical universities in Ukraine, including 82 students in the experimental group and 80 in the control group. Readiness for self-directed professional learning was assessed across three components: motivational-value, cognitive-operational, and activity-reflective. Statistical

analysis was conducted using descriptive statistics and the Pearson chi-square (χ^2) test to determine the significance of differences between groups. The post-test results demonstrated a substantial improvement in the experimental group after the implementation of the pedagogical model. The proportion of students with a high level of readiness increased from 7.1% to 38.2% (an improvement of 31.1 percentage points), while the proportion with a low level decreased from 48.2% to 8.9%. In contrast, the control group showed only minor changes. The findings confirm the effectiveness of the proposed pedagogical conditions in enhancing students' readiness for self-directed professional learning in digital higher education environments.

Keywords: self-directed professional learning; future teachers; innovative environments in higher education; integrated Internet technologies; digitalization.

Introduction

Modern educational systems increasingly expect teachers not only to possess professional knowledge and pedagogical competencies but also to demonstrate the ability for continuous professional development and autonomous learning. In this context, self-directed professional learning has become one of the key competencies of future teachers, enabling them to adapt to technological innovations, respond to educational reforms, and continuously improve their professional practice.

The concept of self-directed learning has been widely discussed in contemporary educational research. Scholars emphasize that the ability to independently plan, regulate, and evaluate learning activities plays a crucial role in developing professional competence and lifelong learning skills. Recent studies demonstrate that self-directed learning contributes to professional effectiveness, motivation, and adaptability in complex educational environments. At the same time, the rapid integration of digital technologies into higher education has expanded the possibilities for supporting autonomous learning through digital platforms, online resources, and interactive educational tools (Çamur & Gogus, 2025).

Despite the growing number of studies on self-directed learning, the existing literature reveals several important limitations. First, many studies focus primarily on general student populations or in-service teachers, while empirical research addressing the development of self-directed professional learning readiness among pre-service teachers remains limited. Second, although digital technologies are widely recognized as an important factor in promoting autonomous learning, most studies examine individual digital tools rather than integrated pedagogical systems that combine digital environments, innovative teaching approaches, and structured training models within teacher education programs. Third, there is still insufficient experimental evidence demonstrating how specific pedagogical conditions and digital learning environments influence the development of self-directed professional learning readiness in higher education contexts.

Another limitation concerns the methodological approaches used in previous research. Many studies rely primarily on theoretical analysis or correlational designs, which limits the ability to establish causal relationships between educational interventions and the development of students' readiness for self-directed learning. Consequently, there is a need for experimental or quasi-experimental studies that provide empirical evidence regarding the effectiveness of pedagogical innovations

aimed at fostering self-directed professional learning among future teachers (Blanco-García, 2021).

Addressing these gaps is particularly important in the context of digitally transformed higher education, where teacher training programs must integrate innovative learning environments, digital technologies, and student-centered pedagogical strategies. The development of such environments requires a systematic approach that combines motivational, cognitive, and behavioral components of learning readiness while simultaneously creating opportunities for autonomy, reflection, and professional self-development.

The purpose of this study is to examine the effectiveness of a pedagogical model aimed at developing pre-service teachers' readiness for self-directed professional learning within an innovative digital higher education environment.

The research specifically focuses on the implementation of a set of pedagogical conditions, including the integration of digital learning technologies, the development of a STEAM-oriented learning environment, and the introduction of a specialized training course designed to enhance students' autonomy and professional self-development. The study also seeks to provide empirical evidence of the effectiveness of these pedagogical interventions through a quasi-experimental research design comparing experimental and control groups.

Literature Review

Self-directed learning (SDL) has become a central concept in contemporary educational research, particularly in the context of digital transformation and the growing demand for lifelong learning competencies. In teacher education, SDL is considered an essential mechanism for fostering professional autonomy, adaptability, and continuous professional development. Scholars emphasize that SDL enables learners to independently set learning goals, regulate their learning processes, and evaluate outcomes, thereby supporting the development of reflective and responsible professionals (García-Martínez & Fallas-Vargas, 2022).

Recent empirical studies confirm the positive relationship between self-directed learning readiness and professional effectiveness. For instance, Çamur and Gogus (2025) found that a higher level of self-directed learning readiness among school leaders correlates with improved professional performance and more effective decision-making in educational management. Similarly, research by Temiaková and Pavlov (2026) shows that self-directed learning is widely practiced among teachers as a strategy for professional development, although the frequency and effectiveness of such learning vary depending on professional experience, available resources, and institutional support.

The integration of digital technologies has significantly expanded opportunities for SDL in higher education. Digital platforms, online resources, and interactive tools provide learners with flexible access to educational content and allow them to construct individualized learning trajectories. Morris and Rohs (2023) highlight the considerable potential of digital technologies to support SDL by facilitating access to information, collaboration, and reflective learning processes. Additionally, empirical evidence indicates a strong connection between SDL and digital competence. For example, Rini et al. (2022) demonstrate that self-directed learning significantly contributes to the development of students' digital literacy in online learning environments. Similarly, Alanoglu et al. (2026) emphasize that digital literacy and

online learning readiness play an important mediating role in the development of self-directed online learning skills.

Despite the widely recognized advantages of SDL, recent studies also emphasize several important limitations and challenges associated with its implementation. One of the key issues concerns the assumption that learners possess a sufficient level of autonomy, motivation, and self-regulation. In practice, many students—particularly at the early stages of higher education—experience difficulties in organizing their independent learning processes, setting clear learning goals, and maintaining consistent motivation (Morris & Rohs, 2023). Without appropriate pedagogical guidance, the shift toward self-directed learning may lead to fragmented knowledge acquisition or reduced learning effectiveness.

Another limitation concerns the role of instructional support in SDL environments. While autonomous learning emphasizes student independence, research suggests that effective SDL requires a balance between learner autonomy and structured pedagogical guidance. Morris and Rohs (2023) note that digital technologies alone do not automatically enhance self-directed learning; learners often lack the necessary competencies to effectively plan, monitor, and evaluate their learning activities. Therefore, structured learning environments and supportive instructional strategies remain essential for ensuring meaningful learning outcomes.

A further critical issue discussed in recent literature relates to the risk of the digital divide in technology-supported self-directed learning. Although digital environments provide new opportunities for autonomous learning, access to digital resources and technological infrastructure remains uneven across student populations. Studies indicate that disparities in access to devices, stable internet connections, and digital competencies may create barriers for some learners when engaging in autonomous digital learning environments (Cardona-Acevedo et al., 2025). As a result, digital learning models that rely heavily on independent use of online resources may unintentionally reinforce educational inequalities.

In addition, the abundance of information in digital environments may create challenges related to information overload and critical evaluation of sources. Students engaged in self-directed learning must independently navigate complex information spaces, assess the credibility of digital resources, and synthesize information from multiple sources. Without well-developed information literacy and reflective skills, learners may encounter difficulties in effectively processing and applying knowledge (Cerda et al., 2022).

Despite the growing body of research on SDL, several gaps remain in the literature. Many existing studies focus either on practicing teachers or general student populations, while empirical research addressing the development of self-directed professional learning readiness among pre-service teachers remains limited. Furthermore, although digital technologies are widely recognized as tools supporting SDL, relatively few studies examine integrated pedagogical models that combine digital environments, innovative teaching approaches, and structured teacher training systems within higher education. Addressing these gaps requires empirical investigation of comprehensive pedagogical interventions capable of fostering SDL while mitigating the limitations associated with autonomous learning in digital environments.

Methodology

Research Design

The study employed a quasi-experimental research design with a pre-test – post-test control group structure. This design was selected to examine the effectiveness of pedagogical conditions aimed at developing pre-service teachers' readiness for self-directed professional learning in a digital higher education environment. The experimental approach enabled comparison between control and experimental groups and provided empirical evidence of the intervention's impact.

Participants

The study involved pre-service teachers enrolled in a higher education institution in Ukraine. Participants were selected using a purposive sampling method to ensure relevance to the research objectives.

The sample was divided into:

- **Experimental group (EG)**: received the intervention based on the developed pedagogical model and digital learning environment.
- **Control group (CG)**: followed the traditional instructional approach without targeted intervention.

Both groups were comparable in terms of initial readiness levels, academic background, and educational program characteristics.

Intervention

The experimental intervention was based on a structured system of pedagogical conditions aimed at fostering readiness for self-directed professional learning. The intervention included:

- Integration of digital learning tools and platforms.
- Implementation of student-centered and activity-based learning strategies.
- Use of STEAM-oriented and problem-based tasks.
- Application of heutagogical principles (learner autonomy and reflection).
- Development of a special training course focused on self-directed learning competencies.

The intervention was implemented over a defined academic period within regular educational activities.

Description of the Special Course

To enhance the methodological transparency of the study and ensure the reproducibility of the research design, the structure and content of the developed special course are presented in detail. The special course was designed according to a modular approach and aimed at integrating theoretical knowledge with practice-oriented activities focused on the use of innovative and digital technologies in professional learning.

The course was developed as part of the pedagogical intervention implemented in the experimental group and was intended to foster students' readiness for autonomous and professionally oriented learning in a digital educational

environment. The curriculum was grounded in contemporary approaches to student-centered learning, digital pedagogy, and competence-based education.

The structure of the course comprised four interconnected modules that progressively developed theoretical understanding, practical skills, and reflective competencies. The first module focused on the theoretical foundations of innovative educational technologies and the digital transformation of higher education. Within this module, students explored key conceptual approaches to innovation in education, analyzed contemporary trends in digital learning environments, and examined the role of technological tools in professional development.

The second module emphasized the development of practical competencies related to the use of digital platforms, interactive educational tools, and collaborative online environments. Particular attention was paid to the integration of project-based and problem-based learning methods supported by digital technologies.

The third module had a practice-oriented focus and involved the application of innovative technologies to simulated professional tasks. Students designed and implemented mini-projects aimed at solving professional problems using digital resources and collaborative strategies.

The fourth module was devoted to reflective practice and the evaluation of learning outcomes. Students analyzed the effectiveness of applied technologies, reflected on their learning experiences, and discussed the potential of innovative tools for future professional practice.

The total workload of the course was 60 hours, including lectures, practical sessions, and independent study, which ensured a balanced integration of theoretical instruction and active learning.

Table 1.
Structure of the Special Course

Module	Module Title	Key Content	Learning Activities	Hours
Module 1	Theoretical Foundations of Innovative Educational Technologies	Concepts of innovation in education, digital transformation of higher education, theoretical models of technology-enhanced learning	Lectures, guided discussions, analysis of scientific literature	15
Module 2	Digital Tools and Technology-Enhanced Learning	Digital learning platforms, interactive educational tools, collaborative online environments, project-based learning	Practical workshops, case analysis, work with digital platforms	15
Module 3	Application of Innovative Technologies in Professional Contexts	Modeling professional situations, design of technology-supported solutions, development of mini-projects	Project work, presentations, collaborative tasks	15
Module 4	Reflection and Evaluation of Learning Outcomes	Evaluation of project outcomes, reflective analysis of learning experience, discussion of future professional application	Reflective discussions, presentations, peer feedback	15

Total course workload: 60 hours (20 hours of lectures, 20 hours of practical sessions, and 20 hours of independent study).

Instrument and Measures

Data collection was conducted using a standardized diagnostic tool developed by the researchers, designed to assess pre-service teachers' readiness for self-directed professional learning.

The instrument measured three components:

- **Motivational-value component** (learning motivation, professional orientation).
- **Cognitive-operational component** (knowledge and strategies for independent learning).
- **Behavioral-reflective component** (self-regulation, reflection, and learning autonomy).

Responses were evaluated using a structured rating scale. The instrument demonstrated acceptable reliability and validity indicators based on pilot testing.

Procedure

The research procedure consisted of three stages:

- **Baseline (pre-test) stage**: assessment of initial readiness levels in both groups.
- **Intervention stage**: implementation of pedagogical conditions and digital learning activities in the experimental group.
- **Post-test stage**: repeated measurement of readiness levels in both groups after the intervention.

The same diagnostic instrument was used in both pre-test and post-test phases to ensure comparability of results.

Data Analysis

Quantitative data were processed using statistical analysis methods in SPSS software.

The following techniques were applied:

- Descriptive statistics (mean, standard deviation)
- Comparative analysis between groups

Chi-square test (χ^2) to determine statistically significant differences between control and experimental groups.

Significance level was set at $p < 0.05$

The analysis aimed to determine the effectiveness of the implemented pedagogical conditions in improving students' readiness for self-directed professional learning.

Ethical Considerations

The study complied with general ethical standards of educational research. Participation was voluntary, and all respondents were informed about the purpose of the study. Confidentiality and anonymity of participants were ensured throughout the research process.

Results and Discussion

Content and features of self-directed professional learning of future teachers in an innovative educational environment of higher education.

Self-directed learning refers to an individual's ability to set goals, regulate their learning process, and evaluate outcomes in accordance with personal and professional values. If we talk about the features of future self-directed learning teachers, it is necessary to characterize them as a process of developing both professional and personal qualities. This allows us to say that self-directed learning reflects the relationship between personal and professional development, which encourages each individual to creative self-realization. Such an approach to understanding a person's self-directed learning involves understanding the value of a person's life, professional and personal; forming professional self-esteem; developing the ability to set goals; thinking through the meaning of their own life; and experiencing and empathizing. Therefore, one cannot help but discuss a person's personal development when discussing their self-directed professional learning (García-Martínez & Fallas-Vargas, 2022).

We consider the personal and professional development of the future teacher as the integration of professional training, personal development, and their internal movement. It is professional training in the innovative educational environment of higher education that determines the content, schemes of professional reflection, forms, and internal movement, thereby providing personal meaning, realization, and energy for self-directed professional learning. Professional learning of pre-service teachers contributes to the formation of an individual style in the process of professional activity. It is comprehensive, grounded in best practices, and an understanding of one's own practice for future professional activity (Fernández Nistal et al., 2019).

Much depends on the teacher's ability to program the self-directed learning of a future teacher: implementing professional plans, defining vectors of change, and developing basic personal skills. Therefore, self-directed professional learning is considered a highly organized, creative, systematic, and planned activity that will continue throughout a specialist's professional life (Jiang et al., 2024).

New approaches, technologies, requirements for classes, new emphasis on learning outcomes, and methodologies force students and teachers to constantly develop competencies, update knowledge, and master new roles to become the creators of an innovative digital environment for the development of each student, and the continuous self-improvement of a teacher and their self-directed professional learning are an integral part of quality education. That is why students and teachers are increasingly planning individual educational trajectories, choosing innovative development routes according to their level of experience, interests, and professional needs to obtain high-quality results in their work, determine ways to achieve them; successfully combine the fulfillment of the norms of real professional and personal self-directed learning; test their strengths, experience, ideas, and achievements; identify weaknesses and quickly make adjustments (Cardona-Acevedo et al., 2025).

Implementation of several tasks and leading approaches in education that contribute to the professional self-directed learning of future teachers through the use of integrated Internet technologies, digitalization of the educational process, and the formation of a STEAM space.

Professional self-directed learning of future teachers is carried out in higher education through the systematization, accumulation, assimilation, updating, and organization of diverse experiences to meet cognitive needs across various activities.

The formation of a STEAM space in the professional self-directed learning of future teachers during their professional training is of great importance. One promising technology is STEAM education, which, in the formation of a new generation of teachers, contributes to the activation of pedagogically innovative approaches to the search for pedagogically oriented self-directed learning and personal development. The formation of professional self-directed learning among future teachers who will be competitive in the market requires the widespread use of non-standard forms and interactive methods. It is necessary to introduce the latest STEAM technologies into higher education, since traditional methods do not enable modern, high-quality training for future teachers with a project-based thinking style.

The STEAM educational space of a higher education institution for a new generation of teachers is a developing and creative environment that should acquire the following properties:

- Flexibility, which means the ability to rebuild educational structures in accordance with the environment quickly, the needs of the individual, and society.
- Didactic transformation of professional disciplines (Zambrano et al., 2022).

Under the STEAM environment in the practice and theory of the educational process, we understand the improvement of the implementation and content of the creative learning process, the set of conditions for the emergence and availability of feedback in such an innovative environment, as a result of which a teacher with critical, clearly expressed thinking, cognitive flexibility is formed; a new generation teacher is ready to cooperate in a team, capable of solving complex tasks of varying complexity, to implement innovative activities in their work in the specialty (Sriwisathiyakun, 2023).

As a result of the study, we have identified the features of the pedagogy of a new approach – heutagogy – as a leading approach in education, which includes the modern doctrine of continuous education and self-education as a lifestyle throughout life, which was caused by the information explosion and the need to find a new approach to organizing learning. In the 21st century, in the conditions of the information flow, the term "heutagogy" is the pedagogy of self-study, the emergence of a new innovative scientific direction on self-education, which is now the leading form of the educational process and is presented as a "net-oriented" theory that fully uses the capabilities of the World Wide Web, including Web 4.0 technologies. Heutagogy provides an opportunity for the conscious involvement of each individual in the educational process, thereby drawing attention to the search for new, effective educational methods for the entire pedagogical society (Navas Bonilla et al., 2025).

Heutagogy solves tasks aimed at the self-directed professional learning of the individual to support additional and basic training:

- Preparation of a person for modern conditions and their adaptation to professional activity.
- Updating of a person's knowledge to constantly changing conditions for appropriate adaptation.
- Individual self-directed learning, diverse creative development, the formation of a worldview, in accordance with modern requirements − aesthetic and moral qualities.

The digital transformation of education for the self-directed professional learning of future teachers is the main trend in modern education. The need to adapt higher education to the requirements of the 21st century and society's active digitalization has become a powerful catalyst for accelerating digital change. The digital transformation of the educational space has become critically necessary, and not just desirable. The development and implementation of digital tools in education for pre-service teachers' professional learning has become one of the main directions in higher education, particularly in the sector's renewal (Díaz Porras, 2025).

The use of interactive educational resources, digital platforms, mobile applications, video lessons, and online communication services for students' self-directed professional learning has become a familiar tool for most people today. Digital tools increase students' motivation to learn and expand teaching capabilities through visualization, game mechanics, and adaptive content. Therefore, self-directed professional learning should be directed towards the development trends of educational systems, towards improving skills in working with modern digital tools, towards the use of open electronic educational resources, a cloud-based educational environment, electronic social networks, and towards the development of international approaches to the digitalization of education, which will allow the teacher to make learning flexible, more personalized, effective, and accessible. Such modern learning will open access to high-quality content and contribute to the formation of a modern generation capable of interacting in a digital environment, thinking critically, and competing in a globalized world (Cerda et al., 2022).

So, the digital transformation of education for the self-directed professional learning of future teachers is a profound change in the educational paradigm, and not just the introduction of the latest technologies. The digital transformation of education requires a rethinking of teaching methods, the teacher's role, and forms of student interaction.

Organization and methodology of experimental work.

In conducting the study, we took into account the subject's general specificity, determining the sample of subjects. The study was carried out during 2023–2025 at the basis of pedagogical universities in three stages:

At the first stage, the state of development of the problem in the psychological, philosophical, pedagogical scientific literature was studied; the documentation of educational institutions (educational and programmatic) was analyzed, in particular, the content of academic disciplines, syllabi, programs, curricula; the purpose of the study was substantiated, theoretical and methodological principles were formulated, and the research tasks were determined. In the experimental study, an appropriate diagnostic tool was developed and selected for research in the educational innovation environment of higher education, at the levels of formation of readiness for professional learning of pre-service teachers.

At the second stage, the choice of the number of respondents was justified, an initial diagnosis was carried out to determine the level of formation of readiness for self-directed professional learning of future teachers; the author's pedagogical conditions of readiness for this process were justified; a teacher training system and an innovative environment were developed, a special course was prepared to introduce technologies for self-directed professional learning of students; which allowed us in the EG to form practical self-directed learning skills, and not only to obtain theoretical knowledge in conditions that simulate the future professional activity of students; the structural components of readiness were identified and justified; the initial stage of the experiment was carried out.

At the third stage, a formative experiment was conducted, the final level of formation of the indicated readiness of students for self-directed professional learning was determined, a statistical and comparative analysis of the experimental data was carried out, conclusions were formulated, and prospects for further scientific research were determined.

Identifying individual and personal indicators of readiness for self-directed professional learning among future teachers was the next task in our study.

Using the modified method of D. Keirsey, the personality structure of future teachers was determined.

It has been proven that future teachers belong to the rational type in terms of their individual typological characteristics. The conclusions of this statement are made from the fact that students strive to make a certain decision as early as possible and then act consistently within a specific plan, working through the intermediate stages of their search on the way to achieving the set long-term goal.

The next stage of the study aimed to examine indicators of future teachers' readiness for self-directed professional learning.

The study of indicators of readiness for self-directed learning among future teachers made it possible to assess students' self-esteem and the characteristic features of their professional and pedagogical self-improvement on their way to professional formation as teachers.

The study made it possible to apply the methodology for diagnosing the personal creative abilities of the participating students and to find out how creative and innovative future teachers consider themselves to be.

The use of statistical analysis and mathematical methods ensured the reliability of the experiment.

Control of side variables at different levels (external expert assessments of qualitative and quantitative nature) ensures the External validity of the research conducted.

Using the Student parametric criterion for independent samples, a comparison of measurement indicators used in the distribution of the feature was made to identify differences. In groups of students, to assess statistically significant differences in the level of development of readiness components, the criterion applied in this study was one of the parametric methods used for samples from normally distributed general populations.

The formula calculated the value of the Student criterion:

$$H_0: \bar{x} = \frac{1}{n}(x_1 n_1 + x_2 n_2 + x_3 n_3 + x_4 n_4 + x_5 n_5)$$

where H_0 is the arithmetic mean, x is the value of one dimension (option), n is the total number of options, x is the points obtained, and n_i is the repeatability of indicators.

Independent samples were used to test the hypothesis. Independent samples were obtained because the EG and CG students were ready to set adequate goals and measure their readiness.

To compare the levels of readiness of members of two independent samples, measurements were carried out on an ordinal scale and analyzed using the Pearson criterion (χ^2). The formula calculated it:

$$\chi_0^2 = \sum \frac{(n'_e - n'_k)^2}{n'_k}$$

χ^2 – value of statistical criterion, n'_k – number of persons in CG, n'_e – number of persons in EG.

For a confidence coefficient of 95% or probability σ = 0.05 for the number of levels and the number of degrees of freedom 5 = C – 1 = 5 – 1 = 4, then, if $T_2 > T_j$, then the critical value of the criterion T_2 = 9.49. This means that the distribution of candidates in CG and EG at the beginning of the experiment does not differ significantly in terms of readiness levels. This indicates that the revealed readiness levels of future teachers will meet the criteria of realism and validity when comparing the results of both groups (CG and EG) at the subsequent stages of the experiment. Based on the current control, the obtained results were analyzed. The teacher organized the control in interaction with the candidates in the form of seminar classes, written surveys, consultations, and active learning methods.

The diagnostic program and methods used during the experimental verification made it possible to trace the dynamics of the dependent variables.

In accordance with the selected methods, the interpretation of the survey results (qualitative) was carried out according to the selected components and criteria.

The structure of the readiness of future teachers for self-directed professional learning (components, criteria, indicators) was revealed:

- **Motivational component** (criteria: value, personal, motivational).
- **Cognitive-operational component** (criteria: cognitive, operational, informational).
- **Activity component** (criteria: functional, evaluative, reflective).

The indicators of the motivational component include: awareness of the goal and objectives of self-directed professional learning, stability of interest in the profession, orientation towards this process, awareness of the significance of professional learning; the need to master professional knowledge, methods of organization, techniques of educational activity, the degree of formation of leading motives, and

formation of professional and personal qualities for self-directed professional learning.

The indicators of the cognitive-operational criterion are: interests of the individual, his psychological-pedagogical and organizational knowledge, systematicity, innovative development, thinking, practice-oriented knowledge of the main areas of self-directed professional learning of the future teacher in the process of school education; formation of ideas about this process; awareness of the presence of elements of self-directed professional learning of the future teacher.

Indicators of the activity component include: the ability to develop, support, and organize educational activities; self-directed learning; adequate application of knowledge of self-directed professional learning in practical activities; originality and independence in solving professional situations; and the manifestation of the individual's reflective activity, taking into account the specifics of professional learning.

The levels of readiness of future teachers for self-directed professional learning are conventionally divided into three levels: high, average, and low.

Let us present the results of the study's initial stage (Table 2 and Figure 1).

Table 2.
Levels of readiness of future teachers for self-directed professional learning (assertive experiment)

Levels	Control Group	Experimental Group
High	6,9%	7,1%
Average	44,8%	44,7%
Low	48,3%	48,2%

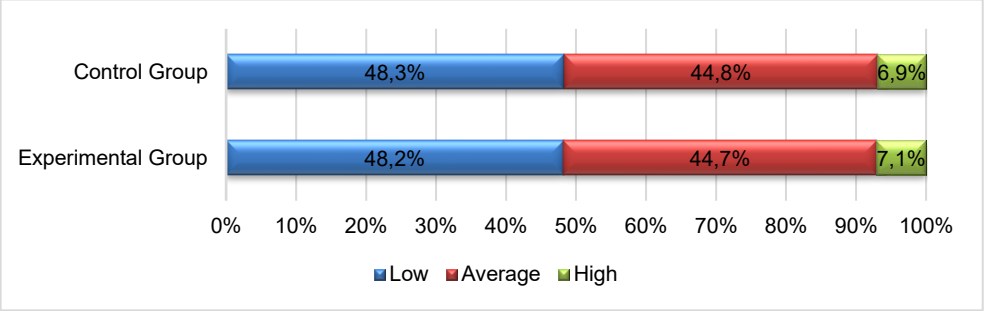


Figure 1. Levels of readiness of future teachers for self-directed professional learning (assertive experiment)

The data obtained at the initial stage of the experiment thus confirmed the low level of formation of future teachers' readiness for self-directed professional learning, which does not allow them to carry out professional activities effectively.

The results of the initial section showed that the groups of students who participated in the experiment had a similar distribution of levels of readiness for self-directed professional learning.

According to the observation results, a high level was observed in only 6.9% of students for the CG and 7.1% for the EG. Students demonstrated the ability and

readiness to consciously perform key functions of self-directed professional learning regardless of the proposed situations and their external factors. The average level was determined in 44.8% of students for the CG 44.7% for the EG. The low level was observed in 48.3% of students for the CG and 48.2% for the EG.

Based on the data analysis, we can conclude that future teachers' readiness for self-directed professional learning is generally low.

When identifying the level of readiness of students for self-directed professional learning, based on the data of the analysis of the questionnaire at the initial stage of the experiment, expert assessment, we come to the conclusions: students do not have a clear understanding of the essence of the learning process; deficiencies in the formation of skills necessary for self-directed professional learning have a significant impact on the level of readiness for the specified process.

The program for the formative stage of the experimental study and for the interpretation of the experimental results.

The results of the initial stage of the study indicated that increasing future teachers' readiness for self-directed professional learning is necessary in higher education. For this purpose, we developed an experimental program that was implemented in the EG. The CG studied according to the standard teaching methodology.

The program of the formative stage of the experimental study included a set of experimental factors (independent variables) introduced into the pedagogical process, which significantly affect the dependent variables, which, in turn, change under the influence of the first: the goal of forming the readiness of future teachers for self-directed professional learning; selective components, updated content of subject programs, active learning methods, innovative forms and digital applications.

The preparation of EG students for self-directed professional learning in higher education shares components with general professional training and is carried out throughout the educational process. At the same time, such training has its own specific features, determined by its nature and the nature of pedagogical activity. In view of this, during the study, we identified the following stages that will contribute to the development of future teachers' readiness for self-directed professional learning in the educational environment of higher education, and proposed for EG respondents:

- **The first stage** is the teacher's adaptation to the profession (the student goes through a period of initial mastery of the necessary innovative digital tools, techniques, mindset, norms, and professional practices, sets goals, and forms value orientations for further self-improvement and self-directed learning).
- **The second stage** is individualization (awareness of carrying out professional activity and its individual capabilities; the beginning of self-directed learning through the profession; awareness of the possibilities for fulfilling professional norms; smoothing out negative qualities and strengthening positive qualities, building an individual modern style of activity).
- **The third stage** – free mastering of the profession by future teachers (mastering the system of scientific skills, knowledge, abilities, the ability to evaluate one's results critically, one's own achievements, the ability to conduct self-reflection, which provides the future teacher with versatile development, familiarizing the individual with educational standards, reproducing previously mastered methodological recommendations, digital tools of developments at the proper

level, the ability to correctly and quickly find information in social networks, the Internet space, as well as the use of modern information technologies in this process).

- **The fourth stage** – self-realization in the profession of a future teacher (the ability to critically evaluate one's own skills, results, achievements; maximum self-realization in professional activity; conducting self-reflection in the self-directed learning process; transition to a creative state and mastering the professional culture of personality, which affects oneself, the surrounding socio-pedagogical environment; implementation of the process of forming social and professional qualities; improvement of professional activity).

The use of integrated Internet technologies, which was proposed in the EG, made it possible to implement important tasks for the self-directed professional learning of students: to optimally integrate forms of using Internet technologies in education and professional activities, taking into account the main aspects of the educational process; by taking into account the skills of working on the Internet and the level of students' computer skills, to minimize the technical complexity of the tasks; by giving students great freedom in the information space and time for actions, to take into account the individual characteristics of students; since students must be able to organize their own time, it is necessary to teach them to be more responsible for their own knowledge, to decide what information can be used to complete the task, in what form the student should present their point of view.

The study considered it necessary to create a new, innovative educational environment for EG students, including the widespread use of multimedia teaching aids, STEM, and IT technologies. It updated laboratory facilities for studying professionally oriented subjects. In such an innovative and creative environment as the one in which EG students were, the requirements for organizing the educational process in such an environment for the professional, modern training of future teachers increased. In the STEAM methodology, the focus was on a practical task or a professional problem. EG respondents learned to find ways to solve the problem not only in theory but also in real time, using digital tools through mistakes and trials. In the STEAM space, EG students received much more autonomy than in classical education; they determined the appropriate pedagogical technologies necessary for developing creative, cognitive, and mental qualities, the level of which in the modern market of educational services determines students' competitive ability.

The theoretical and methodological basis of the developed innovative environment for the formation of future teachers' readiness for self-directed professional learning, in which EG students studied, was the following approaches:

- The synergistic approach treats self-directed professional learning as a nonlinear dynamic process of self-organization that occurs with the help of internal factors and under the influence of interactions with external factors. Within the framework of teacher training, this means the ability to self-direct professional learning, adapt to change, and make non-standard pedagogical decisions.
- The acmeological approach provides training for future teachers, as individuals, for continuous self-directed professional learning, focused on the highest professional achievements.
- The anthropocentric approach allows organizing, based on self-education, the process of forming students' readiness for their self-directed professional learning and strengthening students' internal activity in professional activities.
- The activity approach contributes to paradigmatic changes in education, provides an opportunity for the individual to self-directed professional learning,

to specially organized activities aimed at self-realization and achievement of their certain ideal; provides students with a general style of thinking, which is a new turn of the spiral in the development of science.

- The competency-based approach is considered in the plane of the formation of certain competencies in a future teacher, which contribute to their continuous self-directed professional learning and successful solution of professional tasks.
- The axiological is oriented to a person as the highest value, and during the selection of methods, forms, and content of training future teachers, it encourages professional continuous self-directed learning, allowing for the consideration of their value orientations, and is considered in the context of students' awareness of the values of self-directed professional learning.
- The systemic approach involves research into the professional continuous self-directed learning of future specialists and the process of high-quality training for future teachers to support this learning, which constitutes a pedagogical system.
- The personal approach ensures continuous self-directed professional learning in the training of specialists; orientation on the personality of each student.
- The synergistic approach allows us to consider students' continuous, self-directed professional learning as a process of constant development in accordance with the evolution of society, nature, and man, and the universal laws governing society.
- The culturological approach, as a basis, involves using the phenomenon of culture to explain and understand pedagogical processes and phenomena, particularly those that underpin preparing future teachers for continuous, self-directed professional learning.
- The creative approach orients future teachers to the search for non-standard solutions and new approaches in pedagogical, professional, and organizational activities. In this context, self-directed professional learning in personality involves the development of innovative initiative, the generation of original methods, creative thinking, and the ability to experiment among students.
- The reflective approach emphasizes the importance of analyzing each student's own activities, identifying errors, evaluating achievements, and deriving new development goals.
- The contextual approach ensures the creation of conditions as close as possible to professional real-world activity.
- The heutagogic approach consists of collecting the best, organizing self-education, and innovative practices, seeking effective ways for personal and professional growth by searching for a new paradigm of education, conscious inclusion of students in education, where the individual begins to play the role of a manager of their knowledge.

Such a system of teacher training in a developed, innovative environment allowed us at the EG to develop practical, self-directed learning skills and not only to obtain theoretical knowledge under conditions that simulate students' future professional activity.

Pedagogical conditions, a teacher training system has been developed for the educational process of EG students, an innovative environment and a special course have been created with the aim of introducing digital innovative technologies for the self-directed professional learning of teachers and forming students' readiness for the outlined phenomenon, which is what the formative experiment was aimed at.

The study outlines the following pedagogical conditions that ensure the self-directed professional learning of students:

- Creation of a creative digital environment, the effectiveness of which is ensured by innovative learning approaches, productive methods, and features of the educational process that create a motivational field for professional self-realization.
- Self-determination and professional orientation in a modern, innovative society.
- Support of positive motivation for self-directed professional learning.
- Creation of a socio-communicative digital-rich space in the process of interactive interaction of students to demonstrate positive professional experience and create "situations of success" in higher education.

Dependent variables: level of readiness for self-directed professional learning of future teachers in general, components, criteria, and indicators.

In our study, we identified the following additional variables:

Individual qualities of students (interests, abilities, attitudes toward self-directed professional learning, and professional duties) are factors that depend on the pedagogical process. In various ways in the experiment, these additional variables were eliminated as much as possible.

When conducting diagnostics, the methods used at the initial stage were used. This made it possible to compare the results of the research stages more correctly. Experimental data were obtained for the motivational, cognitive-operational, and activity components and were distributed across three levels (low, average, high).

According to the study on determining the readiness of future teachers for self-directed professional learning, the data were summarized across the three identified components.

The results are presented in Table 3 and Figure 2.

Table 3.
Generalized results of future teachers' readiness for self-directed professional learning across all components (formative experiment)

Levels	Control Group	Experimental Group
High	9,1%	38,2%
Average	53,8%	52,9%
Low	37,1%	8,9%

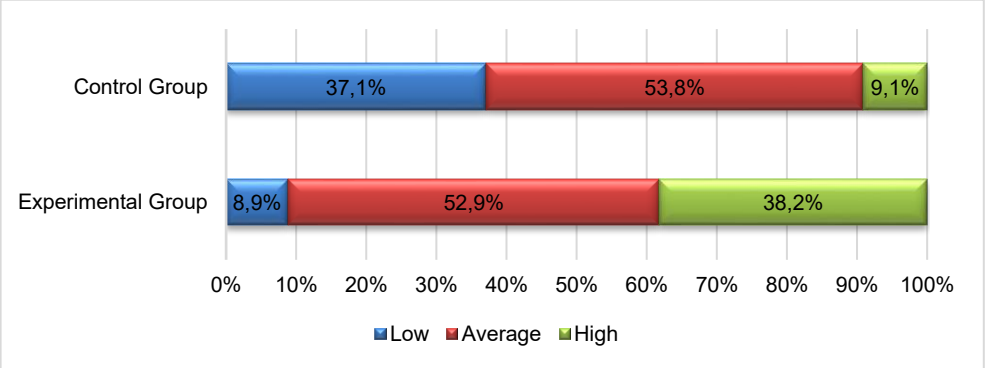


Figure 2. Generalized results of future teachers' readiness for self-directed professional learning across all components (formative experiment)

At the formative stage of the experiment, we applied mathematical and statistical methods to substantiate the conclusions drawn from the experimental work.

To assess the statistical significance of differences in readiness for self-directed professional learning at the end of the experiment between CG and EG students, the Pearson criterion (χ^2) was used.

According to the results of calculating the Pearson criterion (χ^2), the alternative hypothesis H_1 is accepted about the significant influence of the experimental factor on the studied process, which was manifested in the influence on the educational process of EG students: pedagogical conditions, innovative teacher training system, innovative environment, and special course.

The results of the study indicate significant differences between CG and EG at the 0.05 level of significance. This means that our null hypothesis, adopted at the initial stage, is consistent with the observed results: these differences are determined by innovations (pedagogical conditions, the teacher training system, the creation of an innovative environment, and a special course), and the distribution of students in groups by readiness levels differs.

The formative experiment allowed us to form the following conclusions that will confirm the effectiveness of the experimental work:

- In the experimental groups, the number of students who have reached a high level of readiness is higher with the use of pedagogical conditions, an innovative teacher training system, an innovative environment, and a special course; in the control groups, the number of students with an average level prevails, where classes were held according to the traditional organization of the educational process.
- The results of the mathematical and statistical analysis conducted between the CG and the EG before the experiment indicate no statistically significant differences in the level of readiness of future teachers for self-directed professional learning across all components. After the experiment, statistically significant differences were observed between the CG and the EG.

Analysis of digital data on the dynamics of changes in future teachers' readiness for self-directed professional learning indicates that the initial indicators in the CG and the EG for conducting the initial diagnosis were approximately the same. The method of mathematical and statistical analysis reinforces this statement: no statistically significant differences were found “at the entrance” between the level of readiness of respondents in the CG and the EG for self-directed professional learning.

For a reliability of 95%, or a probability coefficient of $\sigma = 0.05$, generally accepted in pedagogical research, for the number of degrees of freedom and the number of levels $C = 4 - 5 = C - 1 = 4$, then: $T_2 = 9.49$ − critical value of the criterion. This means that the distribution of future teachers' levels of readiness for self-directed professional learning in CG and EG at the end of the experiment differs significantly, confirming the statistical significance of the results. The difference in EG between the components is insignificant.

The results obtained in this study demonstrate a significant increase in the proportion of students with a high level of readiness for self-directed professional learning in the experimental group (from 7.1% to 38.2%), which confirms the

effectiveness of the implemented pedagogical conditions. These findings are consistent with previous research emphasizing the positive impact of structured digital learning environments on self-directed learning development.

In particular, the results align with the study by García-Martínez and Fallas-Vargas (2022), who reported that students engaged in personalized and technology-supported learning environments demonstrate higher levels of autonomy and self-regulation. However, unlike their correlational findings, the present study provides experimental evidence, confirming a causal relationship between pedagogical intervention and increased readiness levels.

Similarly, the findings support the conclusions of Rini et al. (2022), who identified a strong relationship between self-directed learning and digital literacy development. The substantial increase in high-level readiness in the experimental group in this study may be explained by the integration of digital tools and platforms, which, as noted by Rini et al. (2022), facilitate independent learning and cognitive engagement.

The results are also in line with the research of Alanoglu et al. (2026), who highlighted the mediating role of digital competence in the development of self-directed online learning. In the present study, the implementation of a STEAM-oriented digital environment and a structured special course contributed to the development of both digital competence and self-directed learning readiness, reinforcing the interdependence identified in previous studies.

At the same time, the findings extend the conclusions of Morris and Rohs (2023), who argued that digital technologies alone do not guarantee the development of self-directed learning skills. The significant differences between the experimental and control groups in this study confirm that the effectiveness of digital learning depends on structured pedagogical support, including guided activities, reflection, and targeted training.

Furthermore, compared to the findings of Temiaková and Pavlov (2026), who reported variability in self-directed learning depending on experience and context, the results of this study demonstrate that purposeful pedagogical conditions can significantly reduce such variability and ensure more consistent development of readiness among students.

In contrast to studies highlighting challenges such as low initial autonomy and motivation (Morris & Rohs, 2023), the present research shows that these limitations can be effectively addressed through a combination of motivational, cognitive, and activity-based components within a structured pedagogical model.

Thus, the obtained results not only confirm existing theoretical assumptions about the importance of digital and student-centered learning environments but also provide new empirical evidence regarding the effectiveness of an integrated pedagogical model in developing readiness for self-directed professional learning among pre-service teachers.

Conclusions

The study examined the development of pre-service teachers' readiness for self-directed professional learning in the context of digital higher education. The results confirm that self-directed professional learning represents a complex integrative construct that combines motivational-value, cognitive-operational, and behavioral-

reflective components. The analysis of the initial stage of the experiment demonstrated that the majority of students showed insufficient levels of readiness for self-directed professional learning, which indicates the need for purposeful pedagogical support and the transformation of teacher training practices in higher education.

The implementation of the proposed pedagogical conditions, including the integration of digital learning technologies, the development of a STEAM-oriented learning environment, the use of student-centered and activity-based learning strategies, and the introduction of a specialized training course, contributed to a significant improvement in students' readiness for self-directed professional learning. Statistical analysis confirmed the effectiveness of the experimental intervention: students in the experimental group demonstrated a higher proportion of high-level readiness indicators compared to the control group, where traditional teaching approaches were applied.

The study provides empirical evidence that the formation of readiness for self-directed professional learning requires a systematic pedagogical approach that combines technological, methodological, and motivational components. The results emphasize the importance of creating innovative digital learning environments that encourage autonomy, reflection, and continuous professional development among future teachers.

From a theoretical perspective, the research contributes to the advancement of teacher education theory by clarifying the structure and pedagogical conditions for developing readiness for self-directed professional learning in digitally transformed higher education. The findings expand existing research by experimentally validating a model that integrates digital technologies, heutagogical principles, and STEAM-oriented learning practices within teacher training programs.

The practical implications of the study lie in the possibility of applying the proposed pedagogical conditions and training model in teacher education programs at higher education institutions. The integration of digital learning tools, flexible learning environments, and reflective learning strategies can significantly enhance students' autonomy, professional motivation, and ability to engage in lifelong learning.

Despite its contributions, the study has several limitations. The research was conducted within a limited sample of pedagogical universities, which may affect the generalizability of the results. In addition, the study focused primarily on quantitative indicators of readiness, while qualitative aspects of students' professional development and long-term effects of the intervention require further investigation.

Future research should focus on extending the empirical scope and methodological rigor of the present study: it is necessary to conduct longitudinal studies to examine the sustainability and long-term effects of self-directed professional learning readiness, particularly tracking how these competencies evolve during the transition from pre-service to in-service teaching; further studies should investigate the differential impact of specific components of the pedagogical model (motivational-value, cognitive-operational, and activity-reflective) using multivariate statistical techniques (e.g., structural equation modeling) to determine their relative contribution to overall readiness development; it is important to explore the effectiveness of the proposed model across diverse educational contexts, including different academic disciplines, institutional types, and cultural settings, in order to assess its generalizability and contextual sensitivity; future research should

incorporate mixed-methods designs, combining quantitative measurement with qualitative approaches (e.g., interviews, reflective journals, learning analytics data) to gain deeper insight into students' individual learning trajectories and mechanisms of self-directed learning development; a promising direction involves the integration of adaptive digital learning systems, where personalized learning pathways are generated based on students' readiness profiles. In this context, research should examine how specific features of digital environments (e.g., feedback mechanisms, scaffolding strategies, and task complexity) influence the development of self-directed learning competencies; future studies should address equity-related factors, including differences in digital access, prior learning experience, and self-regulation skills, in order to identify potential barriers to the effective implementation of self-directed learning in digitally enriched environments.

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Original Article

Utilización de las tecnologías de la información para mejorar la alfabetización mediática del profesorado de las instituciones de educación superior de Ucrania

Using information technologies to improve media literacy of teachers of higher educational institutions of Ukraine

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Resumen

El objetivo del estudio fue fundamentar empíricamente el impacto de las herramientas digitales en el nivel de alfabetización mediática y determinar el papel de la competencia digital en la formación de la capacidad de análisis crítico de contenidos mediáticos. El estudio se llevó a cabo mediante un diseño cuasiexperimental con grupos de control y experimental (n = 120). La intervención consistió en el uso sistemático de tecnologías de la información en las actividades profesionales de los docentes durante un semestre. Los resultados del análisis de varianza indicaron un impacto significativo del uso de las TIC en el nivel de alfabetización mediática ($p < 0,001$), con un efecto gradual en función de la intensidad de su uso. El análisis de correlación demostró una relación positiva entre la competencia digital y los indicadores de alfabetización mediática (r = 0,64–0,73). Las conclusiones destacan la eficacia de la integración de las tecnologías de la información como herramienta para el desarrollo de la alfabetización mediática del profesorado y subrayan la necesidad de la implementación sistemática de prácticas digitales en la educación superior.

Palabras clave: alfabetización mediática; competencia digital; digitalización de la educación; profesorado de educación superior; tecnologías de la información.

Abstract

The aim of the study was to empirically substantiate the impact of digital tools on the level of media literacy and determine the role of digital competence in the formation of the ability to critically analyze media content. The study was conducted using a quasi-experimental design with control and experimental groups (n = 120). The intervention provided for the systematic use of information technologies in the professional activities of teachers for one semester. The results of the analysis of variance indicated a significant impact of the use of IT on the level of media literacy ($p < 0.001$), the presence of a graduated effect depending on the intensity of their use. Correlation analysis demonstrated a positive relationship between digital competence and media literacy indicators (r = 0.64–0.73). The conclusions emphasize the effectiveness of the integration of information technologies as a tool for the development of teachers' media literacy, and emphasize the need for the systematic implementation of digital practices in higher education.

Keywords: digital competence; digitalization of education; higher education teachers; information technologies; media literacy.

Introduction

In the context of the rapid digital transformation of society and the expansion of the global information space, the problem of media literacy has become particularly relevant for the modern education system. The active development of information and communication technologies, the spread of social networks, digital platforms and artificial intelligence tools have significantly changed the ways of creating, distributing and perceiving information (Mazur et al., 2025; Stender et al., 2024). Under such conditions, the ability to critically evaluate information flows, identify manipulative content, counteract disinformation and effectively navigate the digital environment has become a key professional competence. It is relevant primarily for teachers of higher education institutions. Higher education institutions have played a decisive role in the formation of media literacy (Jamil et al., 2022). It is important to note that they have provided the training of future specialists and at the same time formed the professional competencies of the teaching staff. Modern studies emphasize that media literacy has become a necessary condition for the development of critical thinking and ensuring information security in the context of the growth of digital content and disinformation practices (Alcolea-Díaz et al., 2020; Feng & Sumettikoon, 2024). At the same time, researchers also emphasized that the digitalization of education has necessitated the revision of traditional pedagogical approaches and the active introduction of innovative technologies into the educational process (Grygorenko et al., 2021).

In Ukrainian realities, this problem has gained additional importance in the context of information warfare, integration into the European educational space, and the active development of distance and blended learning. The use of digital platforms, multimedia resources, and online tools has created new opportunities for the development of media literacy (Lukianova, 2022; Natriello, 2021). At the same time, it was about increasing the requirements for the level of digital and information competence of teachers (Malieiev et al., 2024; Potapchuk et al., 2026). Despite the significant number of studies devoted to digital competence and media education, the issue of targeted development of media literacy of teachers of higher education institutions using information technologies required additional attention.

Modern scientific discourse has emphasized the significant potential of information technologies in increasing the effectiveness of teaching, developing critical thinking, and forming an interactive educational environment (Scolari, 2019; Verhalle & Loos, 2025). The use of multimedia tools, digital educational platforms, interactive services and virtual interaction technologies actively contributed to the creation of adaptive and flexible learning models focused on the needs of the modern information user. At the same time, there was a need to systematize approaches to the use of information technologies precisely as a tool for the development of media literacy of teachers, taking into account pedagogical, psychological and technological aspects (Vošnjak & Vogrinc, 2026). Therefore, the existing contradiction between the growing requirements for the level of media literacy of teachers of higher education institutions and the insufficient development of methodological support for its formation by means of information technologies determined the relevance of this study.

In the modern academic environment, media literacy was increasingly considered both as an individual competence and as a component of the institutional culture of a higher education institution. Teachers in this context acted as mediators between information flows, digital technologies and students. It was on the level of their training and competence that the educational process contributed to the formation

of critical thinking, information resilience and the ability to counteract manipulative practices. For this reason, the issue of developing media literacy among teachers required a comprehensive analysis that combined technological, pedagogical and socio-cultural aspects.

The purpose of the article is to analyze the possibilities of using information technologies to increase the media literacy of teachers of higher education institutions of Ukraine and to determine effective approaches to their integration into the educational process.

H1. The use of information technology in the professional activities of higher education teachers statistically significantly increased their level of media literacy compared to traditional approaches to teaching.
H2. There was a statistically significant positive relationship between the level of digital competence of teachers and their ability to critically analyze media content.

To achieve the research goal and test the proposed hypotheses, a quasi-experimental design was used with the participation of experimental and control groups. The study examined the impact of systematic use of information technologies on teachers' media literacy during one academic semester and assessed the relationship between digital competence and the ability to critically analyze media content. The methodological framework consists of comparative and statistical approaches. The article is organized as follows. The following section examines the theoretical foundations of media literacy, digital competence, and the use of information technologies in higher education. The methodology section describes the research design, participants, intervention procedures, tools, and data analysis methods. The results section presents empirical data on the effectiveness of information technologies in increasing media literacy and the relationship between digital competence and critical media analysis skills. The discussion and conclusions sections compare the results and outline their practical significance for higher education institutions in Ukraine.

Literature Review

In modern scientific discourse, media literacy is considered as a complex human ability to search, select, critically evaluate, interpret and ethically use information in the digital environment. Studies have treated media and information literacy as one of the basic competencies of a modern person (Turpo-Gebera et al., 2021). This competence has ensured critical engagement in the information space, safe navigation in the online environment and responsible interaction with digital technologies (Voitovych et al., 2025). In this context, media literacy is increasingly associated simultaneously with the ability to analyze media texts and with the development of digital competencies, information security, resistance to disinformation and the ability to reflectively consume content.

A significant place in the research has been occupied by the problem of digital competence of teachers as a prerequisite for the effective use of information technologies in the educational process. The European framework for digital competence of teachers DigCompEdu has defined the digital competence of a teacher as a multidimensional construct. It covered professional interaction, selection and creation of digital resources, management of learning with the help of technology, digital assessment and support of autonomy of education seekers (Dzogovic et al., 2025). In later studies, this logic was developed in the direction of considering digital competence as a technical skill (Mateus et al., 2026). Modern scholars have interpreted it as a pedagogically integrated ability, which undoubtedly

influenced the quality of teaching, adaptability of the educational environment and readiness for innovations in higher education (Miguélez et al., 2020). A separate block of works is devoted to the use of information technologies for the development of critical thinking, digital culture and new forms of academic interaction. Scientific articles have repeatedly emphasized that the integration of digital tools, web resources, interactive platforms, multimedia solutions and online services has increased the involvement of participants in the educational process, increased the flexibility of learning and created conditions for the formation of new types of competencies (Nikou & Aavakare, 2021; Rojas-Estrada et al., 2023). At the same time, the emphasis is mainly on education seekers, future teachers, or the general impact of technology on educational quality. At the same time, the issue of targeted improvement of media literacy of higher education teachers has received less systematic evaluation.

The Ukrainian context has given this issue special importance. Researchers who have analyzed the development of media education in Ukraine have emphasized that in the context of information warfare, digital transformation of education, and the growth of manipulative content, media literacy has ceased to be an optional skill and is becoming an element of a teacher's professional stability (Svyrydenko & Terepyshchyi, 2020). Ukrainian research in recent years has traced the integration of media education into the training of future teachers, the formation of information literacy, the development of digital culture, and the adaptation of the European framework of competencies to national conditions (Zhukova et al., 2023). At the same time, there are still few empirical studies that would directly assess the impact of specific information technologies on the growth of media literacy among higher education teachers in Ukraine.

At the same time, in modern research, there was a clear tendency towards a predominantly theoretical understanding of media literacy or its study at the level of education seekers. At the same time, empirical studies aimed at analyzing changes in teachers' professional practices remained limited. This was especially true of scientific works that used experimental or quasi-experimental designs with a quantitative assessment of the effectiveness of the introduction of information technologies. This situation led to the need for further scientific research that would allow moving from describing the potential of digital tools to empirically confirmed conclusions about their real impact on the formation of media literacy.

Therefore, the analysis of scientific sources has demonstrated that, despite significant attention to digital competence, media education, and the technologization of the educational process, a research gap remains in the modern literature regarding the comprehensive study of the use of information technologies. This is especially relevant in terms of improving the media literacy of teachers in higher education institutions in Ukraine. The issues of pedagogical conditions for the effective use of such technologies, criteria for assessing changes in the level of media literacy of teachers, the relationship between digital competence, critical analysis of media content and professional activities in the university environment are also insufficiently addressed. It is these gaps that determined the feasibility of the proposed study.

Methodology

Research Design

The study was conducted using a quasi-experimental design with control and

experimental groups. This approach made it possible to assess the impact of the use of information technologies on the level of media literacy of teachers of higher education institutions of Ukraine. The chosen methodology also made it possible to establish relationships between key research variables.

The experiment lasted for one academic semester and involved the introduction of a set of digital tools into the teaching activities of teachers in the experimental group. At the same time, in the control group, the educational process was carried out using traditional approaches.

Participants

The study involved 120 teachers from four higher education institutions in Ukraine (designated as University 1, 2, 3, 4 to ensure anonymity).

Participants were divided into:

control group (CG) – 60 people
experimental group (EG) – 60 people
The average age of the participants was 38.6 years (SD = 7.4), teaching experience ranged from 3 to 25 years. All participants provided voluntary informed consent to participate in the study.

The research involved scientific and pedagogical staff of higher education institutions of Ukraine who met the specified inclusion criteria. The sample was formed according to the principle of purposeful selection, taking into account the professional relevance of the participants to the subject of the study (See Table 1).

Table 1.
Inclusion and Exclusion criterio

No	Inclusion criteria of participants:	Exclusion criteria of participants:
1	Employed as a teacher at a Ukrainian higher education institution during the study period	Held exclusively administrative positions without regular teaching responsibilities
2	Had at least 3 years of teaching experience;	Had less than three years of teaching experience
3	Had experience using digital resources and information technologies in teaching	Failed to complete one or more stages of the study
4	Provided voluntary informed consent to participate	Submitted incomplete or incorrectly completed questionnaires
5	Participated in all stages of the study (pre-test, intervention, and post-test)	Participated in external media literacy training programs during the study period

Source: Authors' own elaboration.

Within the framework of the experiment, the experimental group was involved in the systematic use of information technologies aimed at developing media literacy, in particular:

interactive online platforms (LMS, Google Classroom);
tools for analyzing media content (fact-checking resources, digital archives);
multimedia tools (video analysis, data visualization);
digital services for creating content (presentations, interactive whiteboards);
elements of blended and distance learning.

The intensity of technology use was variable (low, medium, high levels), which made it possible to additionally test the impact of the frequency of their use.

Intervention

To collect empirical data, a set of psychodiagnostic and author's methods was used:

Media Literacy of Teachers Scale (MLTS), which included 4 subscales:

critical analysis of media content;
assessment of information reliability;
digital ethics and security;
media content creation.

Digital competence scale (adapted from DigCompEdu).

Questionnaire on the frequency of IT use in professional activities (low / medium / high).

All scales provided for assessment on a 5-point Likert scale. The reliability of the instruments was confirmed using the Cronbach's coefficient (α = 0.82–0.91).

Procedure and tools

The study took place in several stages. The first of them was pre-testing - measuring the basic level of media literacy and digital competence (See table 2).

Table 2.
Pre-testing indicators in the control and experimental groups

Indicator	Control group (n = 60), M ± SD	Experimental group (n = 60), M ± SD	t	p
General level of media literacy	3.21 ± 0.41	3.24 ± 0.39	0.41	0.684
Critical analysis of media content	3.18 ± 0.46	3.20 ± 0.44	0.24	0.811
Evaluation of information reliability	3.27 ± 0.43	3.29 ± 0.40	0.26	0.796
Digital ethics and security	3.34 ± 0.38	3.31 ± 0.41	-0.42	0.676
Media content creation	3.05 ± 0.49	3.08 ± 0.47	0.34	0.735
Digital competence	3.36 ± 0.45	3.40 ± 0.42	0.50	0.619

Source: Authors' own elaboration.

As can be seen from the pre-test results, no statistically significant differences were found between the control and experimental groups at the initial stage ($p > 0.05$ for all indicators). This indicated sufficient homogeneity of the sample and allowed us to interpret further differences at the post-test stage because of the experimental effect.

Then an intervention was carried out - the introduction of information technologies into the educational process (16 weeks). At the end, post-testing took place - a repeated measurement of indicators after the experiment was completed.

Statistical analysis methods were used to process the obtained data. Data processing was carried out using SPSS / R software.

To test the hypotheses, the following methods were used: ANOVA (analysis of variance) - to assess the differences between the control and experimental groups (H1); post hoc tests (Tukey HSD) - to determine paired differences between the levels of intensity of IT use; correlation analysis (Pearson r) - to establish the relationship between digital competence and media literacy (H2); multiple regression analysis - to determine the contribution of individual factors to the formation of media literacy.

The content validity of the instruments was ensured as a result of expert evaluation. 5 specialists in the fields of media education, digital pedagogy, educational psychology and teaching methods in higher education were invited to the expert group. The experts assessed: the correspondence of the statements to the theoretical constructs of the study; the clarity and unambiguousness of the formulations; the relevance of the items to the declared subscales; the general logic of the structure of the instrument.

According to the results of the expert analysis, some formulations were clarified, and some content redundancies were removed. The consistency of the expert assessments indicated a sufficient level of content validity of the instrument.

To ensure the validity and reliability of the instrument, a multi-level psychometric test was conducted. The content validity of the media literacy scale was ensured by expert evaluation by five specialists in the field of media education, digital pedagogy and educational psychology. After pilot testing on a sample of 30 teachers, individual formulations were refined. Construct validity was tested using exploratory factor analysis: the KMO value was 0.86, the Bartlett criterion was statistically significant ($\chi^2 = 1248.37$; $p < 0.001$), which confirmed the adequacy of the sample and the correlation matrix for factorization. The reliability of the scales, estimated by the Cronbach's alpha coefficient, ranged from 0.82 to 0.91, which indicated a high level of internal consistency.

The frequency of use of information technologies was assessed using an author's questionnaire, which contained 8 items regarding the regularity of use of digital platforms, multimedia tools, content creation services, information verification tools and online communication in professional activities. Responses were recorded on a five-point Likert scale from 1 ("almost never") to 5 ("very often"). For further analysis, an integral indicator was calculated in the form of an average score, which was considered as a continuous variable (Appendix 1).

Ethical aspects of the study

The study was conducted in accordance with ethical standards of academic integrity. All participants were informed about the purpose of the study and provided voluntary informed consent to participate. Anonymity and confidentiality of personal data were guaranteed at all stages of the study.

Results and Discussion

Results

In order to empirically test the hypotheses put forward, a comprehensive statistical analysis was conducted, which consisted of comparing indicators between groups,

assessing the impact of the intensity of information technology use, and studying the relationships between key variables. The analysis was carried out based on the results of post-testing, which made it possible to assess the changes that occurred after the introduction of the experimental effect.

First of all, the differences between the control and experimental groups in terms of the general level of media literacy were analyzed. Additionally, the impact of the frequency of information technology use on the studied indicator was studied, which made it possible to clarify the nature of the detected effect. Special attention was paid to the analysis of the relationships between digital competence and the components of media literacy, which made it possible to test the second hypothesis of the study.

Comparison of post-test results between the control and experimental groups demonstrated significant differences in media literacy levels.

Table 3.
Media literacy indicators (post-test)

Group	N	M ± SD
Control (CG)	60	3.38 ± 0.42
Experimental (EG)	60	4.12 ± 0.36

Source: Authors' own elaboration.

The results of the analysis of variance indicated the existence of statistically significant differences between the groups:

$$F(1, 118) = 86.47, p < 0.001, \eta^2 = 0.42$$

The obtained value of η^2 indicated a large effect size, which indicated a significant impact of the use of information technologies on the level of media literacy of teachers. Thus, the proposed results confirmed the hypothesis H1.

For a more detailed analysis, the impact of the frequency of use of information technologies (low, medium, high levels) was investigated. To clarify the nature of the detected effect, a correlation and regression analysis of the frequency of use of information technologies as a continuous indicator was conducted. This approach avoided artificial categorization of data and provided a more accurate assessment of the relationship between the intensity of IT use and the level of media literacy of teachers (See Table 4).

Table 4.
The level of media literacy depending on the intensity of IT use

Level of IT usage	N	M ± SD
Low	40	3.45 ± 0.39
Medium	40	3.82 ± 0.37
High	40	4.21 ± 0.34

Source: Authors' own elaboration.

The results of the one-way analysis of variance showed the following:

$$F(2, 117) = 54.63, p < 0.001, \eta^2 = 0.48$$

This indicated that there were statistically significant differences between the levels

of information technology use. To clarify the nature of these differences, a post hoc analysis was conducted using the Tukey HSD criterion.

Table 5.
Results of the post hoc analysis (Tukey HSD)

Group Comparison	Mean Difference (MD)	SE	p
Low – Medium	-0.37	0.08	0.004
Low – High	-0.76	0.08	<0.001
Medium – High	-0.39	0.07	0.002

Source: Authors' own elaboration.

The results of the post hoc analysis demonstrated that all pairwise comparisons were statistically significant. The largest difference was observed between the groups with low and high levels of IT use. This confirmed the presence of a gradual (graded) effect: with increasing intensity of use of information technologies, the level of media literacy statistically increased.

To test the hypothesis of the relationship between digital competence and media literacy, a correlation analysis was conducted using the Pearson coefficient.

Table 6.
Correlations between variables

Variables	r	p
Digital competence – general media literacy	0.71	<0.001
Digital competence – critical analysis	0.68	<0.001
Digital competence – credibility assessment	0.64	<0.001
Digital competence – content creation	0.73	<0.001

Source: Authors' own elaboration.

The results showed strong positive correlations between digital competence and all components of media literacy. This indicated an increase in the level of digital competence, which was accompanied by an increase in the ability to critically analyze information and effectively work with media content.

In order to determine the relative contribution of individual factors to the formation of media literacy, multiple regression analysis was used.

Table 7.
Results of the regression model

Predictor	β	t	p
Digital Competence	0.52	8.94	<0.001
Frequency of IT Use	0.39	6.87	<0.001
Teaching Experience	0.12	2.11	0.037

Source: Authors' own elaboration.

The model was statistically significant:

$$R^2 = 0.58, F(3, 116) = 53.21, p < 0.001$$

This meant that the included variables explained 58% of the variation in the level of media literacy. The most significant predictor was digital competence, which is consistent with the results of the correlation analysis.

Therefore, the results obtained showed a statistically significant effect of the use of information technologies on the level of media literacy of teachers. The proposed results confirmed the existence of a close relationship between digital competence and the ability to critically analyze media content. The identified graded effect of the intensity of IT use further strengthened the obtained conclusions.

Thus, both hypotheses of the study (H1 and H2) were confirmed.

Discussion

The proposed research results confirmed the key role of information technologies in the formation of media literacy of teachers of higher education institutions. A statistically significant impact of the use of digital tools on the level of media literacy was revealed. It was consistent with modern scientific approaches that considered the digital educational environment as an important factor in the development of critical thinking (Reyna et al., 2018), information culture and the ability to analytically process media content (Albardía et al., 2025; Da Porta & Morabes, 2024).

In this sense, the analysis of the participants' responses demonstrated a growing awareness of the need for a critical approach to information and a gradual increase in the level of integration of digital tools into everyday pedagogical practice. These findings make it possible to consider the recorded quantitative changes not merely as isolated data, but as a manifestation of more complex transformations in the professional behavior of teachers, which aligns with the perspectives on institutional digital adaptation highlighted by Colón Zayas (2024).

It is important to note that the results obtained reflected not only a formal increase in the indicators on the scales. It was also about significantly deeper changes in the professional activities of teachers, which were associated with a rethinking of the role of information technologies in the educational process.

Hence, the results of testing the hypothesis H1 demonstrated that the integration of information technologies into the professional activities of teachers contributed to a significant increase in the level of media literacy. This correlated with the main conclusions of several scientific works that the effective use of digital resources in teaching optimized the educational process, formed new cognitive and metacognitive skills of teachers (Fernández-Otoya et al., 2024; Reeves-Huapaya et al., 2025). The large effect size found ($\eta^2 = 0.42$) indicated that the impact of information technologies was not random, but systemic.

Of particular importance was the establishment of a graduated effect of the intensity of use of information technologies. That is, with the increase in the frequency of their use, the level of media literacy statistically increased. This made it possible to argue that it was important not only to use digital tools. It was also important to regularly integrate them into the educational process, where they would act as critically important factors. Similar conclusions were consistent with the results of studies that were devoted to the digital transformation of education (Özcan, 2022; Rodríguez Cruz et al., 2025). There, the importance of systematic implementation of technologies was emphasized.

The results of the hypothesis test H2 also confirmed the existence of a close relationship between digital competence and media literacy. The strong positive correlations revealed indicated that digital competence served as a basic condition for the development of the ability to critically analyze media content. This is

consistent with the results of other scientists who have repeatedly emphasized the integrative nature of digital and media competences (Asfaha & Nag, 2023; Kabakus et al., 2025). In this context, digital competence was both a technical skill and a significant cognitive resource that ensured effective interaction with the information environment (Mokhtari, 2023; Pakhomova et al., 2023). The results of the proposed regression analysis additionally confirmed the leading role of digital competence as a key predictor of media literacy. At the same time, the significant contribution of the frequency of use of information technologies indicated that the formation of media literacy was the result not only of the individual characteristics of the teacher. The features of the organization of the educational process also had a significant impact. This provision expanded traditional ideas about media education, focused on the need to create an appropriate digital educational environment (Gómez-Trigueros et al., 2019; Lukianova & Ovcharuk, 2023).

The results obtained had important practical implications. First of all, the feasibility of integrating information technologies into the system of advanced training of teachers was confirmed. The latter has been repeatedly proposed in the scientific literature. The proposed results also demonstrated the need to develop specialized programs for the development of media literacy, which would combine the formation of digital skills with the development of critical thinking. Thirdly, the effectiveness of the graduated approach to the use of IT made it possible to recommend the implementation of differentiated learning models depending on the level of digital training of teachers.

Special attention was paid to the interpretation of the obtained results in the broader context of the transformation of the role of the teacher in the conditions of digitalization of education. The modern teacher increasingly acted as a facilitator of learning, a moderator of information flows and a mentor in the digital environment. In this regard, the development of media literacy has acquired the meaning of individual competence and at the same time an important professional standard that determined the quality of the educational process. Therefore, the introduction of information technologies should be considered in the future as a tool for a deeper pedagogical transformation.

At the same time, the results of the study should be interpreted taking into account certain limitations. In particular, the study was conducted within a limited sample of Ukrainian higher education institutions, which could affect the possibility of generalizing the results. Secondly, the use of self-assessment tools always contained an element of subjectivity. Also, the duration of the experiment is limited to one semester, which did not allow assessing the long-term effects of the influence of information technologies.

Conclusions

In conclusion, this research confirms that the systematic integration of information technologies acts as a systemic catalyst for advancing media literacy among higher education faculty. The robust effect sizes identified demonstrate that casual digital exposure is insufficient; rather, sustained, multi-level digital interaction is required to significantly elevate capabilities in critical text analysis, data verification, and content creation. Consequently, higher education institutions must shift from generic ICT training toward comprehensive frameworks that blend digital operational efficiency with media cognitive resilience.

The scientific novelty of the study consisted in the comprehensive empirical substantiation of the relationship between the use of information technologies, digital competence and the level of media literacy of teachers.

The practical significance of the results obtained was the possibility of their use in the development of teacher training programs and the creation of media literacy courses.

Prospects for further research will consist in expanding the sample, using mixed methods (in particular, combining quantitative analysis with qualitative interviews), as well as studying the long-term impact of digital educational practices on the formation of media literacy.

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Appendix 1.

ICT Use Frequency Questionnaire for Teachers

Instructions for the respondent:
Please rate how often you use the following information technologies in your professional (teaching) activities.

Use a scale from 1 to 5:

1. Almost never
2. Rarely
3. Sometimes
4. Often
5. Very often

Questionnaire items

How often do you use learning management systems (LMS) (e.g. Moodle, Google Classroom, Canvas)?

How often do you use online platforms for communication with students (Zoom, Microsoft Teams, Google Meet, etc.)?

How often do you use multimedia materials (videos, podcasts, interactive presentations) in the educational process?

How often do you use digital tools for creating educational content (Canva, PowerPoint, Prezi, Genially, etc.)?

How often do you use tools to verify the accuracy of information (fact-checking resources, academic databases)?

How often do you use online resources and digital libraries to prepare educational materials?

How often do you use interactive digital services (Kahoot, Mentimeter, Quizizz, etc.) in the learning process?

How often do you use digital tools for assessment and feedback (online tests, Google Forms, LMS assessments)?

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Original Article

IA como andamiaje cognitivo en la educación bilingüe: Impacto en la comunicación lingüística y literaria de estudiantes no filológicos

AI as cognitive scaffolding in bilingual education: Impact on linguistic and literary communication of non-philological students

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Resumen

El objetivo del artículo fue evaluar el efecto de la integración didáctica guiada de IA como andamiaje cognitivo y dilucidar el mecanismo de este efecto. Se realizó un experimento en un diseño de preprueba/postprueba con grupos de control (GC): total N=132; 16 semanas; grupo experimental total (GE) = 66, GC = 66). El GE utilizó el uso regulado pedagógicamente de ChatGPT, lectura asistida por IA, Google Translate y Grammarly. Los resultados mostraron la superioridad del GE sobre el GC en todos los componentes. La lectura de textos profesionales aumentó en el GE al 82-85% (del 65-69%), mientras que en el GC, al 66-72%. El TTR aumentó en el GE a 0,51-0,54 (de 0,37-0,46), en el GC, a 0,40-0,47. En la tarea escrita, el GE demostró el mayor aumento en los criterios de interpretación (psicología: 3,0→4,3) y lógica de la argumentación (3,1→4,1; 3,3→4,2), mientras que la precisión gramatical aumentó de forma más moderada (GE: aproximadamente 59–66%→74–80%). El análisis de correlación confirmó el mecanismo mediado: la relación entre IA×interpretación fue r=0,49–0,74, IA×escritura académica – r=0,58–0,71, IA×gramática – r=0,55–0,62; también se registraron las relaciones entre TTR×interpretación r=0,58–0,73, y lectura×argumentación r=0,61–0,72 (p<0,05–0,01). Las perspectivas de investigación incluyen comparar el uso guiado y autónomo de herramientas de IA y probar los efectos a largo plazo de su integración en el aprendizaje del idioma inglés.

Palabras clave: enseñanza de lenguas extranjeras; apoyo cognitivo para el aprendizaje; interpretación de textos; discurso argumentativo.

Abstract

The aim of the article was to assess the effect of guided didactic integration of AI as cognitive scaffolding and to elucidate the mechanism of this effect. An experiment was conducted in a pre-test/post-test design with control groups (CG): total N=132; 16 weeks; total experimental group (EG) = 66, CG = 66). The EG used pedagogically regulated use of ChatGPT, AI-assisted reading, Google Translate and Grammarly. The results showed the superiority of the EG over the CG in all components. Reading of professional texts increased in the EG to 82–85% (from 65–69%), while in the CG – to 66–72%. TTR increased in the EG to 0.51–0.54 (from 0.37–0.46), in the CG – to 0.40–0.47. In the written task, the EG demonstrated the greatest increase in the criteria of interpretation (psychology: 3.0→4.3) and logic of argumentation (3.1→4.1; 3.3→4.2), while grammatical accuracy increased more moderately (EG: approximately 59–66%→74–80%). Correlation analysis confirmed a mediated mechanism: gains in linguistic resources were associated with higher-order outcomes, including TTR×interpretation (r=0.58–0.73) and reading×argumentation (r=0.61–0.72) (p<0.05–0.01). The research prospects include comparing the guided and autonomous use of AI tools and testing the long-term effects of their

integration into English language learning. Overall, the findings suggest that AI-based cognitive scaffolding strengthens linguistic resources (reading and lexical diversity), which in turn supports clearer logical structuring of arguments and more grounded text interpretation in bilingual non-philological students.

Keywords: foreign language education; cognitive support for learning; text interpretation; argumentative speech.

Introduction

AI has become a visible and almost familiar part of the higher education space. In English language learning, students increasingly rely on AI every day. It helps them to process texts, search for information, and explain complex passages in accessible language (Lo et al., 2024; Zhu & Wang, 2025). AI assistants support academic writing by suggesting wording, helping to structure the text, and providing feedback (Ali, 2024; Wah, 2025). Other artificial tools help train reading, vocabulary, grammar, and pronunciation in a self-learning mode (Behforouz & Al Ghaithi, 2025; Yang & Li, 2024).

Reviews show a generally positive but uneven impact of AI on English learning outcomes (Xu et al., 2025; Zhu & Wang, 2025). Text comprehension, vocabulary, and written work quality are most often improved. At the same time, the effect of AI varies depending on the tasks given by the teacher and the imposed constraints. As Rivero and Yin (2025) point out, the same tools can either develop autonomy or increase dependence on prompts. Therefore, it is important to investigate not only whether AI “works”, but also how it changes academic communication. The data on the impact of AI on students’ text interpretation and argumentation logic remain particularly controversial. The number of controlled empirical studies on bilingual non-philological students, in particular in Ukrainian higher education institutions (HEIs), is limited.

The concept of cognitive scaffolding originates from socio-cognitive learning theory and refers to the temporary support provided to learners to facilitate the performance of tasks that would otherwise exceed their current level of competence (Lo et al., 2024; Zhu & Wang, 2025). Traditionally, scaffolding is associated with teacher guidance, structured prompts, and mediated learning interactions that gradually foster learner autonomy. In contemporary digital learning environments, technological tools can also function as scaffolding mechanisms by supporting comprehension, reducing cognitive load, and structuring complex cognitive operations (Hong et al., 2025; Godwin-Jones, 2023; Yao & Fan, 2025). From this perspective, AI systems may be interpreted not merely as sources of information or automation, but as dynamic cognitive supports capable of mediating linguistic processing, interpretation, and argument construction (Barrot, 2024; Yang & Li, 2024; Zhang, 2025).

The aim of this study is to test the effect of guided integration of AI tools as cognitive scaffolding for the development of linguistic and literary English-language communication of bilingual non-philology students. The study is aimed at clarifying the mechanism of influence of the use of AI (through linguistic resources) on the results of English-language communication of bilingual students and at substantiating a pedagogically appropriate model of its integration into higher education.

The aim involves the fulfilment of the following research objectives:

1. Analyse the dynamics of linguistic and literary English-language communication of non-philological students using AI tools.
2. Establish the differentiated influence of AI on formal language indicators (grammatical accuracy, lexical diversity, reading of professional texts) and cognitive-speech components (text interpretation, logic of argumentation, academic writing).
3. Substantiate the mechanism of indirect influence of AI on the development of argumentative and interpretive competence of bilingual students.

The practical significance of the study is to determine the real effect of the guided integration of AI tools in teaching English. The obtained results help teachers to reasonably use AI as cognitive scaffolding in linguistic and literary communication. The proposed approaches can be integrated into curricula for bilingual non-philological students.

Literature review

The integration of AI into language education is changing traditional pedagogical practices, shifting learning from teacher-centered approaches to more adaptive educational ecosystems. Academic reviews document a general trend toward increased student engagement and autonomy with AI, but emphasize that the effect depends on context, access, and methodological support. There is no clear consensus in the current literature on which components of foreign language competence AI best supports. Research results vary by task type, specific tool, and level of didactic regulation. Earlier CALL-based interventions also demonstrated that structured integration of computer-assisted learning environments can produce measurable improvements in students' English achievement, particularly when digital tools are embedded within pedagogically regulated instructional models (Al-Khayyat, 2015).

On the one hand, a number of studies demonstrate tangible positive effects of AI interventions on specific skills. For example, positive dynamics of results under AI support is shown for reading in English as a Foreign Language (EFL) (Behforouz & Al Ghaithi, 2025). In the area of literary competence and analytical writing, some authors note additional benefits when AI is combined with learning models that involve high levels of student engagement (Jadwe et al., 2025), with the effect of "flipped learning" in EFL being interpreted as enhancing cognitive engagement and autonomy (Lee & Wallace, 2018). At the same time, these positive findings contrast with the caveats of Fang and Han (2025). On the material of genre- and culturally complex texts, AI more often produces simplified or falsely convincing interpretations. Therefore, the effect of using AI depends on the type of text and the cognitive complexity of the assignment.

There are also contradictions in the theoretical and methodological explanations of the mechanisms of AI influence. Early research in Computer-Assisted Language Learning conceptualized digital technologies as mechanisms of structured learner support, adaptive feedback, and guided development of language competence (Beatty, 2010). Contemporary CALL and second language acquisition research emphasizes that technological assistance does not automatically result in learning outcomes without cognitive engagement and internalization processes (Godwin-Jones, 2023). Recent developments in AI-driven language technologies have significantly expanded possibilities for text generation, feedback, and linguistic

mediation in educational contexts, raising new questions about pedagogical boundaries and quality control (Barrot, 2024).

The empirical results on writing and communication are also interpreted ambiguously. It was shown that the interaction of humans and generative AI in academic writing can be complementary, but requires developed skills in critically evaluating machine responses (Ali, 2024). At the same time, it was proven that learning outcomes depend not so much on the “availability of AI” as on the intensity and nature of interaction with it, which makes pedagogical design a key variable (Alhamam, 2025). At the emotional level, systematization shows that AI support can be accompanied by heterogeneous emotional reactions that affect the stability of effects (Zhang & Liu, 2025), while reviews of ChatGPT emphasize methodological and research “blank spots” (Lo et al., 2024). The generalized data of meta-analysis, despite the generally positive trend, emphasize the variability of effects and the dependence on the conditions of implementation (Xu et al., 2025).

In the bilingual aspect, another “break” of interpretations is observed. On the one hand, a framework was proposed where AI influences through autonomous learning, administrative processes and teaching support – but with a warning about the risks of bias and limitations of teacher autonomy (Escobar Alméciga et al., 2025). On the other hand, it was shown that interaction with GenAI can activate translinguistic strategies in writing, when the native language is used as a resource for finding solutions to ideas, rather than as an “obstacle” (Yang & Lin, 2025). Empirical data indicate an increase in learning outcomes, motivation and self-regulated AI-mediated learning (Wei, 2023). In the field of translation, there is also no one-dimensional conclusion.

So, recent studies show a field of methodological and pedagogical contradictions rather than a coherent consensus. AI can enhance individual language resources (reading, vocabulary, writing), but its impact on “higher” components (interpretation, argumentation, literary communication) is uneven, context-dependent, and mediated by pedagogical design. This discrepancy in results and explanations leads to an academic gap. There is a lack of controlled empirical data on the integrated impact of AI on the linguistic and literary communication of bilingual non-philological students— and on the mechanism through which this impact is realized.

Methods and Materials

The study is based on an experimental design and quantitative data analysis to assess the impact of AI on linguistic and literary English-language communication; the following methods were used:

1. A pedagogical experiment (pre-test/post-test with a CG) was used to test the effect of guided integration of AI on English-language communication indicators and to compare the dynamics between the EG and CG.
2. Quantitative testing of language competence (grammatical accuracy, Type–Token Ratio, comprehension of professional texts) was used to record changes in students’ linguistic resources during the semester.
3. Analytical assessment of argumentative writing by rubric (comprehension, interpretation, logic of argumentation, linguistic design) was used to measure the “higher” cognitive-speech components of literary English-language communication.
4. The correlation method (Pearson r) was used to identify relationships between the intensity of AI use and language/cognitive-speech indicators, as well as to test the mediated mechanism of influence through language resources.

5. Statistical t-tests were used to statistically test changes (paired t-tests: pre→post within groups) and differences between groups (independent t-tests for post–pre increments) in order to clearly and transparently assess the effect of the intervention.

Participants and sampling.

The study included undergraduate non-philological students (N = 132) studying at three HEIs in Ukraine:

1) Psychology (National Pirogov Memorial Medical University, Vinnytsia);
2) Agroengineering (Poltava State Agrarian University);
3) Ecology (National University of Water Management and Environmental Management).

All participants were classified as academic bilinguals who use EFL (L2) in an educational context. Inclusion criteria were:

1) Age 18–22 years;
2) Status as an undergraduate non-philological student;
3) Completion of a relevant English/English for Specific Purposes (ESP) course in the specified semester;
4) Absence of participation in parallel intensive English programmes outside the course (according to self-assessment/questionnaire data).

Students were informed about the experiment through an announcement by the instructor in class and an official group chat, after which they were given an information sheet and a voluntary consent form. All participants were classified as academic bilinguals using English as an L2 in an educational context. The gender composition of the sample was mixed: women made up 60%, men 40% of the total sample.

Each institution formed two groups — EG and CG — with 22 participants each (a total of 44 students per major; total N = 132, EG = 66, CG = 66). Randomization was carried out by generating random numbers and assigning participants a group code (EG/CG) after pre-testing. This approach ensured comparability of groups within each HEI, not between institutions. The comparability of the baseline level between EG and CG within each HEI was confirmed by the pre-test results ($p > 0.05$).

“Academic bilinguals” in this study were defined as students who (1) had a B1–B2 or higher level on an English pre-test, (2) had studied English in formal education for at least 5–10 years (self-report), and (3) regularly used English as an L2 for academic purposes (reading/working with professional materials, completing written assignments), as confirmed by a short frequency questionnaire (weekly self-report). Students who did not meet these criteria were not included in the sample.

Research procedure

Educational materials and assessment criteria were standardized for all three HEIs. To minimize uncontrolled AI use, both groups were provided with explicit academic integrity guidelines. Students in the control group were instructed to complete all course-related tasks without the use of AI tools. Compliance was monitored through a brief academic integrity checklist administered periodically during the semester, in

which students confirmed adherence to the experimental conditions. Additionally, AI tools were strictly prohibited during pre-test and post-test assessments, which were conducted under supervised classroom conditions. While complete control of students' out-of-class behaviour is methodologically unattainable, this procedure ensured reasonable regulation of AI exposure within the experimental design. The experimental phase lasted one academic semester (16 weeks) offline. Training in both groups was carried out according to the same programme using identical authentic English-language academic (ESP) texts selected according to the majors (psychology, agricultural engineering, ecology). The texts were informative and argumentative in nature, contained professional terminology, and were comparable in volume and complexity to ensure correct comparison of results between groups. The difference was in the controlled integration of AI tools into EG. The experimental AI integration programme was developed taking into account the principles of controlled cognitive support and aimed at developing linguistic and literary English-language communication of bilingual non-philological students. The programme was implemented during one academic semester and combined classroom and independent work of students (Appendix A). The AI was used according to clearly defined pedagogical scenarios, which allowed directing students' work not to mechanically obtain ready-made answers, but to support higher-level thinking operations, in particular analysis, interpretation, and argumentation. All AI-generated results were subject to mandatory analysis, refinement and rethinking by students, which ensured active cognitive involvement and preservation of academic integrity. Different AI tools were used within the programme depending on the type of educational task: ChatGPT was used to analyse English-language texts, generate ideas and structure arguments; Google Translate – to compare translation options and identify semantic discrepancies; Grammarly – to edit the language design of written works; AI reading assistants – to explain terminology and paraphrase complex fragments of text. At the same time, the programme clearly limited the excessive use of AI: copying ready-made answers without own intellectual processing was prohibited, and the final result had to reflect the student's independent interpretative and analytical work.

The intensity of AI use during the experiment was determined by a standardized self-report (a short weekly report), in which students recorded the frequency of using ChatGPT / AI-assistant for reading / Google Translate / Grammarly specifically for course tasks (reading, interpretation, lexical transformation, argument planning, editing). The frequency was assessed on a scale (0 = did not use, 1 = 1 time/week, 2 = 2–3 times/week, 3 = 4–5 times/week, 4 = daily); an integral intensity index (0–16) was formed based on the total score, which was used in the correlation analysis and to construct low/moderate/high intensity groups.

The EG students systematically used AI tools to understand texts, expand their vocabulary, as well as create and edit written responses. The CG performed similar tasks without the use of AI, relying on traditional teaching methods. It is important to note that students were not allowed to use AI tools during the pre-test and post-test assignments. Literary English communication was assessed in a complete autonomy in order to identify the level of interpretative and argumentative skills internalized in the process of earlier work with AI tools. Within the framework of this study, linguistic communication was considered as a set of formal and receptive language skills (grammatical accuracy, lexical diversity, reading of professional texts). Literary communication was interpreted as the semantic implementation of these resources in the process of interpreting an English text and constructing an argumentative written statement.

Instruments and data collection

Language communication was assessed using pre-test and post-test results, which included indicators of grammatical accuracy (percentage of correct forms), lexical diversity (Type–Token Ratio, TTR), and comprehension of professional English texts. Literary English communication was investigated using an argumentative writing task based on an authentic academic text of 400–450 words. Students' written works (200–250 words) were assessed using four criteria: understanding of the content, interpretation of ideas, logic of argumentation, and linguistic design. The assessment was carried out on a five-point scale. The written works were assessed by two independent experts using an analytical rubric; calibration was carried out before the assessment, and inter-expert agreement was checked using Intraclass Correlation Coefficient (ICC): absolute agreement. A blind assessments were performed to group and stage (pre/post), and discrepancies were reconciled by re-review.

Data analysis

Quantitative data were processed in SPSS. Descriptive statistics, paired Student t-tests (pre-test → post-test), and Pearson correlation analysis were used. Independent t-tests for the magnitude of the increase (post–pre) were used to compare the EG and CG. The statistical significance level was set at $p < 0.05$. Additionally, an analysis of the relationship between the intensity of AI use and language and cognitive-speech indicators was conducted. The use of t-tests and correlations meets the objectives of the study (assess pre/post changes and relationships between indicators) and is sufficient to interpret the effects within the chosen design and sample size. In this study, the priority was to provide transparent interpretation of changes and comparability of results across the three educational contexts; the application of more sophisticated models is planned for a larger sample and in longitudinal designs.

Research limitations

The limitations include a relatively small sample size, a focus exclusively on non-philological majors, and the short duration of the experiment, which did not allow for the assessment of long-term effects of AI use. A particular difficulty was the control of individual strategies for using AI tools, despite the guided pedagogical design.

Results and discussion

Analysis of the pre-test and post-test results showed positive dynamics of the level of English proficiency in all study groups. At the same time, the EG of students majoring in Psychology, Agroengineering, and Ecology of three different HEIs demonstrated significantly higher rates of growth of language indicators compared to the CG.

The growth was recorded for all measured components, but its intensity varied depending on the type of language activity. The greatest increase was observed in those types of tasks that involved understanding the content of the English text, its interpretation and construction of one’s own reasoned statement, while changes in grammatical accuracy were more moderate in nature (see Table 1). This configuration of results is consistent with prior studies demonstrating that AI-supported learning environments tend to produce stronger effects on meaning-related and organizational aspects of language use than on formal grammatical

accuracy. Zhang (2025), for example, reported substantial improvements in argument structuring and content development, while grammatical gains remained comparatively limited. A similar interpretation is supported by Hong et al. (2025), who argue that AI tools facilitate cognitive resource redistribution rather than direct correction of linguistic form.

Table 1.
Average indicators of language communication (pre-test → post-test) by majors

Major	Group	Grammatical Accuracy (%)	Lexical Diversity (TTR)	Reading professional texts (%)
Psychology	CG	64 → 68	0.42 → 0.44	66 → 70
	EG	63 → **78**	0.43 → **0.51**	65 → **82**
Agroengineering	CG	60 → 63	0.38 → 0.40	62 → 66
	EG	59 → **74**	0.37 → **0.48**	61 → **79**
Ecology	CG	65 → 69	0.45 → 0.47	68 → 72
	EG	66 → **80**	0.46 → **0.54**	69 → **85**

Source: developed by the authors

Quantitative analysis showed that in all EGs the increase in indicators was statistically significant ($p < 0.05$). The largest changes were recorded in the indicators of reading professional texts and lexical diversity of written speech. This was observed regardless of the major, although the absolute values varied. Comparable tendencies have been observed in vocabulary-oriented AI research. Pryma et al. (2025) found that AI-assisted writing contributed to measurable expansion of students' lexical repertoires and improved textual coherence. Our results replicate this pattern: AI integration was associated with more active use of academic and professional terminology. At the same time, Pryma et al. (2025) note potential risks, including the emergence of mechanical phrasing and reduced originality, which reinforces the importance of balanced AI usage.

Literary English communication was assessed by offering students the task: to read a short academic text in English (400–450 words) and write a reasoned comment (200–250 words) based on the content of the text. The assessment was carried out according to the criteria: understanding of the content, interpretation of ideas, logic of argumentation, language design (see Table 2).

Table 2.
Indicators of literary English communication of non-philological students (pre-test → post-test)

Major	Group	Understanding the content	Interpretation of ideas	Logic of argumentation	Language presentation
Psychology	CG	3.2 → 3.6	3.1 → 3.5	3.0 → 3.4	3.3 → 3.6
	EG	3.1 → 4.2	3.0 → 4.3	3.1 → 4.1	3.2 → 4.0
Agroengineering	CG	3.0 → 3.4	2.9 → 3.2	3.1 → 3.4	3.0 → 3.3
	EG	3.0 → 3.8	2.8 → 3.6	3.0 → 3.7	3.1 → 3.6
Ecology	CG	3.3 → 3.7	3.2 → 3.6	3.4 → 3.8	3.3 → 3.7
	EG	3.2 → 4.1	3.1 → 4.0	3.3 → 4.2	3.2 → 4.0

Source: developed by the authors

In all majors, the EG demonstrated a more intensive increase in the criteria of literary English communication compared to the CG. The most sensitive to the controlled integration of AI were the interpretation of ideas and the logic of argumentation: in psychology, the increase in interpretation was +1.3 (3.0→4.3) and argumentation +1.0 (3.1→4.1), while in the CG these changes were more moderate

(mainly +0.3–0.4). In terms of the final level of logic of argumentation, the highest values were demonstrated by students of Ecology (EG: 4.2), while the growth was stable but less intense in all components in Agroengineering. In general, the differences between the EG and CG are interpreted as the result of an internalized (not “instant”) effect: during the pre/post assessment, AI was not used, therefore the recorded changes reflect mediated cognitive-linguistic development due to the controlled integration of AI into the learning process. This predominance of gains in interpretation and argumentation aligns with empirical findings indicating that AI support strengthens higher-order cognitive processes involved in analytical writing. Zhang (2025) similarly observed that AI assistance most strongly affected argument organization, whereas grammatical components demonstrated only moderate growth. Such dynamics may be explained by the cognitively indirect nature of AI influence: generative systems create hybrid writing environments requiring learners to evaluate, refine, and critically interpret machine-generated outputs (Yao & Fan, 2025).

Correlation analysis showed that the relationship between the intensity of AI use and the indicators of interpretation and academic writing is stronger than between the use of AI and formal grammatical skills (see Table 3).

Table 3.
Correlation between the intensity of AI use and key linguistic and cognitive-speech indicators (Pearson r)

Predictor	Cognitive level (β)	Emotional-value level (β)	Behavioural level (β)
Task type: digital simulations	0.38	0.31	0.22
Task type: multimedia cases	0.41	0.35	0.18
Task type: interactive platforms	0.29	0.28	0.15
Learning activity: high	0.35	0.48	0.32
Learning activity: medium	0.21	0.32	0.24
Learning activity: low	0.12	0.19	0.16
Gender: women	0.27	0.42	0.37
Gender: men	0.14	0.26	0.19
Starting level: high	0.39	0.33	0.28
Starting level: medium	0.26	0.25	0.23
Starting level: low	0.17	0.18	0.16

*p < 0.05; *p < 0.01
Source: developed by the authors

Table 3 shows that AI most effectively affects the complex cognitive-speech components of English-language communication. At the same time, the correlation between the intensity of AI use and the logic of argumentation turned out to be weaker compared to the correlations with language resources, in particular lexical diversity and text interpretation. This indicates that the formation of an argumentative written expression is not reduced to the direct influence of technological tools. Instead, it is mediated by the level of development of language resources and cognitive text processing. This interpretation is theoretically compatible with the concept of cognitive offloading. Hong et al. (2025) suggest that delegating routine operations to AI frees cognitive resources for interpretation and evaluation. Simultaneously, Yao and Fan (2025) emphasize that AI-supported writing introduces additional cognitive demands associated with prompting and verification. Together, these mechanisms help explain why AI effects are stronger in interpretive and lexical-semantic dimensions.

In order to explain the mechanism of the influence of AI on literary and interpretive English-language communication, an additional correlation analysis was conducted between the language indicators that underwent changes as a result of the use of AI and the indicators of interpretation and argumentation of written speech (Table 4).

Table 4.
Correlation between the intensity of AI use and key linguistic and cognitive-speech indicators (Pearson r)

Indicator	Psychology	Agroengineering	Ecology
TTR × text interpretation	0.73**	0.58*	0.70**
Reading × argumentation	0.68**	0.61*	0.72**

*p < 0.05; *p < 0.01
Source: developed by the authors

The results showed a moderate to strong relationship between the level of lexical diversity of written speech and the ability to interpret English texts (r = 0.66–0.73; p < 0.01 depending on the specialty). A similar trend was observed between the results of reading professional texts and the logic of argumentation in written works (r = 0.61–0.70; p < 0.01).

The obtained results indicate that the impact of AI on literary and interpretive English-language communication is indirect and is realized through the strengthening of linguistic resources, in particular lexical diversity and skills of reading professional texts in English. Similar effects have been documented in AI-assisted reading research. Studies report significantly higher comprehension outcomes when AI tools are incorporated into text-processing activities (Doğan & Talan, 2025). The present data extend this observation by demonstrating that improvements in reading professional texts are closely linked with the development of argumentative writing logic.

The intensity of AI use was assessed by the frequency of use of AI tools during the course tasks. Based on these data, an integral intensity indicator was calculated. Next, students were divided into three intensity levels (low/moderate/high) and the average increase in results (post–pre) was compared. In order to test the assumption of the nonlinear nature of the impact of AI, it was analysed how the increase in linguistic and literary indicators changes depending on the level of intensity of AI use (Figure 1).

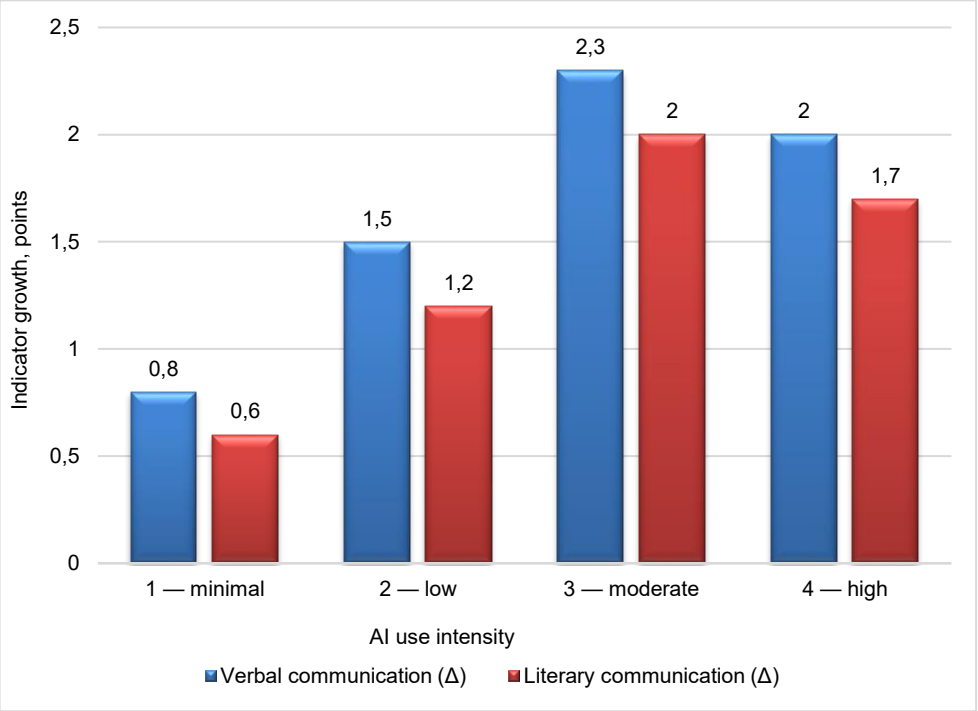


Figure 1. The relationship between the AI use intensity and the increase in indicators of verbal and literary English communication of non-philological students.
Source: developed by the authors

Figure 1 shows a nonlinear relationship between the AI use intensity and the growth of indicators of verbal and literary English-language communication. In both dimensions, a gradual increase in results was recorded under conditions of minimal and low intensity of AI use, with maximum values achieved at a moderate level of its use. The nonlinear nature of this relationship confirms that pedagogical effectiveness depends not on the intensity of AI usage per se, but on its structured integration. Excessive reliance may reduce cognitive engagement, a concern also reflected in recent AI-in-education analyses (Deep & Chen, 2025). These findings reinforce the argument that AI functions most effectively as a cognitive support rather than a substitute for learner effort.

Under high AI use intensity, a decrease in the average growth of both verbal and literary communication is observed. This indicates the absence of a direct proportional relationship between the frequency of technology use and the educational effect. At the same time, the dynamics of verbal communication is somewhat higher compared to literary communication at all levels of intensity, which reflects the different degree of sensitivity of these components to the pedagogical implementation of AI tools.

Overall, the obtained results indicate that the impact of AI on linguistic and literary English communication is systemic but mediated. AI does not act as a direct means of increasing formal linguistic accuracy, but primarily activates higher-level cognitive and speech processes.

From a theoretical perspective, the obtained results are best explained as part of the socio-cognitive concept of mediated learning. According to it, digital tools function as cognitive mediators that redistribute the learning load between technical and

mental operations. In this context, AI acts as a dynamic scaffolding, enhancing access to language resources while requiring the student to actively participate in evaluating, interpreting, and editing the results.

Conclusions

The study (N=132; 16 weeks) found that guided integration of AI into English language learning for non-philological students is associated with higher gains in language and literature scores compared to traditional learning. In the EG, the gains were greatest in reading specialized texts and lexical diversity (TTR): for example, reading increased by +17–18 pp. (EG: 65→82; 61→79; 69→85), while in the CG — by +4 pp. (66→70; 62→66; 68→72). TTR in the EG increased by +0.08–0.11 (0.43→0.51; 0.37→0.48; 0.46→0.54), in the CG — by only +0.02.

According to the criteria of argumentative writing, the EG showed more noticeable changes in the "higher" components: interpretation increased to +0.8–1.3 points (e.g., 3.0→4.3), and logic of argumentation to +0.7–1.0 points (e.g., 3.1→4.1), while in the CG the increases were mostly +0.3–0.4 points. Grammatical accuracy also increased, but more moderately than other components (e.g., EG: 63→78; CG: 64→68). Correlation data support the mediated nature of the changes: the relationship "intensity of AI use × interpretation" was higher (r≈0.49–0.74) compared to "AI × grammar" (r≈0.55–0.62), and strong relationships were also recorded between language resources and "higher" indicators (e.g., TTR × interpretation r≈0.58–0.73).

The obtained results serve as the basis for the pedagogical design of classes using AI. These include the scenario-based implementation of tools such as ChatGPT, AI-assistant readers, Google Translate, and Grammarly in working with authentic professional texts, lexical enrichment, and structured argumentative writing with control of academic integrity and intensity dosage. Further research may be focused on comparing guided and autonomous models of using AI tools. It is also important to study the long-term effects of integrating AI into English language teaching. Particular prospects for further research include comparative studies examining the effects of AI-assisted learning across different levels of language proficiency (e.g., B1 vs. C1), which may clarify the role of linguistic competence in mediating AI-related learning outcomes.

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Appendix A.

Programme for the guided integration of AI into the teaching of bilingual non-philological students

Programme Stage	Learning Objective	Type of Activity	AI Tool	Example of a Pedagogically Directed Prompt	Cognitive Function	Expected Learning Outcome	Monitoring and Evaluation
1. Orientation	Formation of a conscious attitude towards AI	Introduction, instruction	ChatGPT	*"Explain how AI can support learning without replacing critical thinking."*	Metacognitive reflection	Understanding the role of AI as a tool to support, not replace, thinking	Oral discussion, reflective mini-note
2. Reading authentic text	Development of understanding of a professional text	Analytical reading	AI reading assistant, ChatGPT	*"Explain the key concepts of this paragraph using academic English at B2 level."*	Semantic decomposition	A deeper understanding of the content, terminology	Comparison of own resume and AI explanation
3. Interpreting content	Building of interpretive competence	Semantic analysis	ChatGPT	*"Provide two alternative interpretations of this argument and explain their differences."*	Interpretation, analysis	The ability to see the multiplicity of meanings	Written comment + oral defence
4. Lexical enrichment	Expanding Academic Vocabulary	Lexical Transformation	ChatGPT, Grammarly	*"Replace general words with discipline-specific academic vocabulary without changing meaning."*	Lexical Variability	TTR growth, term precision	Comparative analysis of text versions
5. Structuring the argument	Developing Writing Logic	Planning	ChatGPT	*"Create a logical outline for an argumentative response based on this text."*	Logical Organization	Clear argument structure	Checking the compliance of the plan with the final text
6. Writing a draft	Realization of Argument	Academic Writing	ChatGPT (limited)	*"Generate a draft introduction. I will revise and expand it."*	Cognitive Scaffolding	Activating ideas without automation	Analysis of changes between AI draft and final
7. Critical Editing	Developing Responsible Writing	Editing	Grammarly, ChatGPT	*"Identify weaknesses in argument logic but do not rewrite the text."*	Critical evaluation	Improving the quality of argumentation	Teacher comments on corrections
8. Comparative analysis	Awareness of the Impact of AI	Reflexive Analysis	ChatGPT	*"Compare my original version and the revised one. What improved and why?"*	Metacognitive integration	Awareness of one's own progress	Reflective report
9. AI Limitations	Preventing Addiction	Controlled Exclusion	–	Assignments without AI	Self-regulation	Autonomous Skills Test	Test writing without AI
10. Final Assignment	Skill Integration	Argumentative Commentary	Limited use	*"Suggest feedback questions for self-checking, not content."*	Knowledge integration	Balanced Use of AI	

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Original Article

Tendencias innovadoras en la formación de futuros trabajadores sociales en el contexto de la transformación digital de la educación

Innovative trends in the training of future social workers in the context of the digital transformation of education

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Resumen

El artículo describe los requisitos de la sociedad para la formación profesional de los trabajadores sociales en el contexto de la transformación digital. Se revelan el propósito, las características principales y los niveles de preparación de los futuros trabajadores sociales para las condiciones de la transformación digital de la educación. Se caracterizan las funciones y los principios didácticos básicos de la actividad profesional de los trabajadores sociales en las condiciones de la transformación digital de la educación. En la etapa experimental, implementamos el sistema desarrollado para desarrollar la preparación profesional de los futuros trabajadores sociales para las condiciones de la transformación digital en la educación mediante la creación de condiciones pedagógicas y un entorno educativo digital universitario. Para probar la hipótesis de investigación, utilizamos criterios no paramétricos estableciendo criterios paramétricos: criterio de Pearson, criterio F de Fisher, criterio t y análisis de correlación. En el punto de corte de determinación, los estudiantes en los grupos de control y experimental estaban aproximadamente en el mismo nivel de preparación descrita; Tras realizar un trabajo experimental en el grupo experimental, observamos mejores resultados y concluimos que el nivel de los estudiantes aumenta significativamente al implementar un sistema experimental para formar la preparación profesional de los futuros trabajadores sociales para las condiciones de la transformación digital de la educación, mediante el desarrollo de condiciones pedagógicas y la creación de un entorno educativo digital en la universidad.

Palabras clave: tendencias innovadoras; formación de trabajadores sociales; transformación digital de la educación; entorno educativo digital de la universidad; recursos digitales.

Abstract

The article outlines society's requirements for the professional training of social workers in the context of digital transformation. The purpose, main features, and levels of readiness of future social workers for the conditions of digital transformation of education are revealed. The functions and basic didactic principles of the professional activity of social workers in the conditions of digital transformation of education are characterized. At the experimental stage, we implemented the developed system to develop the professional readiness of future social workers for the conditions of digital transformation in education by creating pedagogical conditions and a university's digital educational environment. To test the research hypothesis, we used non-parametric criteria by establishing parametric criteria: Pearson's criterion, Fisher's F-criterion, t-criterion, and correlation analysis. At the ascertaining cut, students in the control and experimental groups were at approximately the same level of outlined

readiness; after conducting experimental work in the experimental group, we see higher results, and we conclude that the level of students significantly increases when implementing an experimental system for forming professional readiness of future social workers for the conditions of digital transformation of education, by developing pedagogical conditions and creating a digital educational environment of the university.

Keywords: innovative trends; training of social workers; digital transformation of education; digital educational environment of the university; digital resources.

Introduction

The changes that have occurred in society in recent years are accompanied by numerous social, political, and economic problems that, to some extent, affect the life of a person who is sensitive to functional and structural transformations and fully reproduces all aspects of society. The rapid development of social education has become a response to the demands of the time, which, by its content and essence, through the performance of a preventive, anticipatory function of preparing each member of society for life, is designed to ensure the social security of society in a period of change and to ensure the upbringing and training of a person oriented towards professional activity in the social sphere (Bjerregaard et al., 2018; Joiner, 2019).

In the context of the digital transformation of education, the requirements for professional training of social workers are increasing, which is caused by the modernization of higher education, the introduction of innovative trends in the training of social workers, an increase in the number of categories of the population that, in the context of the digital transformation of education, need social protection, socio-economic changes in society (Pinazo-Hernandis & Carcavilla-González, 2026).

The purpose of professional training for future social workers in higher education institutions is to create an optimal educational and digital environment for the professional and personal formation of the future specialist and to assess the adequacy of the level of professional training for the future workplace (Chiner et al., 2022; Pérez-Durán et al., 2025).

The main feature of the professional readiness of social workers is the ability to address innovative trends in training, complex, specialized tasks under the conditions of the digital transformation of education, and practical problems in the field of professional activity or in the learning process that involve the use of innovative pedagogical conditions. The professional activity of a social work specialist consists of implementing general functions by making operational decisions within their competence; introducing digital technologies for operational, organizational, and heuristic work procedures; and preparing information for the professional activity program (Chakradhar, 2018; Correa Arias & García Híjar, 2021).

The development of digital technologies and the growing demand for higher education today are stimulating the emergence of a new type of mega-university and a network of universities without borders. Modern society sets new and innovative requirements for the professional qualities and personality of a social work specialist. Digitalization, while affecting various aspects of training, changes educational processes, which is especially relevant in the context of reform and decentralization of the social service provision system.

High-quality education in the modern conditions of a digital society is a key guarantee of the realization of social workers' intellectual potential, an indicator of the level of training in higher education, and a factor in their professional competitiveness. A graduate who is preparing to master the profession of a social work specialist must have digital competencies, not only deep subject knowledge, but also the ability to effectively use digital transformations of education and online services in the educational process. Digitalization plays an important role in transforming the educational process, as modern society requires the education sector to use digital tools for learning and to provide convenient access to knowledge through social networks and online platforms for communication, knowledge exchange, and collaboration (Halász, 2018).

Despite the growing integration of digital technologies into higher education, the preparation of future social workers remains largely focused on traditional professional competencies, while the systematic development of digital readiness for professional practice has received insufficient empirical attention. Existing studies primarily examine individual aspects of digital competence, ICT use, or digital literacy among social work students; however, limited evidence exists regarding comprehensive pedagogical systems that combine pedagogical conditions with a university digital educational environment to develop professional readiness for digital transformation.

Furthermore, previous research has predominantly described the importance of digital technologies in social work education without experimentally evaluating their effectiveness through structured pedagogical interventions. Consequently, there remains a lack of empirically validated models capable of improving future social workers' motivational, cognitive, and activity readiness for professional practice in digitally transformed educational contexts.

Addressing this research gap is important because higher education institutions require evidence-based approaches that can effectively prepare future social workers to meet the challenges of digitalized professional practice while supporting the modernization of social work education.

The aim of this study was to evaluate the effectiveness of a pedagogical system designed to enhance the professional readiness of future social workers for the digital transformation of education by implementing evidence-based pedagogical conditions and establishing a university digital educational environment. Specifically, the study sought to determine whether the proposed intervention significantly improves students' motivational, cognitive, and activity readiness compared with traditional educational practices.

Literature Review

The digital transformation of higher education has substantially changed the professional preparation of social workers, requiring graduates to possess not only disciplinary knowledge but also advanced digital, collaborative, and problem-solving competencies. Although previous studies consistently acknowledge the growing importance of digital technologies in social work education, they differ considerably regarding the pedagogical approaches considered most effective for developing these competencies.

Several researchers agree that digital competence has become an essential prerequisite for successful professional practice. López Peláez et al. (2020) demonstrated that a substantial gap persists between the digital skills required in

contemporary social work and the actual competencies of both students and practicing professionals. Similarly, Gómez-Poyato et al. (2022) found that although university students are often considered "digital natives," their technological proficiency does not automatically translate into professional digital competence. These findings consistently indicate that digital literacy develops through structured educational experiences rather than through everyday technology use alone.

A similar conclusion is presented by Kamrujjaman et al. (2023), whose systematic review emphasizes that professional readiness depends on the integration of theoretical knowledge with practical experience, critical thinking, and evidence-based decision-making. Likewise, Joiner (2019) argues that digital transformation should be accompanied by ethical and responsible use of digital technologies, highlighting digital ethics as an indispensable component of professional education. Collectively, these studies support the need for comprehensive educational strategies rather than isolated digital skills training.

Despite this general consensus, researchers differ regarding the most effective pedagogical mechanisms for developing professional readiness. Winardy and Septiana (2023) emphasize game-based learning and role-playing as effective approaches for developing communication and decision-making skills, whereas Pérez-Durán et al. (2025) highlight active learning and educational games for strengthening professional engagement and collaborative problem-solving. In contrast, Lichtenberger-Majzikné and Fischer (2017) consider reflective practice and feedback mechanisms to be the primary drivers of professional competence development. These differing perspectives suggest that no single instructional strategy is sufficient to address the multidimensional nature of professional readiness in digitally transformed educational environments.

Another unresolved issue concerns the conceptualization of digital competence itself. Some studies primarily treat digital competence as technological proficiency and ICT literacy (Gómez-Poyato et al., 2022), whereas others define it more broadly by incorporating communication, collaboration, ethical decision-making, lifelong learning, and professional adaptability (Joiner, 2019; López Peláez et al., 2020). This conceptual inconsistency complicates the comparison of empirical findings and limits the development of standardized approaches to evaluating professional readiness. The study by Pradeep and Sathyamurthi (2017) is devoted to the work of social workers with the community. The professional activities of social workers are revealed, seeking to encourage the vitality of families, individuals, and communities and to create positive change. The authors consider the work of a social worker to be such that society changes for the better, that the work itself benefits the community, and that it is full-fledged for those who need it.

Furthermore, the majority of previous investigations have adopted descriptive, survey-based, or cross-sectional research designs that identify competency deficits without experimentally testing educational interventions capable of addressing them. Although existing research convincingly demonstrates the importance of digital technologies in social work education, considerably less attention has been devoted to evaluating integrated pedagogical systems that combine pedagogical conditions, institutional digital environments, and structured instructional interventions within controlled educational settings.

Therefore, a significant research gap remains regarding the experimental validation of comprehensive pedagogical models designed to improve future social workers' professional readiness for digital transformation. Specifically, there is insufficient

empirical evidence concerning the effectiveness of integrating pedagogical conditions with a university digital educational environment in simultaneously developing motivational, cognitive, and activity components of professional readiness.

The present study addresses this gap by experimentally evaluating a comprehensive pedagogical system implemented within higher education institutions. Unlike previous descriptive investigations, this research examines whether the integration of targeted pedagogical conditions and a digitally enriched educational environment produces statistically significant improvements in the professional readiness of future social workers for practice in digitally transformed educational contexts.

Methodology

Research Design

This study employed a quasi-experimental mixed-methods research design to evaluate the effectiveness of a pedagogical system aimed at developing the professional readiness of future social workers for the digital transformation of education. The research combined quantitative methods to measure changes in students' readiness levels and qualitative methods to obtain a deeper understanding of participants' learning experiences during the intervention.

The experimental design included two parallel groups: an experimental group that participated in the developed pedagogical intervention and a control group that continued studying according to the traditional curriculum. Measurements were conducted before and after the intervention using identical assessment procedures, enabling the comparison of learning outcomes between groups.

Participants

The study involved 189 undergraduate students majoring in Social Work from higher education institutions in Ukraine. Participants were divided into an experimental group (EG, n = 98) and a control group (CG, n = 91). Students were enrolled in comparable educational programmes and had similar academic backgrounds. Before the intervention, no statistically significant differences were observed between the groups regarding their overall level of professional readiness, confirming the comparability of the samples.

Participation in the research was voluntary. All participants were informed about the objectives of the study and provided informed consent before data collection.

Assessment Framework

Professional readiness for work under conditions of digital transformation was conceptualized as a multidimensional construct consisting of three interrelated components:

- Motivational component – students' professional motivation, readiness for continuous professional development, openness to educational innovation, and positive attitudes toward digital transformation.
- Cognitive component – theoretical knowledge of digital technologies, digital educational resources, ICT integration, digital communication, and contemporary approaches to social work education.

- Activity component – practical skills in applying digital technologies, collaborative online work, digital communication, problem-solving, and implementation of digital educational tools in professional practice.

For each component, corresponding criteria, indicators, and three levels of readiness (high, medium, and low) were established before the experiment.

Research Instruments

Data were collected using complementary quantitative and qualitative instruments. The principal quantitative instrument was a structured questionnaire designed according to the three-component model of professional readiness. The questionnaire assessed motivational attitudes, theoretical knowledge, and practical digital competencies using standardized rating scales.

The questionnaire was supplemented by pedagogical observation, semi-structured interviews, diagnostic surveys, and criterion-based achievement tests. Pedagogical observation focused on students' engagement, collaboration, digital communication, and participation in technology-supported learning activities throughout the intervention. Interviews provided qualitative evidence regarding students' perceptions of digital learning and professional development.

Content validity of the assessment instruments was established through expert review involving specialists in pedagogy, digital education, and social work. Prior to the main experiment, the instruments were piloted with a separate group of students to evaluate clarity, comprehensibility, and feasibility of administration. Necessary revisions were introduced following expert recommendations and pilot feedback.

The use of several complementary instruments enabled methodological triangulation and increased the credibility of the findings.

Educational Intervention

The pedagogical intervention was implemented only in the experimental group throughout the formative stage of the study. The intervention integrated four interconnected pedagogical conditions:

- Creation of an innovative university digital educational environment.
- Organization of collaborative interaction between teachers and students through digital technologies.
- Support of students' continuous professional self-development in a digital learning environment.
- Modernization of instructional methods through the integration of innovative digital technologies.

The intervention incorporated learning management systems, online educational platforms, multimedia learning resources, videoconferencing, cloud-based collaboration tools, digital assessment instruments, electronic educational materials, virtual learning environments, research-oriented learning, project-based activities, collaborative problem-solving, and interactive communication technologies.

Students in the control group completed the same academic programme but without implementation of the experimental pedagogical system.

Data Analysis

Quantitative data were analysed using IBM SPSS Statistics.

Descriptive statistics (frequencies, percentages, means, and standard deviations) were calculated to describe participants' readiness levels.

Pearson's chi-square (χ^2) test was applied to compare the distribution of readiness levels between the experimental and control groups. Student's *t*-test was used to evaluate differences in continuous variables where appropriate, while Fisher's criterion was applied to verify the significance of experimental effects. Statistical significance was established at $p < .05$.

Qualitative data obtained from interviews and pedagogical observations were analysed using thematic analysis and were used to complement the quantitative findings.

Validity and Reliability

Several procedures were employed to enhance the methodological rigor of the study. Internal validity was supported through identical assessment procedures for both groups, standardized implementation of the intervention, and equivalent learning conditions except for the experimental treatment.

Content validity was ensured through expert evaluation of the research instruments. Methodological triangulation was achieved by combining questionnaires, interviews, observations, and achievement tests. Pilot testing confirmed the clarity and applicability of the instruments before the main study.

Reliability was strengthened by using standardized data collection procedures, consistent assessment criteria, identical testing conditions, and statistical verification of the obtained results.

Ethical Considerations

The research complied with the ethical principles governing educational research. Participation was voluntary, informed consent was obtained from all participants, confidentiality of personal information was maintained throughout the study, and all collected data were anonymized prior to statistical analysis. Participants were informed that they could withdraw from the study at any stage without academic consequences.

Results and Discussion

In the process of the study, we identified two groups of future social workers who participated in the experiment to determine the level of their professional readiness for the conditions of digital transformation of education (CG, EG):

- **The control group (CG)**, which included such future social workers that the process of their professional training was not subject to changes (for the final experiment as a standard for comparison);
- **The experimental group (EG)**, which included future social workers, was subject to a process of professional training that was pedagogically and experimentally influenced, that is, the implementation of an experimental system for forming the professional readiness of future social workers for the conditions

of digital transformation of education, by developing pedagogical conditions and creating a digital educational environment of the university.

The number of participants in the experiment was 98 in the EG and 91 in the CG.

We identified the components, criteria, and indicators of the readiness of future social workers:

Motivational component. Main criteria: motivation, tolerance, initiative. Indicators: aspirations, interests, orientation, awareness, attitude, need, recognition.

Cognitive component. Main criteria: Psychological-pedagogical and socio-pedagogical knowledge in the field of social work and digital transformation of education. Indicators: level of special knowledge, level of basic knowledge.

Activity component. Main criteria: mastering the methodology for forming professional readiness by future social workers in the conditions of digital transformation of education and creating a digital educational environment. Main indicator: skills.

Organization of the ascertaining stage of experimental research.

At the ascertainment stage of the study, a survey, an interview, and a questionnaire were conducted. Based on the results obtained, conclusions were drawn regarding the level of formation of the motivational component of readiness:

1. Future social workers:

   - Do not realize the significance and necessity of developing skills and abilities to implement an experimental system for building professional readiness for the conditions of digital transformation of education, by developing pedagogical conditions and creating a digital educational environment with parents, communities, and individuals.
   - Do not show a desire for self-improvement and professional growth in inclusive education.
   - Perform an objective self-assessment of the ability to select effective forms, methods, techniques, and means of interaction with parents in inclusive education.
   - Do not show interest in or concern for interaction with parents under the conditions of the digital transformation of education.

2. At the same time, future social workers realize what pedagogical conditions their professional training depends on.

The application of the Pearson criterion in the process of the ascertaining stage of the experiment showed the following results of the level of formation of the motivational component of the readiness of future social workers to the conditions of the digital transformation of education:

- Low level of readiness of future social workers in 60.8% of students.
- Average level of readiness of future social workers in 27.0% of students.
- High level of readiness of future social workers in 12.2% of students.

The data presented indicate a low and average level of formation of the motivational component under the conditions of the digital transformation of education and underscore the need to implement an experimental system.

The next stage of the study (the ascertaining stage) was to identify the state of formation of the cognitive component of the readiness of future social workers to the conditions of the digital transformation of education in accordance with the specified criteria and indicators. For this, we developed control and test questions.

The following results of the ascertaining section were obtained:

- Low level of readiness of future social workers in 52.4% of students.
- Average low level of readiness of future social workers 34.4% of students.
- High level of readiness of future social workers 13.2% of students.

The data presented also indicate the prevalence of low and average levels of cognitive component formation among future social workers in the context of the digital transformation of education and underscore the need to implement an experimental system.

At the next stage of the ascertaining experiment, we clarified the state of formation of the activity component of readiness of future social workers to the conditions of digital transformation of education.

The following results of the ascertaining section were obtained:

- Low level of readiness of future social workers – 51.3% of students.
- Average low level of readiness of future social workers – 34.4% of students.
- High level of readiness of future social workers – 14.3% of students.

The data presented in the ascertaining section indicate the predominance of low and average levels in the formation of the activity component of readiness among future social workers in the context of the digital transformation of education and underscore the need to implement an experimental system.

The next parameter investigated in the ascertaining experiment was the speed of task completion. Methods of mathematical statistics were used at this stage.

The relative costs of training time (t*) were determined using the formula:

$$t^* = \frac{t_s}{t_{sw}}$$

t_s – time for students to complete the learning task.
t_{sw} – time of completing the educational task by future social workers involved in the experiment.

Relative costs of learning time – a value that is inverse to the coefficient of mastering the activity and is reflected in the corresponding scale.

The high cost of learning time t* is demonstrated by experimental data.

The next parameter determined in the ascertaining experiment was the number of options for methods and forms of interaction proposed by future social workers in

the conditions of digital transformation of education. The relative creativity indicator was used:

$$K_{kp}^{*} = \frac{K_s}{K_{sw}}$$

K_s – number of options for forms and methods of interaction in the context of digital transformation of education, proposed by students;
K_{sw}– number of variants of methods and forms of interaction in the conditions of digital transformation of education.

The relative creativity indicator K_{kp}^{*} according to the results of the ascertaining experiment, is at the intersection of low and average levels, in the range of 0.26–0.33, and does not meet the requirements for the readiness of future social workers to the conditions of digital transformation of education.

Table 1.
Levels (high, average, low) of readiness of future social workers to the conditions of digital transformation of education by individual components (ascertaining stage)

Level	Motivational Component, n (%)	Cognitive Component, n (%)	Activity Component, n (%)
High	23 (12.2%)	25 (13.2%)	27 (14.3%)
Average	51 (27.0%)	65 (34.4%)	65 (34.4%)
Low	115 (60.8%)	99 (52.4%)	97 (51.3%)
Total	**189 (100.0%)**	**189 (100.0%)**	**189 (100.0%)**

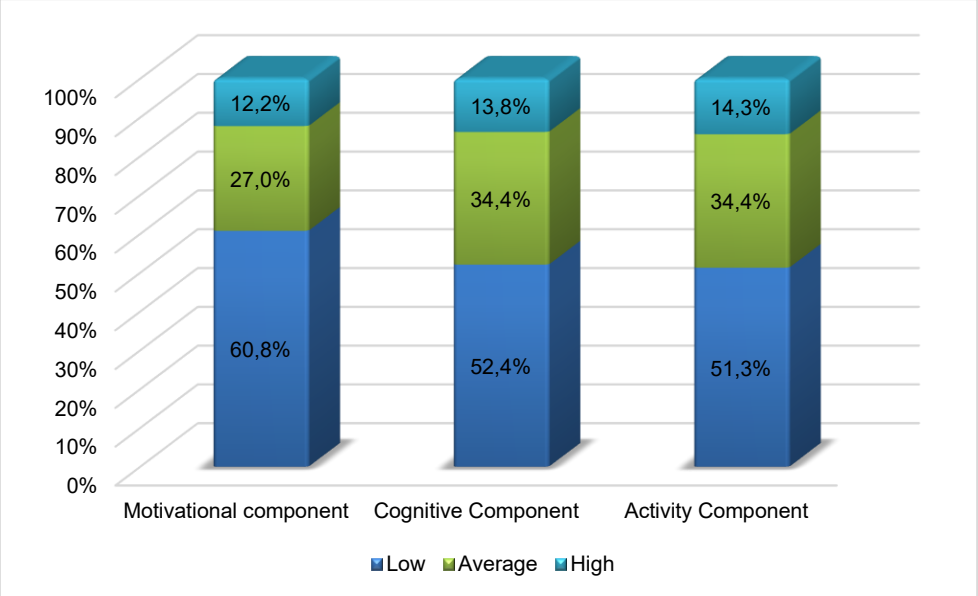


Figure 1. Levels (high, average, low) of readiness of future social workers to the conditions of digital transformation of education by individual components (ascertaining stage)

The generalization of the measurement results at the ascertaining stage of the study indicates the ineffectiveness of the traditional organization of professional training of future social workers in higher education institutions in terms of the formation of the components we are studying.

Taking into account the rapid development of the social sphere, innovative trends in the training of social workers in the context of the digital transformation of education, there is a need for a clear awareness of the possibilities of the educational digital space of higher education institutions in order to implement professional training that will allow the field of social work to integrate innovative conditions, means, and resources to ensure the innovation of education.

For these reasons, we created an innovative digital educational environment that was implemented in EG students' work. We provided a significant increase in the effectiveness of social worker training and optimal productivity for all participants in educational activities. The creation and functioning of a digitally innovative educational environment for training in higher education institutions for social workers reflected the digital and social nature. They incorporated educational innovations to improve the educational process.

In the experimental study, we consider the innovative digital educational environment of the university as a set of digital resources that actualizes innovative tools necessary for EG students in order to improve their professional activities, scientifically and methodologically support the training of future specialists, by introducing digital technologies into the educational environment, such as electronic platforms, video conferences, video lessons, document sharing, systems for tracking academic achievements, virtual laboratories, and the creation of a virtual (digital) educational.

The creation of such a digital educational environment is the primary pedagogical condition for high-quality, innovative training of future social workers.

The emergence of a special content of interaction between teachers and future social workers is defined as the second pedagogical condition for high-quality and innovative training.

The influence of the individual's continuous professional development on the creation of an innovative digital educational environment at the university and its further effective functioning is the third significant pedagogical condition that leads to a qualitative improvement in the digital educational process for training specialists. Methodological and organizational-structural improvement of the educational process and teaching, which is manifested in the university educational environment, is the fourth significant pedagogical condition introduced, alongside the previous pedagogical conditions in the educational process of the EG.

Using the innovative trends in the training of social workers in the EG, we have built an educational environment in the university space and integrated research into the process of professional training directly in the conditions of the digital transformation of education, such as:

- Formation of teaching techniques and research skills, which is focused on research (research-oriented learning).
- Involvement of students in the scientific search for innovations in teaching and research, which are based on research (research-based learning).
- Familiarization of students with the results of modern research when studying professional disciplines − research-led learning.
- Student involvement in scientific discussions, essay writing, and training is carried out under scientific guidance (research-tutored learning).

We will describe the process of training social workers in the context of the digital transformation of education and the key changes that have occurred in the organization of the educational process at EG as a result of the digitalization of the higher education environment.

- The use of digital technologies (video lessons, online platforms, electronic textbooks) provided EG students, regardless of their location, with access to educational materials.
- The formation of an educational open space for training social workers, where ideas and information were exchanged between all participants in the educational process – students, teachers, parents, allowed the exchange to take place at a fast pace and effectively.
- Digital technologies changed teaching methods and enabled the introduction of interactive teaching methods in the training of social workers (use of multimedia resources, project-based learning, collective research), which contributed to the development of critical thinking and increased involvement of EG students in the educational process.
- The development of innovative work skills enabled future social workers of the EG to critically evaluate information sources and solve research and practical tasks.
- The use of learning management systems (LMS), electronic journals, and other digital tools enabled social workers to implement technologically innovative solutions for organizing the digital educational process and to optimize educational and administrative processes.
- The use of analytical platform tools by teachers enabled continuous monitoring of teaching quality during the training of social workers, allowing timely adjustments and analysis of the effectiveness of educational practices in accordance with social workers' educational needs.

As part of our study, we will address the mechanisms of digitalization in higher education, in which the university's educational environment is perceived as a tool for influencing the personal development of social workers and for shaping a subject in the field of social work during professional activity. Therefore, such an environment was designed to support the personal growth and professional development of social workers.

Since the innovative educational digital environment is a structural component of modern higher education, we have meaningfully presented a new structure in the EG with the following characteristics:

- Openness for the dynamic growth of social and professional development of the individual in social partnership.
- To ensure the dynamism of the educational process, the presence of innovative elements is crucial.
- To ensure the effectiveness of the educational and professional process, it is important to adhere to the principles for developing an innovative digital educational environment in the 21st century.
- The presence of strategies for creating a digital educational environment that includes assessment, feedback, and appropriate educational leadership.

Focusing on the structure of the digital educational environment for training social workers, the EG believed that the conditions for its creation in higher education may be:

- The use of innovative digital technologies.
- Taking into account the trust and respect of all participants in the educational process and partnership cooperation.
- Work in a search-creative mode.
- Focusing on the development of social workers and the self-development of each individual.
- Effective use of the material, technical, scientific, methodological, and personnel capabilities of higher education.

We note that new opportunities for improving education in the university space are opened by the development of AI and machine learning, simulated pedagogical situations, automation of administrative processes; ensuring the mobility of information and communication activities of future social workers; development of virtualization and cloud computing technology (creation of virtual laboratories); development of new augmented reality functions; widespread introduction of chatbots; active use of platforms for distance learning and resources for digital literacy of the population; increasing the digital competencies of social workers (use of social networks and their teaching methods), which was introduced into the educational process of EG. Moreover, it has been shown that digitalization offers new learning opportunities, particularly through interactive platforms, distance learning formats, and electronic textbooks, thereby making the educational process more accessible and flexible.

Methodology and results of the formative stage of research and experimental work.

At the stage of experimental work, we implemented the developed system to form the professional readiness of future social workers for the conditions of digital transformation in education by developing pedagogical conditions and creating a digital educational environment at the university.

The purpose of the formative experiment is to implement the developed author's system by developing pedagogical conditions and creating a digital educational environment of the university.

The stages of our research have the following chronology:

- **The first stage** is a theoretical study of the experience of practice regarding the outlined problem: characterization of the research problem, definition of methodological tools, research bases, and analysis of scientific sources.
- **The second stage** is a research program that defines criteria, indicators, and levels of students' readiness for the conditions of digital transformation in education.
- **The third stage** is data processing of the pedagogical experiment: the development of the author's system and its testing in the process of education in higher education institutions. Conducting a formative experiment.
- **The fourth stage** is data generalization and analysis of the work carried out; justification of the identified pedagogical conditions for preparing future social workers for the digital transformation of education, through the development of pedagogical conditions and the creation of a digital educational environment at the university.

Analysis of the data from the ascertaining experiment we conducted to determine the levels of readiness of future social workers for the conditions of digital transformation of education, by developing pedagogical conditions and creating a

digital educational environment of the university, indicates that they are subject to the objective law of data distribution. Therefore, to test the study's hypothesis, we used non-parametric criteria and established parametric criteria: Pearson's criterion, Fisher's F-criterion, t-criterion, and correlation analysis.

In general, the indicators and criteria for the readiness of the described phenomenon are similar to those of the ascertaining experiment, as is the procedure for measuring them.

In order to ensure the validity and reliability of obtaining experimental data, several scientific and methodological measures were used:

1. The reliability of our study in obtaining experimental data is ensured by using standardized research methods that include strict procedures for monitoring the training of future specialists.
2. The reliability of the obtained data is ensured by equalizing the conditions for conducting experimental work on implementing pedagogical conditions and creating the university's digital educational environment.
3. The validity of the obtained data is ensured by the fact that the influencing factors in the experimental groups (EG) and control groups (CG) were the same, with the only exception being the implementation of the experimental system, pedagogical conditions, and the creation of a digital educational environment of the university.

So, at the stage of the formative experiment, according to the indicators of the level of formation of the motivational component of the readiness of future social workers of the EG to the conditions of the digital transformation of education, obtained as a result of applying the Pearson criterion (consistency criterion x^2), we can talk about positive results in the EG:

- Low level of readiness in the EG of future social workers in 5.1% of students.
- Average low level of readiness of future social workers in 16.3% of students.
- High level of readiness of future social workers in 78.6% of students.

The data presented indicate a high level of formation of the motivational component in the EG under the conditions of the digital transformation of education and demonstrate the effectiveness of the implemented experimental system.

The next stage of the study (formative stage) was to identify the state of formation of the cognitive component of the readiness of future social workers to the conditions of the digital transformation of education in accordance with the specified criteria and indicators.

The following results of the formative section were obtained:

- Low level of readiness of future social workers in 12.2% of students;
- Average level of readiness of future social workers in 19.4% of students;
- High level of readiness of future social workers in 68.4% of students.

The data presented also indicate the prevalence in the EG of a high level of formation of the cognitive component of readiness among future social workers for the conditions of digital transformation of education and demonstrate the effectiveness of the implemented experimental system.

At the next stage of the formative experiment, we clarified the state of formation of the activity component of readiness of future social workers to the conditions of digital transformation of education.

The following results of the formative section were obtained:

- Low level of readiness of future social workers in 9.2% of students.
- Average level of readiness of future social workers in 11.2% of students
- High level of readiness of future social workers 79.6% of students.

The data from the formative section indicate a high level of development of the activity component of the readiness of future social workers for the conditions of the digital transformation of education in the EG and demonstrate the effectiveness of the implemented experimental system. In the CG, we do not observe a significant increase in the effective data.

To confirm and verify the effectiveness of the experimental work carried out, the Student coefficient was applied, which was calculated by the formula:

$$t_{ct} = \frac{D}{\sqrt{\frac{p_1 q_1}{n_1} + \frac{p_2 q_2}{n_2}}}$$

D – absolute value of the difference in % between the share of future specialists in the CG and EG;

- p_1, q_1, n_1 – data received in CG.
- p_2, q_2, n_2 – data obtained from EG
- p – the part of students who demonstrate well the level of readiness for the specified phenomenon
- n – absolute number of future specialists.

$$q = 100 - p$$

$$t_{ct} = \frac{D}{\sqrt{\frac{p_1 q_1}{n_1} + \frac{p_2 q_2}{n_2}}} = \frac{D}{\sqrt{\frac{p_1 (100 - p_1)}{n_1} + \frac{p_2 (100 - p_2)}{n_2}}}$$

At the same time, we speak of a positive effect of the experiment when $t_{ct} > 2$.
Through the indicators of readiness components, the Processing of experimental data of future specialists was carried out.

Independent-samples t-tests additionally confirmed statistically significant differences between the experimental and control groups after the intervention ($p < .05$). These results provide further evidence that the implemented pedagogical system produced measurable improvements in students' professional readiness.

In order to analyze the general level of readiness of future specialists in the experimental and control groups, as well as to integrate the indicators of the motivational, cognitive, and activity components, the following quantitative indicators were determined by the formula "averaged relative":

$$P = \frac{n_k + n_e + n_p}{3}$$

– P – averaged in % relative indicator reflecting the number of students with the same level of formation of all readiness components.
– n – number of students at a certain level.

We calculated the "average relative" for the experimental and control groups based on the indicators of the components of students' readiness.

The indicators of the formation of all components of students' readiness based on the results of the formative experiment are shown in Table 2 and Figure 2.

Table 2.
Indicators of the formation of the components of the readiness of future social workers to the conditions of the digital transformation of education (formative experiment)

Level	Motivational Component CG, n (%)	Cognitive Component CG, n (%)	Activity Component CG, n (%)	Motivational Component EG, n (%)	Cognitive Component EG, n (%)	Activity Component EG, n (%)
High	11 (12.1%)	12 (13.2%)	13 (14.3%)	77 (78.6%)	67 (68.4%)	78 (79.6%)
Average	24 (26.4%)	31 (34.1%)	31 (34.1%)	16 (16.3%)	19 (19.4%)	11 (11.2%)
Low	56 (61.5%)	48 (52.7%)	47 (51.6%)	5 (5.1%)	12 (12.2%)	9 (9.2%)
Total	**91 (100.0%)**	**91 (100.0%)**	**91 (100.0%)**	**98 (100.0%)**	**98 (100.0%)**	**98 (100.0%)**

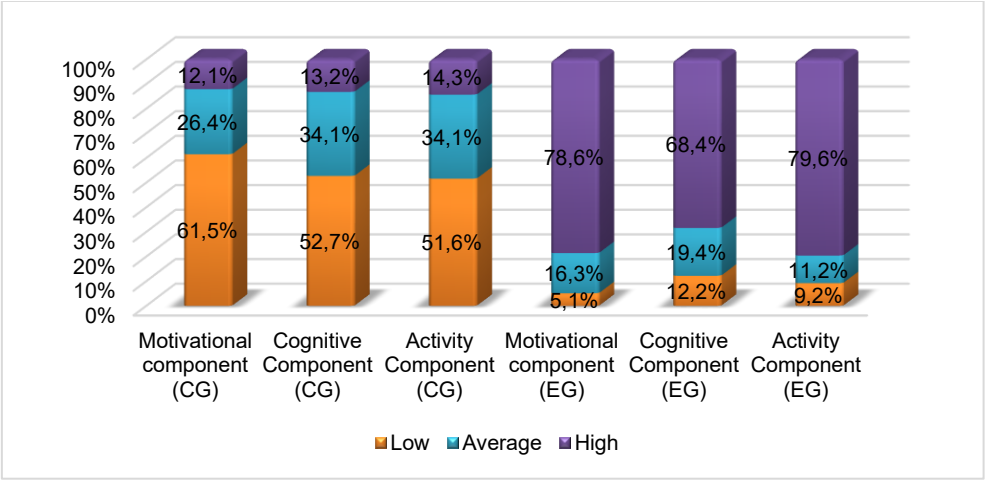


Figure 2. Indicators of the formation of the components of the readiness of future social workers to the conditions of the digital transformation of education (formative experiment)

Pearson's chi-square analysis confirmed statistically significant differences between the experimental and control groups after the intervention across all three readiness components. For the motivational component, the association between group membership and readiness level was statistically significant, $\chi^2(2) = 82.41$, $p < .001$, Cramer's V = .66, indicating a strong effect. Similar results were obtained for the cognitive component, $\chi^2(2) = 57.84$, $p < .001$, Cramer's V = .55, and for the activity component, $\chi^2(2) = 84.93$, $p < .001$, Cramer's V = .67, demonstrating substantial improvements in the experimental group compared with the control group.

These findings indicate that the observed improvements are unlikely to be attributable to chance. The large effect sizes suggest that the implemented pedagogical system exerted a substantial influence on students' professional

readiness for digital transformation across motivational, cognitive, and activity dimensions.

The results of the formative stage show that students' readiness for the outlined phenomenon across all components in the control group is at a low-to-average level.

In contrast, the experimental group is at a high level.

Methods of mathematical statistics were used to process empirical data: Pearson's criterion, Student's t-criterion, and Fisher's F-criterion.

The results of the study prove that before the ascertaining cut, students in the control and experimental groups were at approximately the same level of outlined readiness; after conducting experimental work in the experimental group, we see higher results, and we conclude that the level of students significantly increases when implementing an experimental system for forming the professional readiness of future social workers for the conditions of digital transformation of education, by developing pedagogical conditions and creating a digital educational environment of the university.

The findings of this study demonstrate that the implementation of a comprehensive pedagogical system integrating targeted pedagogical conditions with a university digital educational environment significantly improved the professional readiness of future social workers for the digital transformation of education. The most substantial improvements were observed in the motivational, cognitive, and activity components of readiness within the experimental group, whereas only minimal changes occurred in the control group. These findings indicate that systematic pedagogical support, rather than exposure to digital technologies alone, is essential for preparing future professionals to work effectively in digitally transformed educational environments.

The present results are consistent with previous studies emphasizing that digital competence cannot be developed solely through students' everyday use of technology. López Peláez et al. (2020) reported that a considerable gap exists between the digital competencies required in professional social work and those possessed by university students and practicing specialists. Similarly, Gómez-Poyato et al. (2022) concluded that being a "digital native" does not automatically ensure readiness to apply digital technologies in professional contexts. The significant improvements observed in the experimental group support these conclusions and demonstrate that structured pedagogical interventions can effectively reduce this competence gap.

The positive changes identified in the cognitive component also correspond with the findings of Kamrujjaman et al. (2023), who argued that professional readiness develops through the integration of theoretical knowledge, practical experience, and evidence-based educational practices. In the present study, combining digital educational resources with collaborative learning, research-oriented activities, and authentic professional tasks enabled students to apply theoretical knowledge in realistic educational situations, thereby strengthening both conceptual understanding and practical competence.

The results additionally support the conclusions of Winardy and Septiana (2023), who demonstrated the educational value of interactive and practice-oriented learning methods. However, unlike previous studies that primarily examined isolated instructional approaches such as role-playing or educational games, the current research evaluated a comprehensive pedagogical system that integrated multiple

digital learning strategies within a unified educational environment. This integrated approach may explain the larger improvements observed across all components of professional readiness.

At the same time, the present findings extend previous research by demonstrating that the effectiveness of digital transformation depends not only on technological resources but also on organizational and pedagogical conditions. While Joiner (2019) highlighted the importance of digital ethics and responsible technology use, and Lichtenberger-Majzikné and Fischer (2017) emphasized reflective practice and feedback, the current study suggests that these elements become substantially more effective when embedded within a coherent institutional digital learning environment supported by active pedagogical guidance. Consequently, the findings broaden existing theoretical perspectives by conceptualizing professional readiness as a multidimensional construct influenced simultaneously by technological, pedagogical, motivational, and organizational factors.

Some differences between the present findings and previous studies should also be acknowledged. Many earlier investigations relied primarily on descriptive or cross-sectional survey designs that identified deficiencies in students' digital competencies but did not experimentally evaluate interventions aimed at overcoming these deficiencies. In contrast, the quasi-experimental design employed in the present study enabled direct evaluation of the effectiveness of a structured pedagogical intervention, providing stronger empirical evidence regarding causal relationships between educational practices and improvements in professional readiness.

From a theoretical perspective, this study contributes to the growing body of literature on digital transformation in higher education by providing empirical support for an integrated model of professional readiness that combines motivational, cognitive, and activity dimensions. The findings reinforce competency-based approaches to professional education while extending current theoretical understanding of how institutional digital environments interact with pedagogical conditions to facilitate competence development.

The practical implications of the study are equally significant. The proposed pedagogical system may serve as a methodological framework for higher education institutions seeking to modernize social work programmes in response to ongoing digital transformation. The integration of digital educational environments, collaborative learning, research-oriented instruction, and innovative digital technologies may enhance students' professional readiness while supporting curriculum modernization, faculty development, and institutional digitalization strategies. These findings may also inform educational policy and curriculum design aimed at strengthening the digital competencies of future social workers.

Despite the positive findings, several limitations should be acknowledged. The study was conducted within higher education institutions in one national context, which may limit the generalizability of the results to other educational systems. In addition, the intervention evaluated short-term educational outcomes, whereas future longitudinal studies are needed to examine the sustainability of professional readiness over time and its impact on graduates' professional performance. Future research may also compare different digital pedagogical models, investigate the contribution of artificial intelligence and immersive technologies, and validate the proposed framework across broader educational contexts.

Conclusions

This study contributes to the growing body of research on the digital transformation of higher education by providing empirical evidence that a comprehensive pedagogical system integrating targeted pedagogical conditions with a university digital educational environment can significantly enhance the professional readiness of future social workers. Unlike previous studies that primarily described the importance of digital competence, the present research experimentally validated an integrated educational model that simultaneously developed the motivational, cognitive, and activity components of professional readiness.

The findings extend existing theoretical understanding by conceptualizing professional readiness as a multidimensional construct shaped by the interaction of pedagogical, technological, and organizational factors. The study demonstrates that digital technologies become educationally effective when implemented within a coherent pedagogical framework that promotes active learning, collaboration, professional reflection, and continuous competence development.

From a practical perspective, the proposed pedagogical system provides a methodological framework that may be adopted by higher education institutions seeking to modernize social work education in response to digital transformation. The integration of digital educational environments, collaborative learning strategies, research-oriented instruction, and innovative educational technologies may support curriculum development, improve students' digital competencies, and strengthen graduates' preparedness for professional practice in increasingly technology-mediated educational and social contexts.

Despite these contributions, several limitations should be acknowledged. First, the study was conducted within higher education institutions in Ukraine, which may limit the generalizability of the findings to other educational systems and socio-cultural contexts. Second, the quasi-experimental design evaluated the short-term effectiveness of the pedagogical intervention and did not examine the long-term sustainability of the acquired competencies after graduation. Third, the study focused primarily on overall professional readiness and did not separately investigate the contribution of individual digital technologies or instructional strategies to specific learning outcomes.

Future research should therefore investigate the long-term impact of digital pedagogical interventions through longitudinal research designs, compare alternative models of digital professional training across different higher education institutions and countries, and explore the educational potential of emerging technologies such as artificial intelligence, immersive virtual environments, and learning analytics in preparing future social workers. Further validation of the proposed pedagogical framework in broader educational contexts would strengthen its applicability and contribute to the development of evidence-based strategies for digital transformation in higher education.

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Original Article

Tecnologías digitales en la educación universitaria: Mejora de la competencia digital y la cultura digital de los estudiantes

Digital technologies in university education: Enhancing students' digital competence and digital culture

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Resumen

La transformación digital de la educación superior requiere enfoques eficaces para desarrollar la competencia y la cultura digital del alumnado. El objetivo de este estudio fue evaluar la eficacia de un modelo pedagógico integrado, basado en tecnologías digitales contemporáneas y condiciones pedagógicas específicas, para el desarrollo de la competencia digital y la cultura digital de los estudiantes universitarios. Se empleó un diseño cuasiexperimental de métodos mixtos, que combinó métodos teóricos, empíricos y estadísticos. El estudio incluyó a 184 estudiantes universitarios, asignados equitativamente a un grupo experimental (n = 92) y a un grupo de control (n = 92). La intervención incluyó un curso especialmente diseñado sobre realidad aumentada, tecnologías en la nube, inteligencia artificial, gamificación, Google Glass y laboratorios virtuales, apoyado por un entorno de aprendizaje digital adaptativo, aprendizaje autodirigido guiado digitalmente y monitorización digital de las actividades educativas del alumnado. La cultura digital del alumnado se evaluó mediante criterios motivacionales, de contenido e información, y de actividad, antes y después de la intervención. Tras la implementación del modelo pedagógico, la proporción de estudiantes que alcanzaron un alto nivel aumentó en el grupo experimental del 3,3% al 55,4% en el criterio motivacional, del 5,4% al 57,6% en el criterio de contenido-información y del 5,4% al 56,5% en el criterio de actividad, mientras que las mejoras en el grupo de control fueron sustancialmente menores (19,6%, 13,0% y 26,1%, respectivamente). La prueba χ^2 de Pearson confirmó diferencias estadísticamente significativas entre los grupos después de la intervención. El estudio aporta un modelo pedagógico validado empíricamente que demuestra que la integración de tecnologías digitales innovadoras con apoyo didáctico específico mejora eficazmente la competencia digital y la cultura digital de los estudiantes en la educación superior.

Palabras clave: tecnologías digitales; educación universitaria; formación de estudiantes; alfabetización digital; cultura digital.

Abstract

The digital transformation of higher education requires effective approaches to developing students' digital competence and digital culture. This study aimed was to evaluate the effectiveness of an integrated pedagogical model based on contemporary digital technologies and targeted pedagogical conditions for developing university students' digital competence and digital culture. A mixed-methods quasi-experimental design was employed, combining theoretical, empirical, and statistical methods. The study involved 184 university students, equally assigned to an experimental group (n = 92) and a control group (n = 92). The intervention included a specially designed course on augmented reality, cloud technologies, artificial intelligence, gamification, Google Glass, and virtual laboratories, supported by an adaptive digital learning environment, digitally guided self-directed learning, and digital monitoring of students' educational activities. Students' digital culture was assessed using motivational, content-information, and activity criteria before and

after the intervention. Following the implementation of the pedagogical model, the proportion of students achieving a high level increased in the experimental group from 3.3% to 55.4% for the motivational criterion, from 5.4% to 57.6% for the content-information criterion, and from 5.4% to 56.5% for the activity criterion, whereas improvements in the control group were substantially smaller (19.6%, 13.0%, and 26.1%, respectively). Pearson's χ^2 test confirmed statistically significant differences between the groups after the intervention. The study contributes an empirically validated pedagogical model demonstrating that integrating innovative digital technologies with targeted instructional support effectively enhances students' digital competence and digital culture in higher education.

Keywords: digital technologies; university education; student training; digital literacy; digital culture.

Introduction

The digital transformation of higher education has fundamentally changed the requirements for graduates' professional competencies. Universities are expected not only to integrate digital technologies into teaching but also to foster students' digital competence and digital culture, which are essential for effective learning, professional collaboration, and lifelong development. Consequently, identifying effective pedagogical approaches that support the systematic development of these competencies has become a priority for educational research.

Recent studies have demonstrated the educational potential of artificial intelligence, cloud computing, virtual and augmented reality, gamification, and learning management systems in improving student engagement and learning outcomes. However, most existing research investigates these technologies separately or focuses primarily on technological implementation rather than on their pedagogically integrated application. Moreover, relatively little empirical evidence is available regarding comprehensive pedagogical models that combine multiple digital technologies with specific instructional conditions and evaluate their effectiveness in developing students' digital competence and digital culture using controlled experimental designs. This methodological gap limits the generalizability of existing findings and the development of evidence-based recommendations for higher education institutions.

To address this gap, the present study evaluates the effectiveness of an integrated pedagogical model that combines innovative digital technologies with targeted pedagogical conditions to enhance university students' digital competence and digital culture. The study employs a mixed-methods quasi-experimental design to determine whether the proposed approach produces statistically significant improvements compared with traditional instructional practices. By providing empirical evidence for the effectiveness of this integrated model, the research contributes to the advancement of digitally transformed higher education and offers practical guidance for curriculum design and instructional innovation.

Literature Review

Existing studies consistently demonstrate that digital technologies improve learning engagement, accessibility, and educational outcomes. Digital communication platforms and social media facilitate knowledge exchange and professional networking, allowing students to access current disciplinary developments and participate in collaborative learning communities (Dietrich et al., 2020). Similarly, online learning environments, webinars, and distance education expand educational accessibility and support flexible learning pathways, particularly in international

higher education contexts (Lytras et al., 2022). Virtual and augmented reality further strengthen experiential learning by enabling authentic simulations and multimodal instruction that improve conceptual understanding and practical skill acquisition (Philippe et al., 2020; Taherdoost & Madanchian, 2022).

Recent studies have shifted attention from individual digital tools toward integrated digital ecosystems. Smart educational environments supported by artificial intelligence, the Internet of Things, cloud computing, and big-data technologies improve institutional management, personalize learning, and optimize educational decision-making (García Camargo et al., 2025; Sherman et al., 2022). Likewise, mobile applications, simulation technologies, virtual laboratories, and remote monitoring systems create authentic learning experiences that facilitate professional skill development while reducing the gap between academic preparation and workplace requirements (Gómez-García et al., 2023; Jaramillo-Arévalo et al., 2023; Novoa-Echaurren et al., 2025). Cloud-based learning environments further enhance access to educational resources and support collaborative learning regardless of time and location constraints (Núñez-Solís et al., 2026; Rioseco-Pais et al., 2024; Sangrà et al., 2023).

Another important research direction concerns the application of artificial intelligence and gamification in higher education. AI-driven systems enable adaptive learning, automated assessment, and personalized instructional support, whereas gamification enhances students' motivation, engagement, and active participation in learning activities (Graham et al., 2023; Thomason, 2021). Similarly, augmented reality, Google Glass, and virtual laboratories provide immersive educational experiences that improve visualization, experimentation, and practical problem-solving (Palshkov et al., 2026; Pegalajar Palomino & Rodríguez Torres, 2023).

Despite these advances, previous studies reveal several important methodological and conceptual limitations. Most investigations evaluate individual digital technologies independently rather than examining their combined pedagogical implementation. Consequently, little empirical evidence exists regarding comprehensive instructional models integrating multiple digital technologies within a coherent pedagogical framework. Furthermore, research primarily evaluates technological effectiveness, whereas comparatively less attention has been devoted to understanding how integrated digital environments influence the simultaneous development of students' digital competence and digital culture through controlled experimental studies.

An additional limitation concerns the inconsistent use of key conceptual terms. Although the concepts of digital literacy, digital competence, and digital culture are frequently used interchangeably, they represent different levels of digital development. Digital literacy refers to the basic ability to locate, access, understand, and use digital information and technologies effectively. Digital competence extends beyond operational skills and encompasses the knowledge, critical thinking, ethical awareness, communication, problem-solving, and responsible use of digital technologies in academic and professional contexts. Digital culture represents the broadest construct, integrating digital competence with values, digital citizenship, collaboration, creativity, responsible online participation, and continuous adaptation to technological change. Thus, digital literacy constitutes the technological foundation of digital competence, whereas digital competence serves as the core component of digital culture.

The analysis of previous research indicates an emerging trend toward holistic digital transformation of higher education; however, a significant research gap remains

regarding empirically validated pedagogical models that integrate contemporary digital technologies with targeted instructional conditions to develop students' digital competence and digital culture simultaneously. Addressing this gap, the present study proposes and experimentally validates an integrated pedagogical model combining augmented reality, cloud technologies, artificial intelligence, gamification, Google Glass, and virtual laboratories within a structured educational framework. By evaluating this model through a quasi-experimental design, the study contributes new empirical evidence supporting the effective development of students' digital competence and digital culture in higher education.

The aim of this study was to evaluate the effectiveness of an integrated pedagogical model based on contemporary digital technologies and targeted pedagogical conditions for developing university students' digital competence and digital culture.

Methodology

Research Design

The study employed a mixed-methods quasi-experimental design combining theoretical, empirical, and statistical approaches to evaluate the effectiveness of a system of pedagogical conditions for integrating digital technologies into the university educational process. The experimental research was conducted from 2023 to 2025 and consisted of four consecutive stages: analytical, diagnostic, formative, and analytical-generalizing.

Participants and Sampling

The study involved 184 undergraduate students enrolled in teacher education and related educational programmes at Ukrainian higher education institutions during the 2023–2025 academic years. Participants were selected using purposive sampling, as they were required to be enrolled in programmes where digital technologies constituted an integral component of professional training. The inclusion criteria were: (a) enrolment in the second to fourth year of study; (b) regular attendance of academic courses; (c) willingness to participate voluntarily; and (d) completion of both the pre-test and post-test assessments. Students who failed to complete the intervention or submitted incomplete assessment materials were excluded from the final analysis.

The participants were assigned to an experimental group (EG, n = 92) and a control group (CG, n = 92). Prior to the intervention, the equivalence of both groups regarding the initial level of digital competence and digital culture was confirmed using Pearson's χ^2 test, indicating no statistically significant baseline differences.

Research Methods

The study employed general theoretical methods, including the analysis, synthesis, comparison, and generalization of psychological-pedagogical, socio-philosophical, scientific, and methodological literature. Empirical methods included pedagogical observation, interviews, questionnaires, and pedagogical experimentation. Qualitative and quantitative analyses of students' learning outcomes were conducted to evaluate the effectiveness of implementing digital technologies and the proposed pedagogical conditions within the university educational process.

Procedure

The research was carried out in four stages.

Stage 1 – Analytical. The current state of digital technology implementation in higher education was examined. Educational programmes and course content were analysed, and professionally oriented learning activities were designed to support digital transformation.

Stage 2 – Diagnostic. The initial level of students' digital culture was assessed through observations and diagnostic procedures. Evaluation criteria, indicators, and levels of digital culture formation were established. The results demonstrated a predominance of the initial level in both the experimental and control groups.

Stage 3 – Formative. The experimental group studied the specially developed course *"The Role of Augmented Reality (AR), Cloud Technologies, Artificial Intelligence (AI), Gamification, Google Glass, and Virtual Laboratories in Education and Professional Activities."* During this stage, the developed pedagogical conditions were implemented, contemporary digital technologies were integrated into the educational process, and a digital educational environment was created to enhance students' digital literacy, competence, and culture.

Stage 4 – Analytical and Generalizing. The empirical data collected during the experiment were processed, compared, and interpreted to evaluate the effectiveness of the implemented pedagogical conditions and digital technologies.

Data Collection Instruments

Data were collected using a combination of complementary instruments designed to assess students' digital competence and digital culture from multiple perspectives.

The principal instrument was a structured questionnaire comprising 36 items, organised into three dimensions corresponding to the assessment framework: motivational (12 items), content-information (12 items), and activity (12 items). Responses were recorded using a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Higher scores indicated higher levels of digital competence and digital culture.

To complement the questionnaire data, structured pedagogical observation was conducted throughout the intervention using standardized observation protocols assessing students' engagement, collaboration, autonomous learning, and effective application of digital technologies during classroom and project activities. Semi-structured interviews with instructors were additionally used to triangulate the quantitative findings and obtain qualitative evidence regarding students' progress.

The questionnaire underwent content validation by a panel of five experts in educational technology and higher education pedagogy. Based on their recommendations, several items were linguistically refined to improve clarity and construct alignment. Prior to the main study, the instrument was piloted with 30 students who did not participate in the principal experiment. Internal consistency demonstrated satisfactory reliability (Cronbach's $\alpha = 0.89$ for the overall scale), while reliability coefficients for the three dimensions ranged from 0.84 to 0.91, indicating high internal consistency.

Ethical Considerations

The research was conducted in accordance with internationally accepted ethical principles for educational research. Participation was entirely voluntary, and all students provided written informed consent before data collection. Participants were informed about the purpose of the study, confidentiality procedures, the anonymous processing of research data, and their right to withdraw from the study at any stage without academic consequences.

Results and Discussion

Organization and method of conducting a pedagogical experiment.

During the pilot survey, based on quantitative and qualitative analyses of the research results, a program of experimental work was developed to assess the effectiveness of the system's creation and the pedagogical conditions for the introduction of digital technologies into the university's educational process for the high-quality training of specialists.

Research and experimental work was carried out in 2023 – 2025. 184 students participated in the study.

The first stage of research and experimental work is analytical, focusing on the main problems in implementing digital technologies, designing the content of disciplines across all training cycles, and planning professionally oriented work with students.

The second stage is diagnostic, as the observation was carried out to evaluate the ways of introducing digital technologies and to determine, in the students' activities, the indicators of the formation of digital culture across all criteria.

The third stage of research and experimental work – was defined as a formative stage – the study of additional elements of the content of digitalization of education was introduced into the content of the educational process, the study by EG students of the special course "The role of augmented reality (AR), cloud technologies, artificial intelligence (AI), gamification, Google Glass glasses, virtual laboratories in education and professional activity" was organized and the implementation of the developed pedagogical conditions. As a result, a digital environment for the university was created, and awareness of digital values was raised by including students in organized educational and professional activities across various forms of digitalization.

The fourth stage – analytical and generalizing allows for the generalization of all empirical data, making an interpretation of the experiment and description, and formulating conclusions of the results of research and experimental work.

To achieve the goal of the experimental work – implementation of the system and pedagogical conditions of the outlined problem in the monitoring mode, the evaluation parameters are selected for the phenomenon under study – the criteria, indicators, and levels of manifestation of the formation of the digital culture of students are outlined.

We will describe the criteria and their indicators and show the results obtained at the **ascertainment stage of the experiment** for each criterion.

Motivational criterion.

Indicators – the presence of a stable internal motivation for the digitalization of education and the professional development of students' digital culture; awareness of the need in the professional field for continuous education of each individual; the ability to critically assess one's own achievements and engage in self-reflection.

Table 1.
The results of identifying the indicators of the formation of the digital culture of students according to the motivational criterion in the respondents of EG and CG (ascertaining experiment)

Groups	Initial, n (%)	Basic, n (%)	High, n (%)
Experimental	54 (58.7%)	35 (38.0%)	3 (3.3%)
Control	54 (58.7%)	35 (38.0%)	3 (3.3%)

Source: developed by the authors

We see a clear predominance of the initial level among EG and CG students.

Content-information criterion.

Indicators: depth and scope of knowledge in the professional field, mastery of modern digital technologies for education and professional activity, ability to independently analyze professional literature, methods and techniques for forming digital culture;

Table 2.
Results of identifying indicators of the formation of students' digital culture among EG and CG respondents according to the content-information criterion (ascertaining experiment)

Groups	Initial, n (%)	Basic, n (%)	High, n (%)
Experimental	47 (51.1%)	40 (43.5%)	5 (5.4%)
Control	47 (51.1%)	40 (43.5%)	5 (5.4%)

Source: developed by the authors

We see a clear predominance of elementary-level students of EG and CG.

Activity criterion.

Indicators: the ability to independently search for and process information, evaluate it critically, the ability to organize one's own process of educational and professional activity (time management, planning, self-control), and using various digital technologies and teaching methods.

Table 3.
The results of identifying the indicators of the formation of the digital culture of students in the respondents of the EG and CG according to the activity criterion (ascertaining experiment)

Groups	Initial, n (%)	Basic, n (%)	High, n (%)
Experimental	54 (58.7%)	33 (35.9%)	5 (5.4%)
Control	53 (57.6%)	34 (37.0%)	5 (5.4%)

Source: developed by the authors

We see a clear predominance of the initial level among EG and CG students at the ascertaining stage of the study.

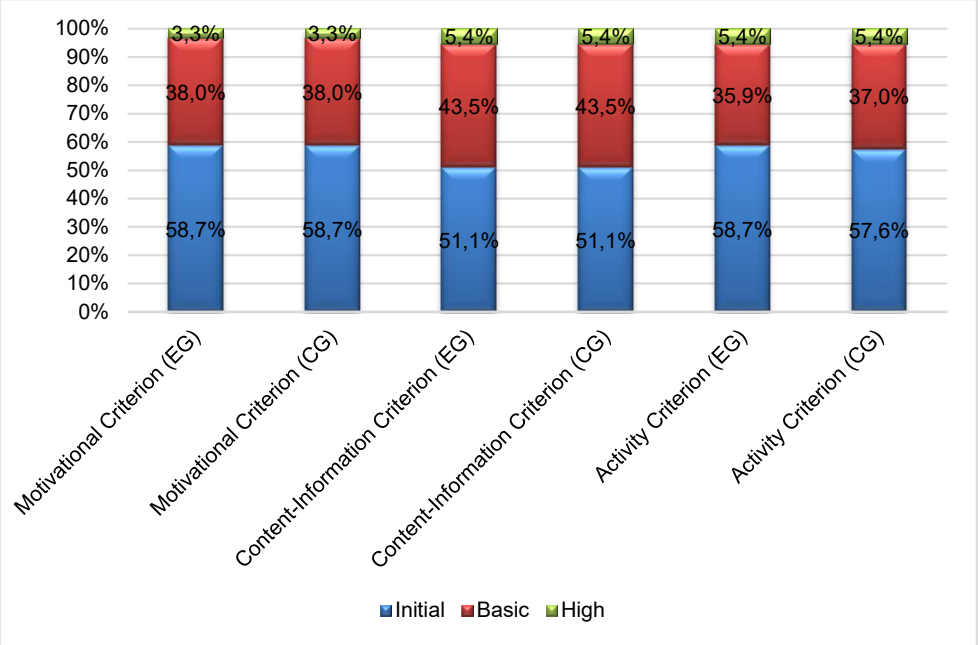


Figure 1. Comparison of the Indicators of Students' Digital Culture Formation by Motivational, Content-Information, and Activity Criteria in the EG and CG (Ascertaining Experiment)

Before tracing the formation of digital culture at the formative stage of the research and experimental work among EG and CG respondents and the effectiveness of the pedagogical conditions for the formation of digital culture, let's check whether the selected EG and CG with the indicated levels of formation of the outlined phenomenon and distributions at the ascertaining stage of the experimental work can be analyzed as identical in composition and do not have truly statistically significant differences.

We use the Pearson χ^2 criterion. It's χ^2_{emp} by the formula:

$$\chi^2_{emp} = N \cdot M \cdot \sum_{i=1}^{L} \frac{\left(\frac{n_i}{N} - \frac{m_i}{M}\right)^2}{n_i + m_i}$$

where N and M are the number of future specialists of the CG and EG who have the i-th level of formation of the digital culture of the future specialist among the respondents of the CG and EG at the ascertaining stage of the research work;

L is the number of levels.

The criterion made it possible to prove the validity of the null hypothesis H_0 Pearson χ^2 – about the reliability of the coincidence of the formation of the digital culture of the future specialist at the ascertaining stage in the respondents of the EG and CG during the experimental research work.

Let's characterize the hypotheses:

H_0 – is the same distribution of future specialists by the levels of formation of the digital culture of the future paramedic in the CG and EG. If in CG and EG $\chi^2_{emp} < \chi^2_{crit}$, then the hypothesis H_0 will be considered proven.

H_1 – there is an unequal level of formation of the digital culture of the future specialist in the CG and EG.

At the ascertaining stage of the experimental work we will find χ^2_{emp} for CG and EG, for the levels of formation of the digital culture of the future specialist in CG and EG.

Let's find χ^2_{crit} for level $\alpha = 0.05$ and the number of degrees of freedom $v = 3 - 1 = 2$

Found $\chi^2_{crit(\alpha=0.05)} = 5.991$
Let's compare χ^2_{crit} with χ^2_{emp}
We see, that $\chi^2_{emp} < \chi^2_{crit}$

We conclude that the future specialists who participated in the experiment in the EG and CG are qualitatively the same.

Results of experimental work on the formation of the digital culture of future specialists in the process of professional training (formative stage). Having received at the ascertaining stage of the study a clear predominance of the initial level among EG and CG students, to qualitatively train specialists in the EG educational process at the formative stage of the study, we introduced developed pedagogical conditions, a special course, and digital technologies that created an innovative system for the development of digital literacy and competence among students:

- Reflection of the dynamics of development during the training of digital competencies.
- Visualization of the relationship between competency levels and educational components using automated software
- Implementation of specific examples of digital competencies in the university space, which makes training more accessible and interesting.
- Placement of methods for developing competencies in digital literacy among students.
- General characteristics of profile software.

In addition to the above-mentioned study, EG students were offered a special course “The role of augmented reality (AR) technology, cloud technologies, artificial intelligence (AI), gamification, Google Glass, virtual laboratories in education and professional activities”.

EG students mastered practical skills using interactive case-study technology in training mode. Students were offered:

- Study the impact of various educational technologies (for example, virtual reality and simulation learning) on the effectiveness of developing digital competencies in future specialists.
- Development of interdisciplinary training modules that integrate digital technologies into professional disciplines, with the aim of in-depth formation of digital professional skills.

- Study of specialists' expectations and needs regarding students' digital competence, and comparison with the results of studies at universities.
- Analysis of international experience in the professional field of preparing students to work in a digital environment.
- Studying the psychological aspects of introducing digital technologies into the university's educational process and their impact on students' motivation and interest in their chosen major.
- Developing and testing specific professional methods for assessing students' digital competence at different stages of study.

In the higher education process, EG students used a variety of software products, tools, and online platforms. The most popular were the following:

- Platforms for exchanging documents and creating them (Microsoft 365 cloud computing platform) and tools for exchanging and storing data and working together.
- Educational activity management systems that allow students to create tasks and tests, online courses, provide reports, and track progress (Moodle system – open-source software).
- Platforms for conferences and video communication (Zoom and Skype).
- Programs for team collaboration and communication with messaging capabilities, video conferencing, virtual "whiteboards", etc. (Google Classroom, Kahoot, Google Forms, Classtime, Microsoft Teams, which can be used as a standalone product and integrated into Microsoft 365).
- Educational and training resources currently available on the Internet; learning management systems and online platforms for effective interaction between students and teachers, 24-hour access to educational material in asynchronous and synchronous modes, monitoring, effective control and assessment of student knowledge.

Teachers in the EG actively used webinars and virtual lectures, developed their own educational modules and interactive online courses.

In the innovative system created for training EG students, pedagogical conditions for developing digital literacy among students were developed and implemented.

Condition 1. Open adaptive information environment of the university, integrated for personalized learning with digital resources and platforms.

For the high-quality training of future specialists and the development of their digital literacy and competence, it is necessary to create an educational environment that ensures constant access to diverse, high-quality sources of professional information and promotes the development of individual students' educational trajectories.

In the context of such a pedagogical condition, we considered an open, adaptive educational environment as an integrated, flexible system of resources and services necessary to adapt to the educational needs of each future specialist and to support each student's independent cognitive activity.

The adaptability of the university's information environment suggests that it is not static but responds to students' individual characteristics and requests: the pace of material assimilation, the level of training, and the need for additional resources. This approach is achieved through systems (automated progress-monitoring

systems, learning platforms with adaptive algorithms) that personalize the educational process.

The openness of the environment supports the principle of continuity of learning. It provides students with access to a range of external and internal resources, including scientific databases, professional online communities, digital libraries, and open educational courses.

Condition 2. Management of students' self-educational activities based on digital support. In the modern educational environment, students' self-educational activities cannot be effective without professional pedagogical support. Competent guidance provides the student with a gradual transition from external motivation to educational autonomy, to responsibility for their own development and self-reflection; it provides tutoring support, where the teacher performs the function of a coordinator: supports regular self-assessment, does not suppress the student's initiative, helps to plan, analyze, determine individual learning goals, and contributes to the correction of the educational trajectory.

Students' self-educational activities were implemented in the EG through video lectures, interactive platforms for accessing educational content, scientific articles, electronic textbooks, and professional protocols. The use of mobile applications and online testing allowed students to choose the pace of material processing, plan their own learning trajectory, and regularly assess their knowledge. Of particular value to EG students were personalized learning services, through which they could adapt their educational path based on their level of training and individual needs.

Collective self-educational activities have enhanced students' interaction and teamwork skills in a professional environment. In particular, this includes students' participation in online discussions, joint educational projects, virtual field excursions, and webinars, which contributed to the exchange of experience, the development of critical thinking, and the collective solution of the tasks set. Digital communication platforms (Google Workspace, Microsoft Teams, Zoom) have provided students with convenient ways to interact and to create an environment for professional, continuous communication.

Condition 3. Digital monitoring of students' educational activity. Modern digital technologies open up new opportunities for personalized support of students' educational and professional activities. The use of platforms for educational analytics, individual planning tools, electronic diaries, and artificial intelligence tools has significantly increased the effectiveness of tutoring support for students.

The introduction of automated monitoring systems made it possible to analyze students' behavioral parameters and record progress in mastering professional knowledge, including activity in educational modules, compliance with task deadlines, regularity of system logins, and participation in group discussions and forums. Such systems used educational analytics tools to collect and interpret data to form a holistic view of each student's dynamics in the educational process. Personalized feedback was a key element of such a system, which was based on established criteria for assessing the development of digital competence, not only the level of professional knowledge. This allowed each student to receive specific recommendations to eliminate the identified gaps in skills and knowledge and improve their own educational strategy. Integration of digital tools with educational communities for high-quality training of specialists turns the process of forming students' digital competence into a multi-vector one: the student actively participates in the creation and dissemination of knowledge and does not consume information

in isolation, learning in a circle of like-minded people. This format of student interaction develops digital competence, social responsibility, academic competencies, the ability for professional mobility, and partnership cooperation.

The inclusion of students in creative, reflective digital activities in the implementation of the formative stage of experimental research using digital methods, developed pedagogical conditions, a special course, digital technologies that created an innovative system for the development of digital literacy and competence among students allowed us to observe positive manifestations of indicators of the formation of digital culture in the educational and professional activities of EG respondents. In CG, we observe minor positive changes.

Let us present the results of the **formative stage of the study**.

Motivational criterion.

Indicators – the presence of stable internal motivation for the digitalization of learning and the professional development of students' digital culture; awareness of the need for continuous learning in the professional sphere of each individual; the ability to critically assess one's own achievements and engage in self-reflection.

Table 4.
Results of identifying indicators of students' digital culture formation among EG and CG respondents by motivational criterion (formative experiment)

Groups	Initial, n (%)	Basic, n (%)	High, n (%)
Experimental	5 (5.4%)	36 (39.1%)	51 (55.4%)
Control	29 (31.5%)	45 (48.9%)	18 (19.6%)

Source: developed by the authors

We see a clear predominance of high levels among EG students and a significant decrease in the initial level in EG. In the control groups, we observe no significant changes compared to EG.

Content-information criterion.

Indicators: depth and scope of knowledge in the professional field, mastery of modern digital technologies for education and professional activity, ability to independently analyze professional literature, methods and techniques for forming digital culture.

Table 5.
Results of identifying indicators of the formation of students' digital culture in EG and CG respondents according to the content-information criterion (formative experiment)

Groups	Initial, n (%)	Basic, n (%)	High, n (%)
Experimental	4 (4.3%)	35 (38.0%)	53 (57.6%)
Control	46 (50.0%)	34 (37.0%)	12 (13.0%)

Source: developed by the authors

We see a clear predominance of high levels among EG students and a significant decrease in the initial level in EG. In the control groups, we observe no significant changes compared to EG.

Activity criterion.

Indicators: the ability to independently search, process information, critically evaluate it, the ability to organize one's own process of educational and professional activity (time management, planning, self-control); use of various digital technologies and teaching methods.

Table 6.
Results of identifying indicators of the formation of students' digital culture in EG and CG respondents according to the activity criterion (formative experiment)

Groups	Initial, n (%)	Basic, n (%)	High, n (%)
Experimental	8 (8.7%)	32 (34.8%)	52 (56.5%)
Control	44 (47.8%)	24 (26.1%)	24 (26.1%)

Source: developed by the authors

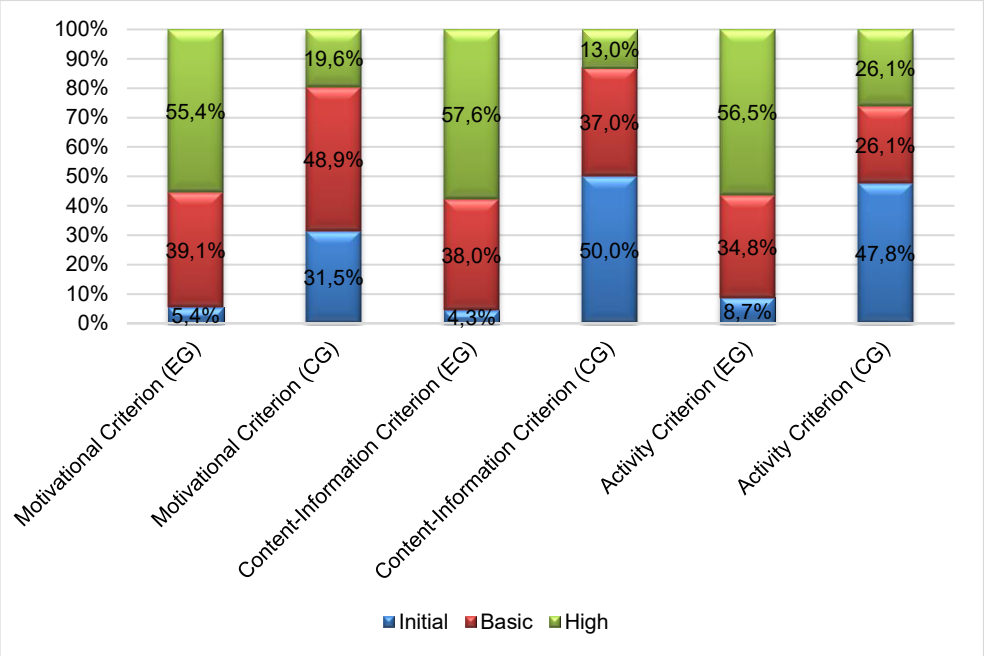


Figure 2. Comparison of the Indicators of Students' Digital Culture Formation by Motivational, Content-Information, and Activity Criteria in the EG and CG (Formative Experiment)

As a result of the formative experiment, we observe a clear predominance at a high level among EG students and a significant decrease from the initial level in EG. In the control groups, we observe no significant changes compared to EG.

The cross-sectional results on the level of digital culture formation among students in EG and CG at the formative stage of the experiment showed that quantitative changes occurred in the experimental groups.

The final diagnostics showed that changes occurred in EG towards an increase in the high level of students' digital culture.

To statistically process the results of the experiment in the experimental and control groups according to the criterion of agreement χ^2 , we used the formula:

$$\chi^2_{emp} = N \cdot M \cdot \sum_{i=1}^{L} \frac{\left(\frac{n_i}{N} - \frac{m_i}{M}\right)^2}{n_i + m_i}$$

The Pearson χ^2 agreement criterion allows us to test the validity of the null hypothesis H_0 about the formation of the digital culture of future specialists in EG and CG at the formative stage of the pedagogical experiment.

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Let's characterize the hypotheses:

H_0 – assumes that the division of students by the levels of formation of digital culture in EG and CG students is the same. When comparing EG and CG, if χ^2_{emp} is below the critical $\chi^2_{emp} < \chi^2_{crit}$, then the hypothesis H_0 will be proven.

H_1 assumes that the level of digital culture formation among students in EG and CG differs.

At the formative stage of the experiment, it was found χ^2_{emp} for EG and CG, for levels $\alpha = 0{,}05$ of digital culture of students in EG and CG.

By substituting the data using Microsoft Excel spreadsheets, the results were obtained. Found χ^2_{crit} for level $\alpha = 0{,}05$ and the number of degrees of freedom $v = 3 - 1 = 2$. Found $\chi^2_{crit(\alpha=0.05)} = 5.991$. Let's compare the critical values χ^2_{crit} with χ^2_{emp}.

Received, $\chi^2_{emp} > \chi^2_{crit}$, which allowed us to accept the alternative hypothesis $H1$ and draw a conclusion about changes in the levels of formation of digital culture of respondents EG and CG, and to say that this statement is not a random phenomenon, but is due to the developed system and the implementation of pedagogical conditions in respondents EG.

So, obtained using the Pearson criterion χ^2 in the experimental work, the data indicate that changes have occurred in the EG towards increasing the high level of formation of students' digital culture, due to the use of digital methods, developed pedagogical conditions, a special course, digital technologies, which created an innovative system for the development of digital literacy and competence, and culture among students.

The findings demonstrate that the integrated pedagogical model significantly improved students' digital competence and digital culture across the motivational, content-information, and activity dimensions. Compared with the control group, students in the experimental group achieved substantially higher proportions of high-level performance after completing the intervention, indicating that combining multiple digital technologies with targeted pedagogical conditions is more effective than using conventional instructional approaches.

These findings are consistent with previous studies demonstrating that digital technologies increase student engagement and learning effectiveness. Graham et al. (2023) reported that comprehensive digital transformation strategies improve students' readiness for blended learning environments, while Pegalajar Palomino and Rodríguez Torres (2023) found positive relationships between systematic use of digital technologies and university students' digital competence. Likewise, Sangrà et al. (2023) emphasized that innovative digital

methodologies promote autonomous learning and facilitate the acquisition of professional digital skills. The present findings extend this evidence by demonstrating that the greatest educational benefits emerge when digital technologies are implemented as components of an integrated pedagogical system rather than as isolated instructional tools.

The obtained results also support studies highlighting the educational potential of artificial intelligence, augmented reality, cloud technologies, and virtual laboratories. Previous research has shown that these technologies improve students' motivation, practical engagement, and conceptual understanding (Falloon, 2020; Gómez-García et al., 2023; Philippe et al., 2020; Taherdoost & Madanchian, 2022; Zhao et al., 2021;). However, unlike many earlier investigations that evaluated individual technologies separately, the present study examined their combined implementation within a structured pedagogical framework supported by adaptive learning environments, guided self-directed learning, and continuous digital monitoring. This integrated approach may explain the considerably larger improvements observed in the experimental group.

Some differences from previous studies should also be noted. Whereas many earlier investigations primarily assessed technological effectiveness or students' satisfaction with digital tools, the present research evaluated broader educational outcomes by simultaneously examining motivational, cognitive, and activity-related components of digital culture. This multidimensional assessment provides a more comprehensive understanding of students' digital development and demonstrates that sustainable improvements require not only access to digital technologies but also pedagogically structured learning experiences and systematic instructional support.

Several factors may explain the effectiveness of the proposed intervention. First, the combination of diverse digital technologies created authentic learning situations that encouraged active participation and collaborative problem-solving. Second, adaptive digital learning environments enabled students to regulate their own learning pace and receive individualized feedback. Third, continuous pedagogical support and digital monitoring strengthened students' motivation, self-regulation, and reflective learning, which are recognized as essential components of digital competence development.

From a theoretical perspective, this study contributes to the growing body of research advocating integrated models of digital transformation in higher education. Rather than conceptualizing digital competence as merely technological proficiency, the findings support a holistic understanding that incorporates motivational, cognitive, behavioural, and ethical dimensions of digital culture. The proposed pedagogical model therefore expands existing theoretical approaches by demonstrating how multiple digital technologies can function synergistically within a coherent educational framework.

The practical implications of the study are equally significant. Higher education institutions may apply the proposed pedagogical model when designing digitally enriched curricula, developing professional training programmes, and improving students' digital competence. The identified pedagogical conditions – including adaptive digital learning environments, digitally supported self-directed learning, and continuous digital monitoring – may also serve as practical guidelines for university instructors seeking to enhance student engagement and learning outcomes during digital transformation initiatives.

The originality of this study lies not in evaluating individual digital technologies, which has been widely addressed in previous research, but in experimentally validating a comprehensive pedagogical model that integrates multiple contemporary technologies within a unified instructional system. By combining artificial intelligence, augmented reality, cloud technologies, gamification, virtual laboratories, and structured pedagogical support in a quasi-experimental design, the study provides empirical evidence for an integrated approach to developing university students' digital competence and digital culture. This contribution addresses an important gap identified in previous literature and offers an evidence-based framework for future educational innovation.

Conclusions

This study demonstrated that the integration of contemporary digital technologies within a structured pedagogical model significantly enhances university students' digital competence and digital culture. Compared with conventional instructional practices, the proposed approach produced substantially greater improvements in the motivational, content-information, and activity dimensions of digital culture, confirming the effectiveness of combining adaptive digital learning environments, digitally supported self-directed learning, and continuous digital monitoring within a unified educational framework.

The principal scientific contribution of this research lies in the experimental validation of an integrated pedagogical model that combines artificial intelligence, augmented reality, cloud technologies, gamification, Google Glass, and virtual laboratories with targeted pedagogical conditions. Unlike previous studies that primarily examined individual digital technologies in isolation, this research demonstrates that their coordinated pedagogical integration produces more comprehensive improvements in students' digital competence and digital culture. Consequently, the study contributes new empirical evidence supporting holistic approaches to digital transformation in higher education.

The practical implications of the findings are significant for universities seeking to modernize educational programmes. The proposed pedagogical model may be adopted in curriculum design, teacher professional development, and institutional digital transformation strategies. Furthermore, the identified pedagogical conditions provide practical guidance for instructors aiming to foster students' digital competence through technology-enhanced, student-centred learning environments.

Several limitations should be acknowledged. The study was conducted within a limited number of Ukrainian higher education institutions using a quasi-experimental design; therefore, caution should be exercised when generalizing the findings to different educational systems or cultural contexts. In addition, the study evaluated learning outcomes immediately after the intervention and did not investigate the long-term sustainability of the observed improvements.

Future research should examine the long-term development of digital competence through longitudinal studies, validate the proposed pedagogical model across different academic disciplines and international educational contexts, and investigate the contribution of specific technologies, including generative artificial intelligence, immersive virtual reality, and learning analytics, to different components of students' digital competence and digital culture.

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Original Article

Sistemas automatizados para evaluar el conocimiento de los estudiantes basados en inteligencia artificial: desarrollo y verificación empírica

Automated systems for assessing student knowledge based on artificial intelligence: development and empirical verification

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Resumen

El estudio tuvo como objetivo desarrollar un modelo conceptual de tres niveles de un sistema automatizado de evaluación del conocimiento basado en IA y proporcionar evidencia empírica sobre su desempeño en un contexto de educación superior. Para ello, se utilizó un diseño cuasiexperimental (pretest-postest) con la participación de 250 estudiantes de especialidades de humanidades (licenciatura: n = 163; maestría: n = 87). El conjunto de herramientas consistió en formas paralelas de la prueba de rendimiento académico (40 tareas, α = 0,83), una escala TAM adaptada. Para el análisis, se utilizaron la prueba t pareada, el análisis factorial confirmatorio, la regresión múltiple jerárquica y el análisis de dominancia. Los estudiantes demostraron un mayor rendimiento académico en el postest tras la implementación del modelo AKS. El análisis mostró una jerarquía de importancia relativa de los niveles (R^2 = ,61): nivel semántico-discursivo (50,8 %) > retroalimentación personalizada (31,1 %) > sintáctico-formal (18,1 %). Los estudiantes percibieron positivamente el sistema en todas las dimensiones del TAM: PU = 3,91, PEOU = 3,67, OS = 3,78. Por lo tanto, la jerarquía de predictores se convirtió en una recomendación importante para los desarrolladores del ASZ con respecto a la prioridad de las inversiones en el nivel semántico. Los hallazgos sugieren que una estrategia de implementación por fases puede representar un enfoque pedagógicamente prometedor. Los resultados son relevantes para las instituciones de educación superior que operan en formato a distancia o semipresencial.

Palabras clave: evaluación automatizada del estudiante; análisis de dominancia; educación superior; analítica del aprendizaje; retroalimentación personalizada.

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Abstract

The study aimed to develop a three-level conceptual model of an AI-based automated knowledge assessment system and to provide empirical evidence regarding its performance within a higher education context. For this purpose, a quasi-experimental design (pretest–posttest) was used with the participation of 250 students of humanities specialties (bachelor's: n = 163; master's: n = 87). The toolkit consisted of parallel forms of the academic achievement test (40 tasks, α = 0.83), an adapted TAM scale. For analysis, paired t-test, confirmatory factor analysis, hierarchical multiple regression and dominance analysis were used. Students demonstrated higher post-test academic achievement following implementation of the AKS model. The analysis showed a hierarchy of relative importance of levels (R^2 = .61): semantic-discursive level (50.8%) > personalized feedback (31.1%) > syntactic-formal (18.1%). Students positively perceived the system on all TAM dimensions: PU = 3.91,

PEOU = 3.67, OS = 3.78. Therefore, the hierarchy of predictors became an important recommendation for developers of the ASZ regarding the priority of investments in the semantic level. The findings suggest that a phased implementation strategy may represent a pedagogically promising approach. The results are relevant for higher education institutions operating in a distance or blended format.

Keywords: automated student assessment; dominance analysis; higher education; learning analytics; personalized feedback.

Introduction

The massive digitalization of the educational process has influenced changes in approaches to assessing educational achievements. Traditional forms of knowledge control, for example, exams, tests, and written works, have given way to automated tools that can check the correctness of answers and analyze the cognitive trajectories of students in real time. For this reason, the issue of developing and implementing automated knowledge assessment systems (AKS) based on artificial intelligence has become particularly relevant for modern pedagogical science and educational practice.

The scale of the problem is determined by several interrelated factors. First, according to UNESCO (2023), more than 220 million students around the world study in partial or full distance learning. In addition, the chronic overload of scientific and pedagogical personnel in higher educational institutions in the conditions of mass education has made it impossible to provide high-quality and timely feedback on each student's work. It should also be taken into account that traditional assessment methods have become methodologically limited, in particular, they take into account only the final result and do not pay attention to the thinking process and the dynamics of the formation of competencies (Fajardo-Ramos et al., 2025).

Therefore, taking into account these three problems: scale, resource limitations and methodological insufficiency, there is a demand for artificial intelligence as an important tool for the transformation of assessment.

Modern AESs are based on a wide range of technologies: automated essay scoring (AES), adaptive computer testing (Computerized Adaptive Testing, CAT), plagiarism detection systems with elements of semantic analysis and predictive learning analytics platforms. An important core of all these areas were the methods of machine learning and natural language processing (NLP), which made it possible to move from formal verification of facts to recognition of semantic structures in the answers provided by students.

It is also worth considering that the problem of automated assessment has become particularly relevant in Ukraine, where the reform of the higher education system in accordance with the standards of the Bologna Process was carried out together with adaptation to the conditions of martial law and the transition of higher education institutions to a hybrid format.

Despite the array of publications on related topics, the research space in this area is heterogeneous. In particular, the existing works mainly concern purely technical aspects of algorithm development. The rest are based on pedagogical principles of assessment. Accordingly, the combination of both dimensions is insufficiently represented in modern science. The scientific novelty of the proposed study is determined by the original conceptual model of AKS, which integrates three levels

of intellectualization: the level of automatic verification, the level of semantic analysis, and the level of personalized feedback.

Therefore, the study aimed to develop and provide preliminary empirical support for a three-level conceptual model of an automated knowledge assessment system (AKS) based on artificial intelligence, which consisted of syntactic-formal verification, semantic-discursive analysis and personalized feedback generation. The research questions are as follows:

DP1. To what extent does the proposed three-level AKS model provide empirical evidence supporting construct and criterion validity when compared with independent human expert assessments across different academic disciplines?
DP2. To what extent were changes in students' academic achievement associated with the implementation of the personalized feedback component of the proposed AKS model?
DP3. What is the assessment of students' perceived usefulness, ease of use and overall satisfaction with the AKS model at each of the three levels of intellectualization, and what factors moderate these perceptions?
DP4. What is the relative contribution of each level of the model—syntactic-formal, semantic-discursive, and personalized feedback—to the overall predictive validity of the system?

Theoretical Framework or Literature Review

Artificial Intelligence in Higher Education and Assessment Systems

Modern research on artificial intelligence in higher education has indicated a notable shift from the use of individual digital tools to the construction of intelligent educational ecosystems. For example, modern systematic reviews (Basilotta-Gómez-Pablos et al., 2022; Durso & Arruda, 2022) have determined that the process of integrating AI has depended on the level of digital competences of teachers and the ability of institutions to adapt pedagogical models to new technological conditions.

Separately, studies by Dung et al. (2026) and Fernandes et al. (2026) have indicated that there is a noticeable connection between AI, data management and the quality of education. These statements have become important for automated assessment systems. However, these studies have been mainly overview and theoretical.

At the same time, the use of AI has been defined as a tool for achieving strategic educational goals. In particular, the authors emphasized that AI enables sustainability and accessibility (Leal Filho et al., 2024). In addition, conceptual models (Lourenço & Valente, 2026) have identified AI as the basis for the transformation of learning, assessment, and academic support within the Education 4.0 paradigm. For this reason, automated knowledge assessment systems (AKS) have become important components of the intellectualization of the educational process. Early developments (Ferreira et al., 2017) focused on dynamic knowledge assessment within adaptive systems. At the same time, it is worth noting that more recent studies have pointed to the importance of integrating assessment with competency-based recommender systems.

In addition, educational risk prediction models (Martinho et al., 2013) have pointed to the important potential of AI for analyzing educational outcomes based on big data. However, most of these studies are conceptual and systematic reviews in methodological terms. Only a small number of researchers have been involved in

empirically testing this issue. This situation determined the importance of conducting this study.

Semantic Processing, Feedback, and Personalization in AI-Based Assessment

Recent studies have drawn attention to the transition from formal-syntactic assessment to semantic analysis of educational outcomes. For example, the work of Dos Santos et al. (2026) pointed to the effectiveness of NLP and text mining in structuring knowledge. These findings have become important for the assessment of open-ended responses. In addition, Lima et al. (2026) and Dos Santos et al. (2026) showed that AI made it possible to analyze complex educational outcomes. In particular, the authors analyzed different competencies and behavioral patterns of students.

Automated feedback played a special role. In particular, Guardia-Paniura et al. (2026) proved that AI-generated feedback became effective under the condition of personalization and pedagogical relevance. It is worth noting that Deroncele-Acosta et al. (2025) pointed out the importance of digitalization and AI for the development of transversal competencies. In addition, Aquino (2026) and Byrka et al. (2024) pointed out the need to combine algorithmic efficiency with the principles of critical pedagogy, in particular, preserving the subjectivity of the student.

Thus, modern research has determined that effective assessment systems should integrate three components: 1. formal verification; 2. semantic understanding; 3. personalized feedback.

However, despite the significant amount of research, there are several significant gaps. In particular, as noted above, most of the work was conceptual in nature. In addition, many works focus on individual technological solutions without integrating them into a single system.

There is also a lack of empirical research that would assess the relative contribution of different components of automated assessment systems to learning outcomes. In addition, there is limited research on the relationship between system architecture and student perception within TAM-type models. This determined the need to develop a hierarchical model of AKS that integrated different levels of intellectualization and was empirically tested.

Methodology

Research design

The study was conducted within the framework of a quantitative research paradigm using a quasi-experimental design “before — after” (one-group pretest–posttest design). According to the classification of modern scientists, such a design will allow maintaining internal validity when studying the effects of educational intervention under the conditions of impossibility of randomized distribution of participants. The unit of analysis was the individual educational interaction of a student with each of the three levels of the AKS model during one semester cycle.

The research process is structured into four consecutive phases: 1. diagnostic phase: at this stage, a pre-test was conducted and demographic data was collected; 2. intervention phase: at this stage, the three-level AKS model was introduced into

the educational process for eight weeks; 3. final phase: post-test and questionnaire on the perception scale; 4. analytical phase: statistical data processing and verification of the conceptual model.

Participants and sampling procedure

The study involved students of mixed majors at higher education institutions in Ukraine. The sample was formed based on purposive selection in compliance with the relevant inclusion criteria: 1. status of a first (bachelor's) or second (master's) level higher education student in the humanitarian field (humanitarian field (philology, history, psychology, pedagogy, philosophy, journalism, law and social sciences, mathematics & computer science education; 2. experience working with digital educational platforms for at least one academic year; 3. voluntary informed consent to participate in the study. Exclusion criteria included: incomplete completion of the instrument (more than 10% of missing values), participation in parallel studies of a similar profile, a break in studies during the intervention phase.

The total sample size was 250 participants. The calculation of the minimum required sample size was carried out using the Cohen formula for a paired t-test with the given parameters: statistical significance level $\alpha = 0.05$, power criterion $(1 - \beta) = 0.80$, and expected effect size $d = 0.50$ (average). The calculated minimum is $n = 199$; the involvement of 250 participants provided a sufficient reserve for possible data screening. The demographic profile of the sample is presented in Table 1.

Table 1.
Demographic characteristics of the study sample (N = 250)

Variable	Category	n	%
Gender	Female	171	68.4
	Male	79	31.6
Age	18–21 years	102	40.8
	22–25 years	109	43.6
	26 years and older	39	15.6
Academic level	Bachelor's degree (Years 1–4)	163	65.2
	Master's degree (Years 5–6)	87	34.8
Year of study	Year 1	48	19.2
	Year 2–3	68	27.2
	Year 4	47	18.8
	Year 5–6 (Master's)	87	34.8
Field of study (ISCED-F 2013)	Philology & Linguistics	67	26.8
	Psychology & Education	58	23.2
	History & Philosophy	45	18.0
	Journalism & Communication	41	16.4
	Law & Social Sciences	24	9.6
	Mathematics & Computer Science Education	15	6.0
Prior digital assessment experience	No experience	54	21.6
	Occasional use (1–2 platforms)	124	49.6
	Regular use (3+ platforms)	72	28.8
Prior AI tool experience	No experience	71	28.4
	Occasional use	126	50.4
	Regular use	53	21.2
Total		250	100.0

Instruments and Procedure

The research instrument integrated several measurement blocks that made it possible to operationalize all four research questions.

Block 1 — Academic Achievement Test. To measure cognitive outcomes, parallel test forms (pre-test / post-test) were developed, consisting of 40 tasks of three types: tasks with the choice of one correct answer (n = 20), tasks to establish correspondence (n = 10), and open-ended tasks with a detailed written response (n = 10). The open-ended tasks were focused on the specifics of humanitarian discourse — argumentation, interpretation of primary sources, and critical analysis — which ensures the content relevance of the instrument to the studied population. The parallelism of the forms was verified on a pilot sample (n = 45): $r = 0.87$ ($p < 0.001$); internal consistency was confirmed by Cronbach's $\alpha = 0.83$.

Although the academic achievement test demonstrated satisfactory psychometric properties ($r = 0.87$; $\alpha = 0.83$), it was specifically developed for the purposes of this study. Consequently, a potential alignment bias between the assessment instrument and the conceptual architecture of the proposed AKS model cannot be completely excluded. To minimize this risk, parallel test forms, independent expert evaluation, and comparison with human-rater scores were employed. Nevertheless, future research should validate the proposed model using standardized or independently developed assessment instruments to strengthen external validity.

Block 2 — Combined Technology Perception Scale. Students' perception of the system was measured using an adapted scale that integrated three subscales: (a) "perceived usefulness" (PU; 6 items); (b) "perceived ease of use" (PEOU; 6 items); (c) "overall satisfaction" (OS; 4 items). Responses were recorded on a five-point Likert scale (1 — "strongly disagree", 5 — "strongly agree"). The psychometric properties of the adapted scale were tested using the confirmatory factor analysis (CFA) method: CFI = 0.96, RMSEA = 0.048, SRMR = 0.051, which met the criteria for acceptable model fit (Hu & Bentler, 1999). Subscale reliability: $\alpha(PU) = 0.87$, $\alpha(PEOU) = 0.84$, $\alpha(OS) = 0.81$.

Block 3 — Author's questionnaire. To collect additional qualitative and contextual data, a special author's questionnaire of 18 items was compiled, which included: experience of previous interaction with digital assessment tools (5 items), subjective assessment of the quality of feedback at each level of the AKS (9 items on the Likert scale), and open-ended questions about barriers and benefits of using the system (4 items). The content validity of the questionnaire was confirmed based on the expert evaluation method (n = 7 experts in the field of educational technologies and humanitarian didactics; content validity index CVI = 0.91).

Implementation of the artificial intelligence system (AI System Implementation)

The developed automated knowledge assessment system (Automated Knowledge Assessment System, AKS) is implemented as a modular three-level architecture. In it, each functional level performed separate analytical tasks and sequentially transferred the results to the next system component. Such an architecture made it possible to make a phased transition from formal verification of students' answers to semantic analysis of content and generation of personalized pedagogical feedback.

The first level (Tier 1 – Syntactic-Formal Verification) was responsible for automated formal-syntactic verification of student works. At this stage, algorithms based on

rules (rule-based approach) were used, which analyzed spelling correctness, syntactic structure, text formatting, completeness of answers and compliance with the established requirements of the task. Pre-processing of texts included tokenization, lemmatization, Part-of-Speech tagging, and Regular Expressions to detect typical structural errors. This level was to ensure high accuracy of automatic verification of formal characteristics of written responses before conducting a deeper semantic analysis. The second level (Tier 2 – Semantic-Discursive Analysis) implemented an intelligent analysis of the content of students' responses using modern methods of Natural Language Processing (NLP). To form semantic representations of the text, pre-trained transformative language models of the BERT/RoBERTa family were used, which provided the generation of context-dependent embeddings of student responses. The similarity between the student's response and the reference responses was determined using the cosine similarity measure. In addition to assessing semantic correspondence, the system analyzed the discursive organization of the text, the logical sequence of argumentation, conceptual coherence, and compliance with the criteria of the evaluation rubric. For this, elements of Rhetorical Structure Theory (RST) and automated comparison of the content of the answer were used.

The third level (Tier 3 – Personalized Feedback Generation) provided automatic formation of individualized pedagogical feedback. The generation of recommendations was based on Retrieval-Augmented Generation (RAG). This involved analyzing the results of previous levels with the student's educational activity profile. The profile included the results of previous assessments, typical errors, the level of formation of individual competencies, and the history of completing educational tasks. Based on the integrated information, the system formed personalized recommendations regarding the strengths of the answer, identified shortcomings, possible ways to eliminate them, and further educational actions. At the same time, the final assessment remained available for verification by the teacher.

The integration of the three levels was carried out through a single modular architecture, in which the results of each previous stage were automatically transferred to the next module. The formal characteristics of the response obtained at the first level were used during semantic analysis, and the results of the semantic assessment together with the student's learning profile formed the basis for generating personalized feedback.

The study used pre-trained general-purpose language models without additional full-scale fine-tuning on specialized subject corpora. This provided an opportunity to test the proposed conceptual architecture in the conditions of using available modern language models.

Research procedure

The research procedure was carried out according to the quasi-experimental design "before — after" and consisted of four consecutive phases. The total study lasted 12 weeks. Each phase was defined by separate tasks, data collection tools and measurement points.

In the first, diagnostic phase (weeks 1–2), the primary measurement of dependent variables was carried out: students completed a pre-test of academic achievements (40 tasks) and filled out an author's questionnaire on their previous experience of interaction with digital assessment tools.

In the next phase - intervention (weeks 3–10) - the sequential implementation of three levels of the AKS model into the natural educational process of the participants is provided. Each level was activated in stages with an interval of two weeks: Tier 1 (syntactic-formal verification) - weeks 3–4; Tier 2 (semantic-discursive analysis) - weeks 5–6; Tier 3 (personalized feedback) — weeks 7–8; integrated use of all three levels — weeks 9–10.

Thus, the model of the automated knowledge assessment system, which is verified in this study, is based on the principles of hierarchical architecture of intellectualization. In particular, each subsequent level is built on the previous one and expands the analytical capabilities of the system from formal-syntactic verification to semantic understanding. The theoretical basis of the model is: adaptive learning theory, psychometric theory of task response, architecture of transformative language models and Technology Acceptance Model. The full specification of the model is given in Table 2.

Table 2.
Conceptual model of the AI-based Automated Student Assessment System

Tier / Level	Theoretical basis	Core construct	Input data	Algorithmic mechanism	Outcome indicator
Tier 1 Syntactic-Formal Verification					
Formal and syntactic control	Rule-based systems; classical NLP	Structural accuracy; lexical conformity; format compliance	Raw student text; submission metadata; formatting parameters	Regex parsingPOS taggingSpell-check pipelineGrammar rules	Accuracy Rate (AR) False Positive Rate (FPR) Cohen's κ (inter-rater) Processing time (ms)
Tier 2 Semantic-Discursive Analysis					
Semantic-discursive analysis	Distributional semantics; IRT, discourse theory	Conceptual coherence; argumentation quality; semantic depth; disciplinary relevance	Tier 1 verified text; reference answer vectors; rubric ontology	BERT / RoBERTa embeddingsCosine similarityRST discourse parsingRubric alignment scoring	Semantic Alignment Score (SAS) Criterion validity (r vs expert) F1-score (per rubric criterion) Discourse coherence index
Tier 3 Personalized Feedback Generation					
Personalized feedback	Adaptive learning, self-regulated learning	Feedback relevance; individualization degree; learning gain attribution; scaffolding adequacy	Tier 1 + Tier 2 outputs; student learning profile; historical performance data	RAG (Retrieval-Augmented Generation) Student profile modellingAdaptive scaffolding logicLLM-based generation	Perceived Usefulness — PU (TAM) Perceived Ease of Use — PEOU (TAM) Overall Satisfaction — OS Learning gain
Integrated AKS results		Holistic student competency profile; longitudinal learning trajectory; predictive performance score		Ensemble scoringLongitudinal profiling	Predictive validity (R^2); overall system accuracy; student learning outcome (post-test score)

The final phase (weeks 11–12) involved conducting a post-test of academic achievement (parallel form to the pre-test, r = 0.87), completing the adapted TAM scale (PU, PEOU, OS) and the open part of the author's questionnaire. The analytical phase was carried out outside the interaction with the participants (See Table 3).

Table 3.
Research procedure aligned with the three-tier AKS model

Phase	Timeline	AKS tier activated	Key activities	Data collection instrument	Measurement point
Phase 1 Diagnostic	Weeks 1–2	— (baseline)	Informed consent; demographic survey; baseline knowledge assessment; prior experience questionnaire	Pre-test (40 items); Demographic form; Author's questionnaire (Block 3, items 1–5)	T0 — baseline measurement
Phase 2 Intervention	Weeks 3–4	Tier 1 Syntactic-Formal	Automated syntax and format checking of written assignments; error flagging; rule-based feedback delivery	System accuracy logs; Author's questionnaire (Block 3, items 6–8)	T1 — Tier 1 exit measurement
	Weeks 5–6	Tier 2 Semantic-Discursive	Semantic coherence and argumentation analysis via BERT embeddings; cosine similarity scoring; comparison with expert ratings	Semantic alignment scores (SAS); Expert rater sheets; Author's questionnaire (Block 3, items 9–11)	T2 — Tier 2 exit measurement
	Weeks 7–8	Tier 3 Personalized Feedback	RAG-based individualized feedback generation; adaptive scaffolding; student learning profile updating	Feedback quality logs; TAM subscale (PU, PEOU); Author's questionnaire (Block 3, items 12–14)	T3 — Tier 3 exit measurement
	Weeks 9–10	Tiers 1+2+3 Integrated use	Full-system interaction across all three tiers simultaneously; naturalistic assessment conditions	Integrated system logs; Overall Satisfaction subscale (OS)	T4 — integrated system measurement
Phase 3 Post-intervention	Weeks 11–12	— (assessment)	Post-test administration; full TAM scale completion; open-ended questionnaire on perceived barriers and affordances	Post-test (40 parallel items); TAM scale (PU + PEOU + OS); Author's questionnaire (Block 3, items 15–18)	T5 — final outcome measurement
Phase 4 Analytical	Post week 12	— (analysis)	Statistical analysis (paired t-test, CFA, regression, dominance analysis); model evaluation; manuscript preparation	R software (v. 4.3.2); packages: lavaan, psych, effectsize	T0→T5 — longitudinal comparison
Total duration		12 weeks (+ analytical phase)		6 measurement points (T0–T5)	

Data analysis

Statistical analysis was implemented using the R software environment (version 4.3.2; R Core Team). The general analysis strategy was based on the hierarchical structure of the research questions and included four consecutive stages: testing statistical assumptions, descriptive statistics, hypothesis testing, and model structure analysis. For each statistical test, the significance level $\alpha = 0.05$ was set; for multiple comparisons, the Bonferroni correction was applied.

Before conducting the main statistical analysis, the relevant assumptions for each method were checked. The normality of the distribution of differences between pre-test and post-test indicators was assessed using the Shapiro-Wilk test; if the distribution was non-normal ($p < 0.05$), the nonparametric Wilcoxon test for dependent samples was used as an alternative. The Levene test checked the homogeneity of variances between subgroups. For regression models, multicollinearity of predictors (VIF < 10), independence of residuals (Durbin-Watson

test) and homoscedasticity (Breusch-Pagan test) were diagnosed.

Pearson correlation coefficients and Cohen's kappa were calculated to examine the degree of agreement between the system's output and the independent expert ratings. These analyses were intended to provide empirical evidence for criterion validity, rather than definitive validation of the proposed model. The paired t-test method was also used with the establishment of practical significance based on Cohen's d effect size; in case of deviation from normality, a non-parametric alternative is provided - the Wilcoxon test for dependent samples. The structure of students' perception of technology (DP3) was determined on the basis of confirmatory factor analysis (CFA) with an assessment of the model's adequacy by the CFI, RMSEA and SRMR indices. The relative contribution of each level of the AKS model to the predictive validity (DP4) was established by the dominance analysis method. For this purpose, the hierarchical multiple regression method was also used.

Results and Discussion

Before conducting statistical analysis, the data were checked for compliance with statistical assumptions, which is a prerequisite for the correct application of parametric methods in quasi-experimental studies. The normality of the distribution of the main variables was checked using the Shapiro-Wilk test: the distribution of pre-test ($W = 0.98$, $p = .112$) and post-test ($W = 0.97$, $p = .089$) scores did not deviate significantly from normal. In addition, the asymmetry and kurtosis indicators for both variables were within acceptable limits. The homogeneity of variances between subgroups (bachelor's vs master's; different specialties) was confirmed using the Levene test ($p > .05$ for all comparisons), which allows the use of parametric tests without Welch's correction.

Descriptive statistics for all key study variables are presented in Table 4. The mean score of students on the pre-test was $M = 58.3$ ($SD = 11.4$). This corresponded to a level below the mean relative to the maximum possible score (100 points) and indicated room for learning growth. In addition, the standard deviation on the pre-test ($SD = 11.4$) exceeded the similar indicator on the post-test ($SD = 10.8$). This indicates the leveling of students' learning outcomes in the process of interaction with the AKS - an effect known in the literature as "narrowing of variance in learning". The mean scores of the TAM subscales - perceived usefulness ($PU = 3.91$, $SD = 0.74$), perceived ease of use ($PEOU = 3.67$, $SD = 0.81$) and overall satisfaction ($OS = 3.78$, $SD = 0.77$) exceeded the neutral value of the scale (3.0). These data indicated a positive perception of the system by the study participants.

Analysis of minimum and maximum values indicated variability in academic achievement before ($min = 28$, $max = 89$) and after ($min = 38$, $max = 98$) the intervention. This determined the feasibility of investigating the moderating effect of demographic variables. The score gain indicator (Δ) indicated significant individual variation ($SD = 6.7$; $min = -4$; $max = +34$).

Table 4.
Descriptive statistics for pre-test, post-test, and TAM subscale scores (N = 250)

Variable	M	SD	Mdn	Min	Max	Skew	Kurt	α
Pre-test score	58.3	11.4	57.0	28	89	0.21	−0.34	0.83
Post-test score	71.6	10.8	72.0	38	98	−0.18	−0.27	0.83
Score gain (Δ)	13.3	6.7	13.0	−4	34	0.09	0.11	—
PU — Perceived Usefulness	3.91	0.74	4.00	1.5	5.0	−0.43	0.18	0.87
PEOU — Perceived Ease of Use	3.67	0.81	3.67	1.3	5.0	−0.31	−0.09	0.84
OS — Overall Satisfaction	3.78	0.77	3.75	1.5	5.0	−0.38	0.14	0.81
Semantic Alignment Score (SAS)	0.74	0.11	0.75	0.41	0.97	−0.22	0.07	—

Note. M = mean; SD = standard deviation; Mdn = median; Skew = skewness; Kurt = excess kurtosis; α = Cronbach's alpha. PU, PEOU, OS were measured on a 5-point Likert scale. SAS = Semantic Alignment Score (cosine similarity, range 0–1). Pre- and post-test scores expressed as percentage of maximum (100 points). Score gain (Δ) = post-test minus pre-test.

To determine the differential impact of the intervention depending on the academic specialty, a comparative bar chart (Figure 1) was formed, which was based on the mean pre-test and post-test scores for each of the five humanities disciplines represented in the sample. Thus, the positive dynamics of academic achievement is noticeable in all groups without exception, but its intensity varied. The greatest increase was recorded among students of the specialties "Philology and Linguistics" (Δ = 14.8 points) and "Journalism and Communications" (Δ = 14.2 points). At the same time, the smallest increase was recorded in the group "Law and Social Sciences" (Δ = 10.1 points). Students of Mathematics & Computer Science Education (n = 15) had a moderate gain (Δ = 12.1), with Tier 2 validity somewhat lower (r = 0.84) compared to humanities disciplines, which may reflect the structural differences between STEM-oriented and discursive academic writing.

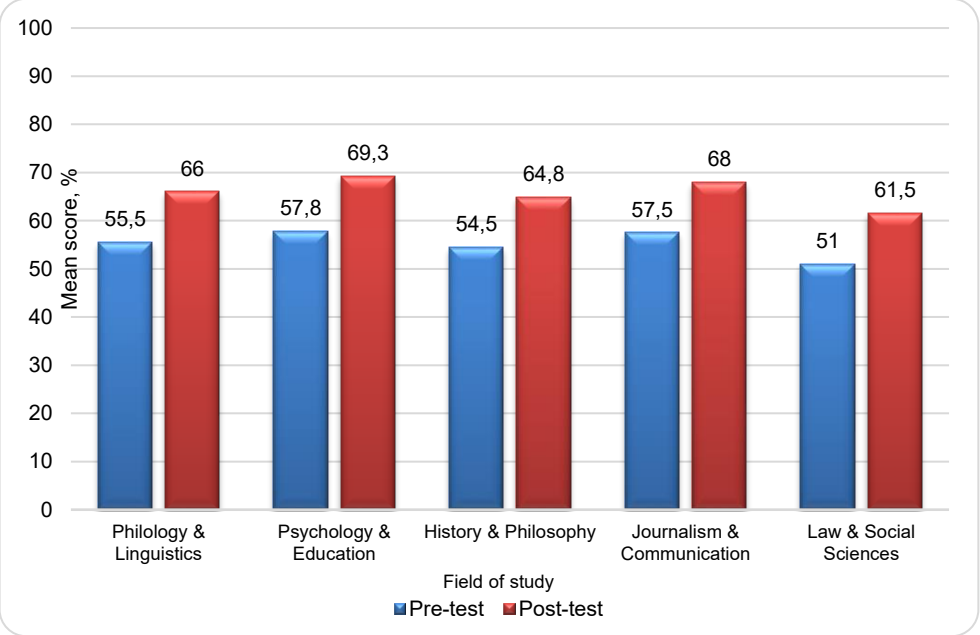


Figure 1. Knowledge Assessment Scores.

An important task of the study was to determine the effectiveness of the implemented three-level model of the AKS in ensuring an increase in the academic achievements of students of humanities specialties. In accordance with the specified research design (one-group pretest–posttest), a paired Student t-test was used to test the corresponding hypothesis. The data from this test indicated an increase in academic achievements: the average score of the participants increased from M = 58.3 (SD = 11.4) on the pre-test to M = 71.6 (SD = 10.8) on the post-test. This indicated an absolute increase of ΔM = 13.3 points (95% CI [12.47, 14.13]): t(249) = 31.42, p < .001. It is important to note the effect size of Cohen's d = 0.98, which indicated a practical effect according to generally accepted interpretive criteria (d ≥ 0.80; Cohen, 1988). The resulting d = 0.98 is significant: it exceeded the median effect size typical of studies on the implementation of technology in the educational process (d ≈ 0.40–0.60).

A differentiated analysis by academic level indicated that a significant increase was recorded in the subgroup of undergraduate (ΔM = 13.3, d = 0.94, p < .001) and graduate (ΔM = 13.3, d = 1.08, p < .001) students. Therefore, despite the increase, the larger effect size in masters (d = 1.08 vs d = 0.94) can be explained by the smaller input variability of scores in this subgroup (SD = 10.4 at pre-test versus SD = 11.8 in bachelors). These indicators mathematically increased the value of Cohen's d with equal increase. At the same time, the higher basic level of knowledge of masters (M = 60.8 vs M = 57.1 in bachelors) did not level the effect of the intervention. On the contrary, this indicator indicated that the AKS model was effective at different levels of input training.

Comparison of the dynamics of the increase between the six measurement points (T0–T5) indicated that the most intensive increase in scores occurred at the stage of transition from Tier 1 to Tier 2 (T1 → T2) and from Tier 2 to Tier 3 (T2 → T3). At the same time, the increase at the stage of integrated use of the system (T4 → T5) became the least pronounced. Details are summarized in Table 5, while the dynamics of learning growth by level of academic training are illustrated in Figure 2.

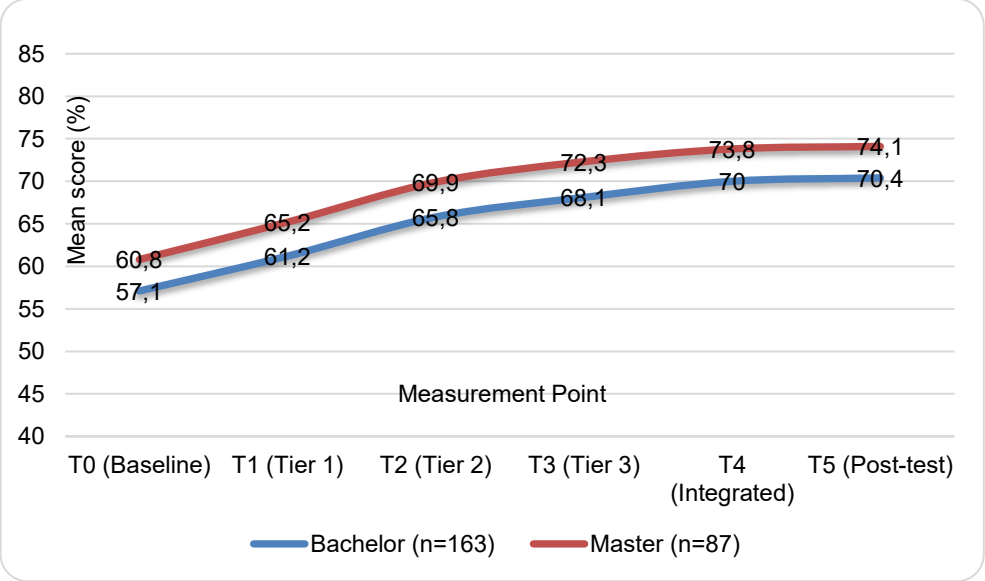


Figure 2. Learning growth by level of academic training

An important aim of the study was to assess the extent to which the results of the

proposed three-level AKS model corresponded to the ratings of independent human experts. This provided evidence regarding construct and criterion validity. The overall correlation between the results of the integrated system and the mean ratings of the two experts was r = 0.87 ($p < 0.001$), indicating a high level of agreement. However, these results should be interpreted as preliminary empirical evidence indicating that the proposed measurement approach is valid, rather than as definitive evidence of construct or criterion validity. Since expert ratings served as the primary external reference, further validation using independent data sets, multiple expert panels, standardized assessment instruments, and diverse educational contexts is needed. The second aim was to examine changes in student academic achievement after the implementation of the proposed AKS model. A paired Student's t-test was used in accordance with the single-group pretest–posttest design. After the intervention, students demonstrated higher posttest scores: the mean score increased from M = 58.3 (SD = 11.4) at pretest to M = 71.6 (SD = 10.8) at posttest, corresponding to an absolute increase of ΔM = 13.3 points (95% CI [12.47, 14.13]), $t(249) = 31.42$, $p < .001$. The observed effect size was large (Cohen's d = 0.98) by conventional criteria (Cohen, 1988) and exceeded the median effect sizes typically reported in educational technology intervention studies (d ≈ 0.40–0.60).

The differentiated analysis by model levels indicated a special pattern that had important theoretical significance for understanding the architecture of the model. In particular, Tier 1 (syntactic-formal verification) had the highest accuracy rate (Accuracy Rate = 96.3%) due to the deterministic nature of the rule-based algorithms. However, Tier 1 had a relatively lower correlation with expert ratings (r = 0.79). Tier 2 (semantic-discursive analysis) based on BERT embeddings and RST parsing indicated the highest correlation with experts (r = 0.91) and F1-score = 0.87. Tier 3 (personalized feedback) indicated lower accuracy (AR = 84.2%). This is determined by the fundamentally different nature of the task: the relevance of personalized feedback is more difficult to formalize verification compared to the accuracy of the assessment. Analysis of the results by specialty indicated that the highest validity indicators were recorded for texts by philology students (r = 0.91 at Tier 2) and psychologists-pedagogues (r = 0.89). The lowest scores were recorded for lawyers (r = 0.82). This pattern can be determined by the specificity of legal discourse, which is characterized by a higher proportion of precedent references, formalized argumentative structure, and terminological density.

Table 5.
TAM subscale scores by AKS

TAM subscale	Tier 1 M (SD)	Tier 2 M (SD)	Tier 3 M (SD)	F (2, 747)	p	η^2	Post-hoc
Perceived Usefulness (PU)	3.61 (0.82)	3.94 (0.71)	4.18 (0.68)	28.74	<.001	.071	T1<T2<T3*
Perceived Ease of Use (PEOU)	3.88 (0.77)	3.64 (0.83)	3.49 (0.84)	11.32	<.001	.029	T1>T2*, T1>T3**
Overall Satisfaction (OS)	3.52 (0.81)	3.79 (0.76)	4.03 (0.72)	19.87	<.001	.051	T1<T2<T3*
CFA model fit	CFI = 0.96; RMSEA = 0.048 [0.031, 0.065]; SRMR = 0.051						

*Note. * p < .05; ** p < .001 for Tukey HSD post-hoc pairwise comparisons. η^2 = eta-squared effect size: small ≥ .01, medium ≥ .06, large ≥ .14 (Cohen, 1988). CFA = Confirmatory Factor Analysis.*

The radar chart in Figure 3 indicated an integrated visual representation of the perception profile for the three levels of the AKS model simultaneously in the three dimensions of the TAM. The characteristic “shift” between the three levels is obvious: Tier 3 occupied the largest area along the PU and OS axes. At the same time,

Tier 1 was inferior to Tier 2 and Tier 3 only along the PEOU axis. The larger polygon area for Tier 3, followed by Tier 2 and Tier 1, suggests a more favorable overall pedagogical profile at higher levels of intellectualization.

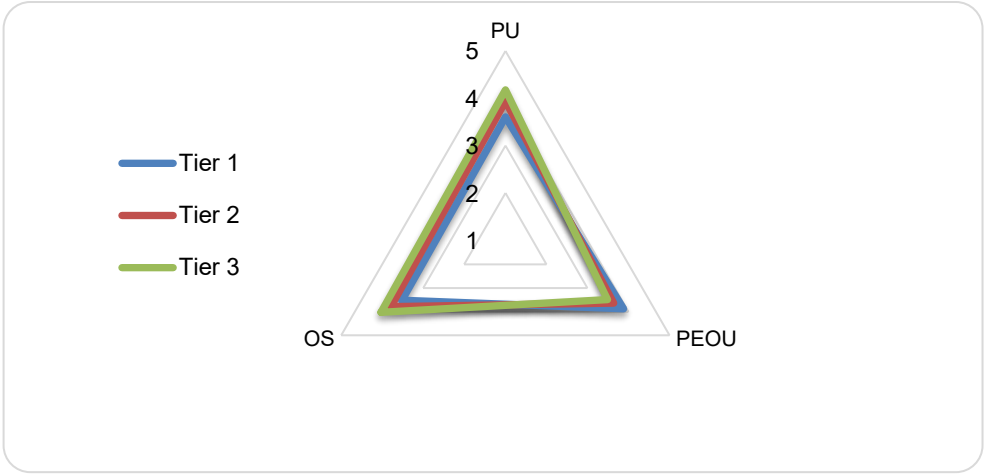


Figure 3. The visual representation of the perception profile for the three levels of the AKS model.
Source: Author's development

The fourth research question was the most difficult in this study, as it involved establishing the overall predictive impact of the three-level model of the AKS on students' academic achievement and decomposing this impact into the relative contributions of each level separately. Standard multiple regression methods were insufficient for this task, since standardized regression coefficients (β) are not correct indicators of the relative importance of predictors. Therefore, dominance analysis was used for this purpose, which decomposes the overall R^2 of the regression model into the contributions of each predictor. Hierarchical multiple regression with three predictors — Tier 1 indicator, Tier 2 indicator: $R^2 = .61$, $F(3, 246) = 128.7$, $p < .001$. Adjusted $R^2 = .607$ indicated a minimal degree of overfitting of the model. All three predictors made a significant contribution to explaining the variability of the dependent variable: Tier 1 ($\beta = 0.18$, $t = 4.21$, $p < .001$), Tier 2 ($\beta = 0.47$, $t = 9.84$, $p < .001$), Tier 3 ($\beta = 0.29$, $t = 6.17$, $p < .001$).

The results of the dominance analysis also indicated a hierarchy of the relative importance of the predictors. The largest overall dominance weight belongs to Tier 2 (semantic-discursive analysis): 0.31. This accounts for 50.8% of the total explained $R^2 = .61$. Thus, the semantic capacity of the system - its ability to capture the conceptuality, argumentative quality and discursive coherence of student responses - became a particularly important single predictor of academic achievement in the humanities.

Tier 3 (personalized feedback) ranked second in dominance weight (0.19, 31.1% of R^2). Thus, students' subjective perception of the system is related to real academic achievement. However, Tier 1 (syntactic-formal verification) received the lowest dominance weight (0.11, 18.1% of R^2). This determined its role as a necessary but insufficient fundamental level of the model.

The analysis of conditional and complete dominance allowed us to establish a stable hierarchy of predictors: Tier 2 completely dominated Tier 1 and Tier 3 in all possible subsets of the models (i.e., adding Tier 2 always increased R^2 more than adding any

other predictor, regardless of what other predictors were already included in the model). Data from the regression analysis and dominance analysis are presented in Table 6.

Table 6.
Hierarchical multiple regression and dominance analysis

Predictor	β	SE	t	p	sr^2	ΔR^2	Dom. weight	% of R^2
Tier 1 — Syntactic score	0.18	0.04	4.21	<.001	.031	.089	.11	18.1%
Tier 2 — Semantic score (SAS)	0.47	0.05	9.84	<.001	.184	.412	.31	50.8%
Tier 3 — Perceived Usefulness	0.29	0.05	6.17	<.001	.072	.109	.19	31.1%
Model	F(3, 246) = 128.7, p <.001			R^2 = .61; adj. R^2 = .607		VIF range: 1.14–1.38		

Note. β = standardized regression coefficient; SE = standard error of β; sr^2 = squared semi-partial correlation (unique variance explained by each predictor); ΔR^2 = incremental R^2 upon entry in hierarchical sequence (Tier1 → Tier2 → Tier3).

Thus, the increase in academic achievement reported in this study (ΔM = 13.3, d = 0.98) is one of the most important empirical findings that needs to be interpreted in the context of the current literature. A systematic review by Cavalcanti et al. (2021) of 60 primary studies on distance learning platforms found that 65% of documented cases of automatic feedback implementation were accompanied by an improvement in student academic achievement. The Cohen's d = 0.98 obtained in our study exceeded the median effect size typical for this body of research (d ≈ 0.45–0.60). This effect can be explained by several factors. In particular, unlike most studies included in the review by Cavalcanti et al. (2021), in which automatic feedback is limited to confirming the correctness of the answer, the AKS model in this study provided feedback of different levels of semantic complexity: argumentative and personalized dimensions. Mello et al. (2022) in a study of the use of NLP and learning analytics for assessing open-ended responses in Brazilian universities confirmed that it was semantically oriented feedback that became an important factor in learning progress when working with extended text responses.

However, it is worth noting that not all previous studies have reported improvements comparable to those observed in this study. Several studies of AI-assisted assessment and automated feedback have reported only modest to moderate improvements in learning outcomes or inconsistent effects across educational settings (e.g., Cavalcanti et al., 2021; Fajardo-Ramos et al., 2025). Such differences may be explained by variations in study design, intervention duration, disciplinary context, and functionality of the AI systems used. In many previous studies, AI tools have primarily been used for automated assessment or basic feedback generation. At the same time, the current AKS has integrated syntactic validation, semantic analysis, and personalized feedback within a single three-tier architecture. Therefore, the results should be interpreted with these methodological and technological differences in mind, rather than as direct evidence of superior effectiveness.

Differences between these results and previous studies may also reflect characteristics of the study population and study design. Participants represented humanities disciplines in which extended written responses and argumentation are the main learning activities. Such contexts may particularly benefit from AI systems capable of semantic analysis and individualized feedback. In contrast, studies conducted in STEM disciplines or using shorter interventions have often reported more modest effects. Furthermore, because this study used a single-group pre-

posttest design, the observed improvements cannot be attributed solely to the AKS intervention. Further research should compare the proposed model with alternative AI-based assessment systems using randomized or controlled experimental designs in different disciplines and educational contexts.

The dynamics of growth between measurement points T0–T5, however, the most intense growth at the stages T1→T3 and a further slowdown after T4, is in agreement with the findings of da Silva et al. (2022). These authors indicated that students who interacted with digital environments had a nonlinear dynamics of learning progress with a characteristic “plateau” after the initial intense growth. The observed effect of slowing growth after T4 did not contradict the overall effectiveness of the model. This effect reflected the natural regularity of adaptive systems, in which the initial “novelty of the stimulus” gradually reduced its motivational potential without reducing the educational effect in absolute terms (Falcão et al., 2020; Skrypnyk et al., 2024).

The correlation between the AKS and experts ($r = 0.87$, $\kappa = 0.79$) became important in the comparative dimension. Hilliger et al. (2020) in their study of the adaptation of learning analytics in Chilean, Colombian and Ecuadorian universities indicated that the main condition for the pedagogical legitimacy of algorithmic assessment systems was their ability to reproduce the numerical result and the logic of the disciplinary judgment of the human assessor. It was this ability that became crucial for the acceptance of the system by the pedagogical community. In this context, it is significant that Tier 2 of our model ($r = 0.91$) exceeded the typical values of inter-expert agreement for the humanities in terms of correlation. This determined the ability of transformative architectures to capture the semantic structures of human text. The lower Tier 2 validity for law students ($r = 0.82$ compared to the average $r = 0.91$ for philologists and psychologists) requires a separate discussion. In particular, Cechinel et al. (2020) in a large-scale mapping of educational analytics initiatives in Latin America pointed to the problem of “contextual shift”. The authors proved that tools developed and verified in one disciplinary space systematically lose effectiveness when transferred to another without prior domain adaptation. In our case, the model, trained mainly on general academic corpora, lost in legal discourse, in which precedential argumentation, terminological precision formed a semantic space that was insufficiently represented in the original training data. Ruiz-Casado et al. (2005) in early studies of automatic extraction of semantic relations for NLP systems recorded a fundamental dependence of the quality of semantic analysis on the representativeness of the training corpus. A practical solution may be fine-tuning of domain-specific variants of the model on legal academic corpora. This direction is developed in studies of automatic evaluation of Portuguese and Spanish texts (Carvalho et al., 2024).

The TAM analysis data (PU = 3.91, PEOU = 3.67, OS = 3.78) indicated a positive perception of AI tools by humanities students. This was a non-trivial result given the traditionally skeptical attitude of the humanities academic community towards algorithmic assessment. In particular, Salas-Pilco and Yang (2020) in their analysis of educational analytics initiatives in Latin America indicated that the main barrier to the adoption of digital educational technologies in the region is the lack of trust in algorithmic solutions by students and teachers. However, the higher PU score for Tier 3 ($M = 4.18$) in our study indicated that the personalized nature of the feedback partially eliminated this trust barrier. In addition, Ramírez-Montoya et al. (2022) indicated that students had a higher level of engagement with AI tools when they offered adaptive learning experiences.

The relationship between the level of intellectualization and perceived ease of use (PEOU: Tier 1 > Tier 2 > Tier 3) was theoretically predictable and consistent with patterns documented in educational technology research in the region. Garcia et al. (2021) and Oksanen et al. (2026) found that students rated more complex tools as less convenient even when they provided greater pedagogical benefit. This fact created a paradoxical tension between subjective perception and objective effect. Resolving this paradox requires thoughtful UX design of the AOS interface, which will be aimed at reducing cognitive load when interacting with the semantic and personalized levels of the system (Fajardo-Ramos et al., 2025; Guerrero-Quiñonez et al., 2023; Kosasi et al., 2020).

The data from the dominance analysis (Tier 2 = 50.8% > Tier 3 = 31.1% > Tier 1 = 18.1% of the total R^2 = .61) were the most informative result of this study. The study indicated that the dominance of Tier 2 (semantic-discursive analysis, 50.8%) confirmed the position about the central role of semantic understanding in the pedagogical assessment of humanities texts. Carvalho et al. (2024) also confirmed that NLP systems based on transformer embeddings had a higher correlation with learning outcomes compared to systems that were based on lexical-syntactic features.

The second most important contribution was made by Tier 3 (31.1%). It is worth considering the fact that Mello et al. (2022) found that the ability of the teacher to provide quality feedback on students' open-ended responses became important for learning progress. At the same time, the automation of this process based on the Tier 3 RAG architecture made it possible to scale personalized feedback without a proportional increase in the workload of the teacher. This effect has been identified as the main pedagogical value of automated assessment systems in education (Cavalcanti et al., 2021; Rodrigues et al., 2020). The potential of automated feedback systems extends beyond the humanities. A small pedagogical study of 60 third-year software engineering students who used AI-based pronunciation training tools (ELSA Speak, Speechling) for one semester found that 51.7% of participants showed significant improvement and 36.7% showed little improvement on a combined protocol of student self-assessment and pedagogical observation. Although the nature of the feedback tasks differed significantly from the discursive assessment proposed in this study, this converging evidence indicated that the underlying mechanism – systematic, personalized, AI-generated feedback – provided measurable learning outcomes across disciplinary contexts. This further strengthened the case for extending the three-tiered AKS architecture beyond the humanities.

The smallest contribution was received by the Tier 1 indicator (18.1%). This determined its role as a necessary, but functionally limited link in the model. da Silva et al. (2022), who analyzed the features of distance learning in Brazilian universities, indicated that formal indicators of text quality (spelling, syntactic structure) became weak predictors of academic success. The authors compared it with indicators of cognitive engagement and quality of argumentation. Other authors have also pointed out that the syntactic-formal level of text processing is a necessary, but insufficient foundation for modern systems (Cechinel et al., 2020; Duarte Ehlert et al., 2025).

Thus, the obtained data have several important practical implications. In particular, the hierarchy of predictors (Tier 2 > Tier 3 > Tier 1) became a direct recommendation regarding the priority of investments in the development of the system. Therefore, improving the semantic-discursive level will provide the highest expected pedagogical effect and should be prioritized compared to increasing the formal

accuracy of Tier 1. In addition, the phased strategy of implementing the levels of the AKS - which is implemented in the design of our study - became a pedagogically sound response to the identified “inverse relationship between depth and simplicity”. In addition, Lin et al. (2024) and Salas-Pilco and Yang (2020) indicated that adaptive interface complexity has become an important condition for the effective implementation of modern AI systems.

At the same time, the use of knowledge assessment systems based on artificial intelligence requires taking into account a number of ethical aspects. First of all, it has become important to ensure the transparency of algorithmic decisions so that teachers and students can understand the general principles of forming grades and recommendations. No less important is the problem of potential algorithmic bias, because language models can interpret student responses differently depending on the characteristics of the discipline, writing style or language structures. In addition, the implementation of such systems requires compliance with the principles of protecting students' personal data and secure storage of assessment results (Feitosa et al., 2025). In the proposed model, automated assessment was considered as a tool to support pedagogical decision-making, and not as a complete replacement for the teacher. That is why the human-in-the-loop principle, in which the teacher retains the ability to check and correct the results of automatic assessment, is considered a necessary condition for the responsible use of artificial intelligence in the educational process.

However, the study has a number of methodological limitations that must be taken into account when interpreting the results. In particular, the use of a quasi-experimental design of the one-group pretest-posttest type without a control group did not allow us to broadly exclude alternative explanations for the observed changes. For example, part of the increase in academic performance could be associated with the use of the AKS system and with the natural academic development of students during the semester (maturation effect). It is also worth paying attention to the opinions of Toda et al. (2018), who discussed the “shadow side” of gamification and digital educational technologies. The authors recalled that any assessment technology that strives for personalization carries the risks of algorithmic bias and increasing inequality between students with different language levels. These points should also be taken into account in further research. It is also worth considering the possible effects of re-testing (testing effect), when participants perform better on the post-test due to prior familiarity with the assessment structure. In addition, the influence of the Hawthorne effect cannot be completely ruled out, according to which the very fact of participation in the study and increased attention to the educational process could have a positive effect on student motivation and, accordingly, on learning outcomes. Also, the academic test was specially designed for the purposes of this study. Despite satisfactory psychometric characteristics, the use of the author's assessment tool may limit the external validity of the results due to the potential risk of constructive agreement between the test structure and the concept of the proposed AKS model.

Additional limitations are that the study was conducted only among students of humanities majors at Ukrainian higher education institutions during one academic semester. This may limit the possibility of generalizing the results to other disciplinary fields, educational systems, and longer periods of use of automated assessment systems. Further research is advisable to conduct using randomized or controlled experimental designs, using standardized assessment tools, independent samples from different universities, and testing the effectiveness of the proposed model in natural science, technical, and interdisciplinary educational contexts.

Conclusions

Thus, the study provides preliminary empirical support for the proposed three-level conceptual model of an automated knowledge assessment system (AKS) based on artificial intelligence.

The study provides preliminary empirical evidence supporting the construct- and criterion-related validity of the proposed three-level AKS model. The overall correlation with the average score of two experts was $r = 0.87$ ($p < .001$), the inter-expert agreement coefficient Cohen's $\kappa = 0.79$, F1-score = 0.89. At the same time, the somewhat lower validity for law students ($r = 0.82$) indicated the need for domain-specific fine-tuning of the model for highly specialized academic genres.

The findings suggest a significant increase in students' academic achievement: $t(249) = 31.42$, $p < .001$, $\Delta M = 13.3$ points, Cohen's $d = 0.98$. This value exceeded the values typical for studies on automated feedback and was recorded in both the subgroup of bachelors ($d = 0.94$) and masters ($d = 1.08$).

In addition, students of humanities specialties generally positively perceived the AKS model on all three dimensions of the TAM: PU = 3.91, PEOU = 3.67, OS = 3.78 (all significantly higher than the neutral value of 3.0, $p < .001$). The revealed pattern — the increase in PU and OS with an increase in the level of intellectualization of the system while simultaneously decreasing PEOU — indicated a fundamental pedagogical compromise between the semantic system and the subjective ease of interaction with it.

The study also recorded a hierarchy of the relative importance of the levels of the model in explaining the variability of educational achievements (total $R^2 = .61$): Tier 2 (dominance weight = .31; 50.8% of R^2) > Tier 3 (.19; 31.1%) > Tier 1 (.11; 18.1%).

All three levels made a statistically significant and unique contribution to the total R^2 and indicated that none of them is redundant in the structure of the model.

Thus, the scientific novelty of this study lies in the verification of a three-level hierarchical model of the AKS, which integrates the syntactic-formal, semantic-discursive, and personalized levels of intellectualization into a single architecture. Hence, the present study provides preliminary empirical support for the proposed three-tier conceptual model.

Further studies should evaluate the proposed model using randomized controlled designs, standardized assessment instruments, and diverse educational contexts to establish its generalizability and strengthen the evidence supporting the proposed architecture.

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Original Article

La gamificación en la formación del profesorado: Cómo mejorar la motivación de los futuros maestros de primaria

Gamification in teacher education: Enhancing the motivation of pre-service primary school teachers

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Resumen

La gamificación se ha consolidado como un enfoque pedagógico eficaz para potenciar la motivación y la competencia profesional de los estudiantes en la educación superior. Este estudio tuvo como objetivo desarrollar y evaluar la efectividad de un sistema de instrucción basado en la gamificación, diseñado para mejorar la motivación de los futuros maestros de primaria. Un diseño de investigación de métodos mixtos combinó el análisis teórico con un experimento pedagógico en el que participaron 104 estudiantes de primer año de la carrera de Educación Primaria, asignados aleatoriamente a un grupo experimental (n = 52) y a un grupo de control (n = 52). La intervención integró herramientas digitales de gamificación, actividades de aprendizaje interactivas y condiciones pedagógicas específicas. El grupo experimental demostró una mejora significativamente mayor que el grupo de control. La proporción de estudiantes que alcanzaron niveles creativos y profesionales aumentó del 26,9 % al 73,1 % en el criterio motivacional y del 26,9 % al 71,2 % en el criterio de contenido-actividad, mientras que la proporción en el nivel bajo disminuyó del 42,3 % al 7,7 % y del 40,4 % al 9,6 %, respectivamente. El análisis estadístico confirmó diferencias significativas entre grupos tras la intervención ($t > 1,967$, $p < 0,05$). Los resultados demuestran que la integración sistemática de la gamificación en la formación docente con apoyo digital mejora significativamente la motivación y la competencia profesional de los estudiantes.

Palabras clave: gamificación del proceso educativo; motivación; futuros maestros de primaria; entorno digital; educación superior.

Abstract

Gamification has emerged as an effective pedagogical approach for enhancing student motivation and professional competence in higher education. This study aimed to develop and evaluate the effectiveness of a gamification-based instructional system designed to enhance the motivation of pre-service primary school teachers. A mixed-methods research design combined theoretical analysis with a pedagogical experiment involving 104 first-year undergraduate students in Primary Education, randomly assigned to an experimental group (n = 52) and a control group (n = 52). The intervention integrated digital gamification tools, interactive learning activities, and targeted pedagogical conditions. The experimental group demonstrated significantly greater improvement than the control group. The

proportion of students achieving creative and professional levels increased from 26.9% to 73.1% for the motivational criterion and from 26.9% to 71.2% for the content-activity criterion, while the proportion at the low level decreased from 42.3% to 7.7% and from 40.4% to 9.6%, respectively. Statistical analysis confirmed significant between-group differences following the intervention ($t > 1.967$, $p < 0.05$). The findings demonstrate that the systematic integration of gamification into digitally supported teacher education significantly enhances students' motivation and professional competence.

Keywords: gamification of the educational process; motivation; future primary school teachers; digital environment; higher school.

Introduction

Modern educational realities require the search for innovative methods that combine personality development and learning through emotionally rich, engaging forms. Educational game technologies have gained widespread popularity, thereby defining the didactic game as a method or means of learning.

Classical approaches are receiving new development in the era of digitalization. Therefore, today, gamification is considered in numerous publications to be an innovative technology for productive activity and learning. The growing interest in gamification across various fields is clearly demonstrated by the corresponding Google service, which is classified as a “breakthrough”.

The digital transformation of higher education has fundamentally changed approaches to teaching, learning, and professional training. The integration of digital technologies into educational practice requires innovative pedagogical strategies capable of increasing students' engagement, motivation, and professional competence. Among these strategies, gamification has attracted considerable attention as an approach that incorporates game mechanics into educational environments to stimulate active participation, collaborative learning, and meaningful knowledge construction. In teacher education, gamification is particularly relevant because future primary school teachers are expected to design motivating, learner-centred, and technology-enhanced learning experiences that meet the educational needs of contemporary schoolchildren.

Recent international studies demonstrate that gamification positively influences learners' academic achievement, intrinsic motivation, engagement, and critical thinking. Research has shown that game-based learning environments improve learning outcomes compared with traditional instruction, promote emotional competence, and encourage active participation in educational activities. Moreover, the integration of digital technologies, including learning management systems, interactive platforms, artificial intelligence, and virtual or augmented reality, has expanded the pedagogical potential of gamification by enabling adaptive, collaborative, and personalized learning experiences.

Despite these advances, several research gaps remain. Existing studies primarily examine isolated gamification tools or specific digital platforms, whereas comparatively little attention has been devoted to the development and experimental validation of comprehensive pedagogical systems that integrate digital technologies, instructional strategies, and organizational conditions to enhance the motivation of pre-service primary school teachers. Furthermore, limited empirical evidence is

available regarding the effectiveness of such integrated approaches within higher education institutions.

The present study addresses this gap by proposing and experimentally evaluating a comprehensive gamification-based instructional system designed to enhance the motivation of future primary school teachers in a digitally supported educational environment. Unlike previous research focusing on individual digital applications, this study examines the combined effect of pedagogical conditions, digital learning tools, and structured gamified learning activities on students' professional development.

The findings contribute to the growing body of research on digital pedagogy by providing empirical evidence regarding the effectiveness of systematic gamification in teacher education. The study also offers practical recommendations for designing digitally enriched learning environments that foster motivation, engagement, and professional competence among future teachers.

The remainder of this article is organized as follows. The Literature Review synthesizes current international research on gamification, digital learning environments, and teacher motivation while identifying the existing research gap. The Methodology section describes the research design, participants, intervention, research instruments, and statistical procedures. The Results and Discussion section presents the findings of the pedagogical experiment and compares them with previous empirical studies. Finally, the Conclusions summarize the main theoretical and practical contributions of the study, acknowledge its limitations, and outline directions for future research.

Literature Review

The effectiveness of gamification in higher education for increasing the motivation of future primary school teachers is supported by international studies.

Interesting and necessary are the studies by Lampropoulos and Sidiropoulos (2024) on students' motivation and level of involvement, and on the increase in their academic results in gamified learning compared to the traditional educational process.

Wulan et al. (2024) demonstrate a positive impact of students' involvement in the gaming process on learning, reveal ways to improve memorization, and present directions for solving educational problems.

Studies by Cès et al. (2026) systematically show how and to what extent board games contribute to the development of emotional competence in children – in particular, they reduce problematic behavior, improve social interaction, support emotional well-being, and help children learn knowledge better.

Vrcelj et al. (2023) review child-centered learning that includes play-based methods to develop problem-solving, decision-making, and critical thinking skills. They conclude that gamification helps to make learning more interactive and interesting for both students and pupils.

Researchers Khaldi et al. (2023) demonstrate the importance of gamification in education and show ways to use aesthetics, game thinking, and game mechanics to promote student motivation, learning, and the resolution of motivational problems.

Scientists Sáez-López et al. (2022) analyze the application of gamification and game-based learning in primary education, highlighting teachers' positive attitudes towards these approaches and emphasizing that appropriate resources, lesson planning, and teacher training can enhance student motivation, commitment, and enthusiasm for interactive learning processes.

Researchers Zaric et al. (2021), taking into account the individual characteristics of education seekers, theoretically substantiate the issue of gamified learning.

However, the issue of gamifying the educational process to increase the motivation of future primary school teachers has not been sufficiently investigated.

The purpose of the study is to develop and test the system's effectiveness for implementing gamification in higher education to increase the motivation of future primary school teachers.

Methodology

Research Design

The study employed a mixed-methods research design combining theoretical and empirical approaches. The theoretical component included analysis, synthesis, comparison, systematization, and generalization of scientific literature on gamification, digital technologies, and professional teacher education. The empirical component consisted of a pedagogical experiment conducted during the 2024–2025 academic year to verify the effectiveness of the developed system for implementing gamification in higher education.

Participants

The study involved **104 first-year undergraduate students** majoring in Primary Education from higher education institutions in Ukraine. The participants voluntarily agreed to participate in the research and met the inclusion criteria established for the study. They were randomly assigned to two equivalent groups: the **experimental group (EG, n = 52)** and the **control group (CG, n = 52)**. Random allocation ensured comparable baseline characteristics of both groups before the intervention.

Research Procedure

The pedagogical experiment consisted of two consecutive stages.

During the **ascertaining stage**, the initial level of students' motivation to use gamification in the educational process was determined.

During the **formative stage**, the experimental group studied using the developed system of gamification implementation and the proposed pedagogical conditions, whereas the control group continued learning according to the traditional educational approach without systematic implementation of gamification technologies.

Research Instruments

The effectiveness of the developed system was evaluated according to two criteria:

– Motivational.

– Content-activity.

For each criterion, four levels of competence formation were identified:

– Creative.
– Professional.
– Basic.
– Low.

The assessment was carried out using a system of diagnostic methods developed for the purposes of the study. The obtained results were recorded as absolute frequencies (**n**) and percentages (**%**) for each level within the experimental and control groups.

Data Analysis

Statistical analysis was performed using descriptive and inferential statistics. Descriptive statistics included frequencies and percentages for each competence level. Differences in the distribution of competence levels between the experimental and control groups were assessed using Pearson's chi-square (χ^2) test at a significance level of $\alpha = 0.05$. The χ^2 test was applied to determine the homogeneity of the groups at the ascertaining stage and to evaluate the effectiveness of the intervention at the formative stage.

Statistical analysis was performed using descriptive and inferential statistics. Descriptive statistics included absolute frequencies (n) and percentages (%) for each competence level. Since the study variables were categorical (creative, professional, basic, and low levels), Pearson's chi-square (χ^2) test was used to compare the distributions between the experimental group (EG) and the control group (CG). The χ^2 test was applied at the ascertaining stage to verify the initial homogeneity of the groups and at the formative stage to evaluate the effectiveness of the pedagogical intervention. Statistical significance was established at $\alpha = 0.05$. A p-value greater than 0.05 at the ascertaining stage indicated that no statistically significant differences existed between the groups before the intervention, confirming their baseline equivalence. Conversely, statistically significant differences observed after the intervention ($p < 0.05$) confirmed the effectiveness of the implemented gamification system.

Ethical Considerations

Participation in the study was voluntary. All participants provided informed consent before the experiment began. The anonymity and confidentiality of respondents were ensured throughout the research, and the collected data were used exclusively for scientific purposes in accordance with generally accepted ethical principles of educational research.

Results and Discussion

Classification of game practices in the educational process of higher education. Advantages and disadvantages of using gamification in education.

An important component of the educational process is game practice, which contributes to the development of key competencies among pupils and students and

to the activation of their cognitive activity. Game practices are actively used not only in primary and secondary education, but also in higher education. The types of game practices in higher education are presented much more widely: these are role-playing games that allow playing certain life roles, business games that provide reproduction of the social and subject specifics of a certain professional activity of an individual, talk show technologies in which all participants participate and provide an opportunity to conduct structured discussions, game-exercises provide consideration of various professional situations, various digital tools to increase the motivation of future teachers (Palshkov et al., 2026).

Media games play a key role in the training of future primary school teachers, contributing to a creative approach to problem-solving, the formation of a comprehensively developed personality, and the ability to communicate effectively, think critically, and adapt to changing conditions in the modern information society (Bassanelli et al., 2022). Thus, the classification of game practices in the educational process of higher education is multidimensional and depends on the content of the material, the purpose of learning, and the age characteristics of each individual. The adaptability and flexibility of game methods are evident in the variety of approaches in modern pedagogy for classification.

The use of gamification in education has certain advantages and disadvantages.

The advantages include:

- New information is easily perceived through the game.
- The game brings relaxation and fun to the educational process.
- The element of competition and excitement present in the game allows you to keep and attract the attention of the audience.
- The game allows you to easily move to the generation of ideas, an active creative process.
- There is no external pressure in the game, and no psychological stress.
- Throughout the game, the senses and movement are trained, adaptation mechanisms are developed, and attention and observation are honed, which serves as preparation for the struggle for life (Aris et al., 2024).
- Teamwork to achieve the game's goal.
- The game develops communication skills.
- Motivation, which is directly derived from the game process, is the primary driver of the student's and child's activity.
- The opportunity to get pleasure and enjoyment from the game, to be equal to all participants in the game process by limiting the freedom of action between players, and conscious acceptance.

Let us name the disadvantages of using gamification:

- Due to the perception of the game as entertainment, a decrease in the level of responsibility, and the lack of recognition as a learning tool.
- Complexity of application (poorly selected games, ignorance of the method of use, unclear rules, etc.).
- Lack of seriousness.
- Opposition from the audience arising from the student's individual, psychological, and pedagogical characteristics.
- In the educational process, the game is not an end in itself.

Based on the different approaches to the use of gamification in education, the teacher's skill in selecting methods and games for application comes to the fore.

The teacher can, through the game, correct the student's behavior; gradually influence children's character; note certain patterns; improve and develop students' skills and abilities; provide psychosocial support to children according to their emotional state and age; and ensure the preservation and stability of mental health.

Use and classification of digital tools to create an effective digital environment in higher education through gamification.

A variety of digital tools are necessary for creating an effective digital environment through gamification (Li et al., 2024). Based on their primary functions, these tools can be broadly classified by the role they play in supporting gamified learning. allowing learners to interact with educational content actively:

- Tools, using game functions, designed to provide content (repositories and electronic libraries, online course platforms, mobile educational applications).
- Tools that provide feedback and assessment of learning achievements, in order to motivate and encourage higher education students to improve their knowledge and practical skills (learning management systems, quizzes, online tests).
- Tools designed to facilitate communication and teamwork (online brainstorming boards, file-sharing platforms, and video conferencing) are important in many gamified scenarios.

Digital tools are characterized by their adaptability and technical sophistication, allowing educators to design higher education learning processes in line with group dynamics and the individual needs of higher education students. Some tools offer simple interfaces designed to motivate higher education students, using icons and points, while others include advanced analytics. Developing teamwork and communication skills can promote collaborative learning through team competitions, *Edmodo, Google Classroom,* and *Moodle*, with gamification plugins that combine educational content with motivating game elements to create a more effective and attractive learning environment. For example, Moodle allows you to store data on learners' educational achievements, administer tests, create interactive courses, and collect feedback (Kuchai et al., 2017).

The ability to integrate gamification plugins, such as *Stash*, *Game*, and *Level Up!*, is particularly valuable, as they allow you to move to a higher level for completing tasks and to add awards and points for education seekers.

Google Classroom provides distribution and quick task creation, communication among students, and assessment. This platform, in combination with other Google tools, enables the organization and monitoring of individual student progress and the building of their educational trajectories.

Edmodo is a system with social network functions that aims to manage learning, support resource sharing and learning communities, and help conduct final and thematic testing for students. Game platforms play a key role in personally oriented learning in educational digital environments, focusing on the student's internal motivation, placing him at the center of the educational process and learning activities, and using game tasks to develop critical thinking skills and to ensure cooperation, communication, and independence.

Game platforms can be adapted to different academic disciplines: mathematics, natural sciences, languages, history, etc.

One example of a game platform is *Kahoot!*, a widely used game-based learning platform that offers interactive tasks and quizzes, making it particularly effective for personally oriented learning (Sinnivasagam & Hua, 2023).

Wordwall is used to develop exercises to consolidate and repeat material, create quizzes, and interactive games (Halatsyn & Feshchuk, 2024). This platform allows you to choose several game formats at the same time, including quizzes or crosswords, "Paired cards", "Spin the wheel", and "Word clouds". The advantages of Wordwall are the ability to adapt tasks to age, ease of use, competition, and instant feedback.

LearningApps is useful across different educational disciplines for developing interactive exercises (Stefaniak & Carey, 2019).

A special educational environment is created by immersive technologies, including augmented and virtual reality tools, that combine them with digital or simulated versions of the real world. Yes, such technologies can merge objects from the real environment with the virtual one and project a variety of digital information beyond the boundaries of device screens. It is enough for students to have only a mobile phone for work. At the same time, the user is transported to the artificial world of virtual reality. A necessary condition for working with such technologies is the availability of special tools. Augmented and virtual reality tools are used to study complex processes and objects (Beheshti et al., 2024).

Students can actively communicate in a virtual environment with virtual characters, working in a setting close to the real one. To increase the motivation of students, augmented and virtual reality tools are used in competitions, ratings, points, and virtual awards, which create an interactive educational environment in which students can receive hints, interact with other objects or subjects, and work with emotional involvement in educational scenarios that form the context (Cabrera-Solano, 2022).

The educational virtual reality platform *ClassVR* contains a large library, uses VR headsets with built-in screens (specialized equipment), and does not require computers or smartphones. ClassVR has a teacher control panel and offers hundreds of videos and interactive images for use across various educational disciplines (Su et al., 2022).

Discord is a cross-platform text messaging program for organizing video and audio conferences and for uniting in communities.

Discord allows you to create virtual communities, where you can integrate additional educational tools, organize channels by topic, communicate in chat or live, and exchange files (Zhang & Huang, 2024).

The use of virtual and augmented reality technologies, digital platforms, and adaptive learning systems supports diverse learning styles and promotes personalized education. Therefore, it can be argued that gamification is shaping a new educational landscape focused on the comprehensive development of the individual (Vera-Monroy et al., 2024). Recent research on distance and blended

learning indicates that integrating gamification into STEAM education has the potential to significantly enhance the effectiveness of the educational process.

Organization and methodology of experimental work.

The use of empirical research methods in the form of a pedagogical experiment is a supplement to the theoretical research, which provided proof of the effectiveness of the developed system for implementing gamification in the educational process to increase the motivation of future primary school teachers, thereby verifying the proposed research goal.

The purpose of the experimental work is to develop and verify the effectiveness of the system for introducing gamification into the higher school educational process to increase the motivation of future primary school teachers through its implementation and approval in higher education institutions.
The plan of the pedagogical experiment outlined separate main stages, each characterized by a sub-goal and a set of tasks.

The **ascertaining stage** aimed to determine the current state of gamification implementation in the educational process at a higher school to increase the motivation of future primary school teachers.

The goal of the **formative stage** was to introduce into the educational process of higher education institutions the developed optimal system and pedagogical conditions for implementing gamification of the higher school educational process to increase the motivation of future primary school teachers.

At the ascertaining stage, a preliminary survey was conducted among 78 respondents, including university teachers and future primary school teachers, to determine their awareness of the content, advantages, and methods of implementing gamification in higher education. The results of this survey were used to identify the current state of the problem and to refine the design of the pedagogical experiment.

To the question to teachers and students, "What advantages do you think gamification of the educational process has compared to traditional approaches to education?" the following results were obtained:

- 84.6% of respondents noted the importance of using Internet resources and emphasized the need to create an effective digital environment of higher education through gamification.
- 79.5% of respondents indicated that future primary school teachers should develop their own lifelong learning trajectories through gamification.
- 61.5% of respondents noted the need to use innovative pedagogical activities, including introducing game-based practices into the educational process and adopting an individual approach to each student.
- 55.1% of respondents noted the importance of introducing STEAM education in higher schools as a key direction for improving the educational process, to motivate students and free up classroom time for implementing game-based methods.

Based on the results of the ascertainment section, we see that students and teachers clearly understand the advantages of implementing game-based practices in the educational process and focus on the necessary professional qualities of a 21st-century specialist.

Let us emphasize the answers to the questionnaire that we received from students.

- 80.8% of future specialists agreed with the statement that “Gamification tools provide students with the opportunity to use the knowledge acquired in practice more effectively”.
- 97.4% of respondents, to demonstrate their understanding of the significance of gamification tools, strongly agreed with the statement: “Gamification tools motivate students to study the discipline more than traditional approaches”.

So, we say that students clearly understand the need to use gamification tools in the educational process because they enhance their competitiveness in the labor market and positively affect their professional competence.

Within the framework of the ascertaining stage, the final step was to determine the initial level of motivation formation among future primary school teachers to use gamification in the educational process to increase professional competence.

We have developed a system of criteria (motivational, content-activity) and levels (creative, professional, basic, low).

The levels of motivation formation of future primary school teachers to apply gamification in the educational process to increase professional competence, according to the motivational criterion, at the ascertaining stage of the pedagogical experiment are shown in Table 1.

Table 1.
Levels of formation of professional competence of students by applying gamification in the educational process according to the motivational criterion at the ascertaining stage

Level	EG, n (%)	CG, n (%)
Creative	3 (5.8%)	3 (5.8%)
Professional	11 (21.2%)	11 (21.2%)
Basic	16 (30.8%)	16 (30.8%)
Low	22 (42.3%)	22 (42.3%)
Total	**52 (100.0%)**	**52 (100.0%)**

Source: developed by the author

Having analyzed the results obtained at the ascertaining stage in the EG and CG according to the motivational criterion, we can state that the majority of respondents in both groups have a basic and low level of formation of the outlined phenomenon according to this criterion, which indicates a vague understanding of the ways of using gamification, the values of their own professional activities and insufficient motivation of students to master the profession.

Monitoring of formation in accordance with the content-activity criterion was carried out, taking into account the peculiarities of the professional training of future primary school teachers.

Two indicators were evaluated according to the content-activity criterion:

- Systematicity and thoroughness of theoretical, general professional, and practical narrowly professional skills, abilities, and knowledge through positive motivation of future primary school teachers.

– Effective use of gamification in the educational process to improve professional knowledge, abilities, and skills in situational professional activity.

The levels of motivation formation of future primary school teachers to use gamification in the educational process to increase professional competence, according to the content-activity criterion, at the ascertaining stage of the pedagogical experiment are shown in Table 2.

Table 2.
Levels of formation of professional competence of students through the use of gamification in the educational process according to the content-activity criterion at the ascertaining stage

Level	EG, n (%)	CG, n (%)
Creative	2 (3.8%)	2 (3.8%)
Professional	12 (23.1%)	11 (21.2%)
Basic	17 (32.7%)	18 (34.6%)
Low	21 (40.4%)	21 (40.4%)
Total	**52 (100.0%)**	**52 (100.0%)**

Source: developed by the author

Having analyzed the results obtained at the ascertaining stage in the EG and CG according to the content-activity criterion, we can state that the majority of respondents in both groups, according to this criterion, have a low and basic level of formation of the outlined phenomenon, which indicates insufficient use of gamification, values of their own professional activity and insufficient motivation of students to use gamification in professional activity.

The average values of the formation indicators were calculated similarly for the EG and CG, according to the content-activity criterion (Table 2).

The study showed that, according to the content-activity criterion, there is no statistically significant difference in the average results between the EG and CG; that is, the difference is random.

Thus, according to the results of the ascertaining stage of the pedagogical experiment, we observe in both groups of students a basic and low level of formation of the outlined phenomenon, which indicates the relevance of the formative stage of the study.

Implementation of an experimental optimal system and pedagogical conditions for implementing gamification of the higher school educational process to increase the motivation of future primary school teachers.

Rather than being implemented as isolated digital tools, the selected applications were integrated into a coherent pedagogical framework aligned with the curriculum of the Primary Education programme. The instructional design followed the principles of constructive alignment, ensuring that each digital resource supported specific learning outcomes, instructional activities, and assessment procedures.

The gamified learning process was organized into four interconnected stages. During the **orientation stage**, interactive polling and diagnostic tools (e.g., Mentimeter and Quizizz) were used to activate prior knowledge, identify students' initial understanding, and increase engagement at the beginning of each learning module. During the **knowledge construction stage**, collaborative platforms and

digital content creation tools (e.g., Genially, Canva, and Powtoon) enabled students to develop educational materials, solve authentic pedagogical tasks, and collaboratively construct knowledge through project-based activities.

The **practice stage** incorporated simulation-based and game-oriented applications, including AI-supported environments and role-playing activities, allowing students to apply theoretical knowledge to realistic teaching situations, develop decision-making skills, and reflect on classroom practice. Finally, the **assessment and reflection stage** employed formative assessment platforms such as Quizizz, Socrative, and Formative to provide immediate feedback, monitor learning progress, and support students' self-regulation throughout the intervention.

To avoid cognitive overload, only a limited number of digital applications were introduced within each instructional module, and each platform served a clearly defined pedagogical purpose. The same core set of digital tools was used consistently across the intervention, allowing students to become familiar with the learning environment while gradually developing professional competence rather than spending time adapting to new technologies. Consequently, digital technologies functioned as pedagogical instruments embedded within the curriculum rather than as independent learning objectives, ensuring that gamification enhanced rather than distracted from the educational process.

Dynamics of developing students' professional competence through the creation of optimal systems and pedagogical conditions for introducing gamification into the higher education process to increase the motivation of future primary school teachers.

The formative stage of the pedagogical experiment took place during 2024-2025. Its goal was to verify the effectiveness of the developed system and the pedagogical conditions of the outlined phenomenon.

The pedagogical experiment provided for two control points: the ascertaining and formative stages.

We also used a comparative method of scientific research in the control and experimental groups, which enabled comparison of diagnostic results for the level of formation of the outlined phenomenon during the pedagogical experiment. A comparative analysis of changes in the level of formation of students' professional competence after the completion of the implementation of the created optimal system and pedagogical conditions for the implementation of gamification of the educational process of higher school to increase the motivation of future primary school teachers was carried out according to each of the specified criteria separately. were identical for the formative and ascertaining stages of the methodology for diagnosing the level of formation of the outlined phenomenon.

Let us consider the results of the diagnostics of the formation of the outlined phenomenon at the formative stage. The levels of motivation of future primary school teachers to use gamification in the educational process to increase professional competence, according to the motivational criterion, at the formative stage of the pedagogical experiment are shown in Table 3.

Table 3.
Levels of motivation of future primary school teachers to use gamification in the educational process in order to increase professional competence according to the motivational criterion at the formative stage

Level	EG, n (%)	CG, n (%)
Creative	21 (40.4%)	6 (11.5%)
Professional	17 (32.7%)	12 (23.1%)
Basic	10 (19.2%)	21 (40.4%)
Low	4 (7.7%)	13 (25.0%)
Total	**52 (100.0%)**	**52 (100.0%)**

Source: developed by the author

Having analyzed the results obtained at the formative stage in the EG and CG by the motivational criterion, we can state that the majority of the EG group respondents have a creative and professional level, and the CG respondents have a basic and low level of formation of the outlined phenomenon by this criterion, although their results have improved. This indicates a significant increase in the motivation of future primary school teachers in the EG to use gamification in the educational process.

The levels of formation of the motivation of future primary school teachers to use gamification in the educational process to increase professional competence, according to the content-activity criterion, at the formative stage of the pedagogical experiment are shown in Table 4.

Table 4.
The levels of formation of the motivation of future primary school teachers to use gamification in the educational process in order to increase professional competence by the content-activity criterion at the formative stage

Level	EG, n (%)	CG, n (%)
Creative	21 (40.4%)	9 (17.3%)
Professional	16 (30.8%)	15 (28.8%)
Basic	10 (19.2%)	12 (23.1%)
Low	5 (9.6%)	16 (30.8%)
Total	**52 (100.0%)**	**52 (100.0%)**

Source: developed by the author

Having analyzed the results obtained at the formative stage in EG and CG according to the content-activity criterion, we can say that in EG, the majority of respondents are at the creative and professional levels. Among CG respondents, a low and basic level of formation of the described phenomenon prevails. However, we also observe a positive shift in CG.

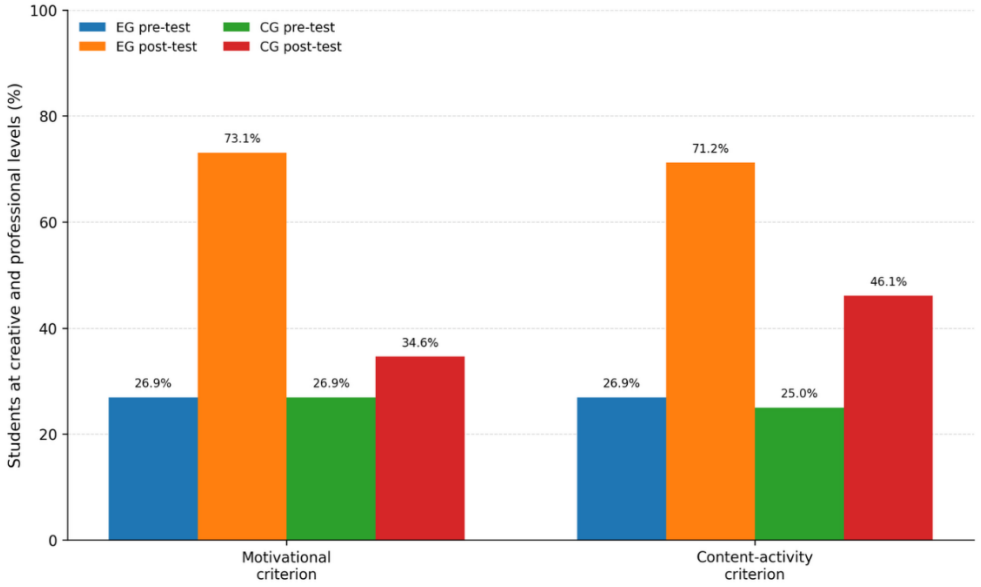


Figure 1. Changes in students' professional competence before and after the intervention according to the motivational and content-activity criteria.

The comparative dynamics of the results obtained in the experimental and control groups demonstrate a substantial increase in the proportion of students who achieved creative and professional levels in the experimental group after the intervention. The changes in the control group were considerably less pronounced, confirming the effectiveness of the proposed pedagogical conditions and the systematic integration of gamification into the educational process. The average values of the formation indicators were calculated in the same way for EG and CG across all criteria, as in the ascertainment experiment.

The average values of the formation indicators were calculated for the EG and CG across all criteria in the same way as in the ascertainment experiment.

Although the results demonstrated a statistically significant improvement in students' professional competence following the implementation of gamification, these findings should be interpreted in light of several pedagogical challenges reported in previous studies. Researchers have noted that some students initially perceive game-based learning as less academically rigorous than conventional instruction, which may reduce motivation among learners who prefer traditional educational approaches. In addition, resistance to unfamiliar digital environments, differences in digital literacy, and concerns about excessive competition have been identified as potential barriers to successful implementation.

These challenges were also observed during the initial stage of the intervention, particularly among students who had limited prior experience with gamified learning environments. However, their influence gradually diminished as participants became familiar with the instructional format and recognized the educational value of game-based activities. To minimize these risks, gamification was integrated into the curriculum as a pedagogical strategy rather than as an independent instructional objective. Competitive elements were balanced with collaborative learning tasks, reflective activities, and continuous formative feedback, ensuring that learning outcomes remained the primary focus of the educational process.

Therefore, the positive outcomes obtained in this study should not be interpreted as evidence that gamification is universally effective in all educational contexts. Its pedagogical value depends on thoughtful instructional design, alignment with curricular objectives, students' digital readiness, and the balanced integration of motivational and cognitive learning activities. These considerations highlight the importance of adapting gamification to the characteristics of learners and institutional contexts rather than treating digital game elements as universally applicable educational solutions.

The findings of the present study are consistent with previous international research demonstrating the positive educational impact of gamification in higher education. In particular, the significant increase in students' motivation and professional competence observed in the experimental group confirms the conclusions of Lampropoulos and Sidiropoulos (2024), who reported that gamified learning environments produce higher academic performance than traditional instructional approaches.

Our findings also support the systematic review by Khaldi et al. (2023), which identified gamification as an effective strategy for enhancing student engagement and motivation in higher education. Similarly, the positive role of digital educational tools identified in this study corresponds to the results of Li et al. (2024), who demonstrated that learning engagement mediates the relationship between digital games and students' motivation. The present findings are further aligned with the conclusions of Sáez-López et al. (2022), who emphasized that successful implementation of gamification depends on appropriate pedagogical design and teacher preparedness. Moreover, our results support the observations of Vrcelj et al. (2023), who concluded that game-based learning promotes active participation, critical thinking, and learner-centred educational practices.

Unlike many previous studies that focused primarily on individual gamification tools or separate digital applications, the present research demonstrates the effectiveness of a comprehensive pedagogical system integrating digital platforms, collaborative learning, formative assessment, and structured pedagogical conditions within teacher education. Therefore, the study extends the existing evidence by showing that the systematic pedagogical integration of gamification contributes not only to higher student motivation but also to the development of professional competence among future primary school teachers.

Conclusions

This study confirmed the effectiveness of a pedagogically designed gamification approach for developing the professional competence of future primary school teachers in higher education. The findings demonstrated that integrating digital game-based strategies into the curriculum contributes to higher levels of student engagement, collaborative learning, reflective practice, and the acquisition of professionally relevant competencies. The statistically significant differences identified between the experimental and control groups after the intervention indicate that the proposed instructional model produced measurable educational benefits.

A key contribution of the study lies not in the use of individual digital applications but in the development of a coherent pedagogical framework that systematically integrates gamification into the educational process. The instructional design aligned digital tools with learning objectives, collaborative activities, formative assessment, and continuous feedback, ensuring that game elements functioned as instruments for achieving educational outcomes rather than as independent learning goals. This

methodological approach reduced the risk of cognitive overload and supported the gradual development of students' professional competence.

The obtained findings are consistent with previous research highlighting the educational potential of gamification while also extending existing knowledge by demonstrating that its effectiveness depends primarily on pedagogically meaningful integration within the curriculum. At the same time, the study acknowledges that the successful implementation of gamification is influenced by students' digital readiness, teachers' methodological competence, and institutional support. Consequently, the positive outcomes should not be interpreted as universally transferable to all educational contexts without appropriate pedagogical adaptation.

The practical significance of the study lies in providing higher education institutions with an evidence-based model for integrating gamification into teacher education programmes. The proposed approach may be used to redesign professional training courses, improve student motivation, strengthen formative assessment practices, and foster the development of professional competencies required in contemporary digital learning environments.

Several limitations should be considered when interpreting the findings. The study was conducted within a single institutional context and focused on one field of teacher education, which may limit the generalizability of the results. Furthermore, the intervention evaluated short-term educational outcomes, whereas the long-term sustainability of competence development was not investigated.

Future research should examine the longitudinal effects of gamification on professional competence, compare the effectiveness of different gamification models across disciplines and educational levels, and investigate how individual learner characteristics, digital competence, and institutional factors moderate the educational impact of game-based learning strategies. Such studies would contribute to refining evidence-based approaches to the pedagogically meaningful integration of gamification in higher education.

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Original Article

Utilización de simulaciones interactivas inmersivas y registros analíticos digitales para mejorar la toma de decisiones y la percepción de la situación de los cadetes

Using interactive immersive simulations and digital analytical records to improve cadets' decision-making and situational awareness

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Resumen

La rápida adaptación de los futuros especialistas a las condiciones extremas de la actividad profesional hace relevante la introducción de simulaciones interactivas para el modelado realista de situaciones didácticas orientadas a escenarios. El estudio evalúa la eficacia pedagógica del entrenamiento con simulaciones interactivas en el desarrollo de habilidades de toma de decisiones, conciencia situacional e interacción en equipo entre los cadetes. Para este propósito, se utilizaron los siguientes métodos: búsqueda focalizada, análisis comparativo y evaluación de la eficacia. La verificación empírica basada en una muestra de 64 cadetes mostró una mejora significativa en la dinámica de desarrollo de los indicadores clave de la formación profesional en el grupo experimental. El tiempo integral de finalización de la tarea disminuyó un 54%, la velocidad de reacción cognitiva aumentó un 67%, la precisión de las acciones objetivo (minimización de errores) aumentó un 46%. Este estudio demuestra un novedoso análisis pedagógico integral de las simulaciones interactivas basado en características técnicas y funcionales, así como en el parámetro integral de preparación para el uso. Investigaciones futuras deberían centrarse en ampliar la muestra de participantes para aumentar la fiabilidad estadística de los resultados.

Palabras clave: Simulaciones interactivas; aprendizaje inmersivo; formación de cadetes; aprendizaje basado en escenarios; Skiftech.

Abstract

The rapid adaptation of future specialists to extreme conditions of professional activity highlights the relevance of introducing interactive simulations for realistic modeling of scenario-oriented didactic situations. The study assesses the pedagogical effectiveness of interactive simulation training in developing decision-making, situational awareness, and team interaction skills among cadets. The following methods were used for this purpose: focused search, comparative analysis, and effectiveness assessment. Empirical verification based on a sample of 64 cadets showed a significant improvement in the development dynamics of key indicators of professional training in the experimental group. The integral time of task completion decreased by 54%, the speed of cognitive reaction increased by 67%, and the accuracy of target actions (error minimization) increased by 46%. This study demonstrates a novel comprehensive pedagogical analysis of interactive simulations based on technical and functional characteristics and the integral parameter of readiness. Further research should focus on expanding the sample of participants to increase the statistical reliability of the results, as well as on analyzing a wider range of interactive technologies to determine their effectiveness in various professional scenarios.

Keywords: interactive simulations; immersive learning; cadet training; scenario-based learning; Skiftech.

Introduction

Modern professional activity in high-risk areas is characterized by intensive dynamism, complexity of professional scenarios and the need for rapid adaptation of future specialists to changing conditions. In the context of modern technology-mediated learning, educational frameworks must transcend traditional reproductive methods to effectively address operational environments characterized by high cognitive demand. While conventional didactic approaches often fail to simulate the fluid uncertainty of high-stakes situations or provide scalable metrics for multi-dimensional performance tracking, integrating gamification principles offers a robust pedagogical solution. Leveraging immersive mechanics, structural risk-free scenarios, and goal-oriented feedback loops directly heightens cognitive engagement, emotional regulation, and stress resilience under pressure.

Furthermore, the systematic incorporation of learning analytics within these digital environments allows for the granular, real-time collection and evaluation of behavioral data, transforming raw operational footprints into actionable formative insights. Consequently, a critical problem arises in conceptualizing interactive simulations not merely as isolated tactical tools, but as sophisticated, data-driven learning ecosystems capable of adapting to the intense cognitive load of modern professional fields.

The aim of the study is to assess the pedagogical effectiveness of interactive simulation training in developing decision-making, situational awareness and team interaction skills among cadets. The aim was achieved by completing the following research tasks:

- To identify interactive simulation tools that can be used as digital learning environments in scenario-based professional training of cadets;
- To characterize the pedagogical and assessment potential of the selected simulation systems; to assess the dynamics of learning outcomes of cadets in the control and experimental groups before and after the pedagogical intervention;
- To interpret the pedagogical mechanisms of the influence of interactive simulation training on the development of decision-making, situational awareness, and team interaction.

The implementation of these tasks is demonstrated in the subsequent parts of the article. Thus, Section 2 focuses on a comprehensive review of the target literature, where the theoretical basis is demonstrated in symbiosis with modern research. The use of simulations and immersive technologies in professional training is actively described. Section 3 provides a description of the materials and methods selected for the study. Section 4 includes not only empirical results, but also their in-depth discussion, contains an analysis of quantitative data and an interpretation of the pedagogical impact of simulations on the target skills of cadets. Finally, the conclusions serve as a logical summary of the main results and a demonstration of promising directions for further research.

Literature Review

Speaking about the modern paradigm of training young specialists for professional activity in difficult and extreme conditions, one should focus on updating didactic methods. The basis of educational transformation should be placed on simulation learning, which acts not only as a separate technical means, but as a holistic pedagogical system (Damianova & Berrezueta-Guzman, 2025). In general, it

integrates a whole range of interactive tools into the educational environment: digital models, virtual and augmented reality technologies, adaptive AI algorithms, etc.

The methodological basis of simulation learning today is the concept of experiential learning, when a student must convert theoretical knowledge into practical skills. A realistic scenario allows for the effective implementation of formative assessment mechanisms and the strengthening of situational awareness of students, including in military education. Thus, interactive immersive training of cadets in complex professional skills is a comprehensive pedagogical method based on the use of digital simulations, virtual and augmented reality, adaptive algorithms of artificial intelligence (AI), and laser training systems. This approach provides modeling of critical professional situations in a controlled digital learning environment, as close as possible to real conditions (Baptista et al., 2024). This contributes to the formation of sustainable professional competencies, increasing the overall level of situational awareness and the effectiveness of decision-making by future officers.

Expanding on this technological foundation, Grier (2012) found that VR technologies act as a powerful enhancer of cognitive interest and increase the effectiveness of professional training, contributing to the development of practical skills in conditions of resource optimization. The study proves that regular use of digital space and time helps to activate higher-order cognitive resources, thanks to which the student moves from the stage of passive perception to active modeling.

This perspective is further supported by Bhange et al. (2024), who complement Grier's findings by examining the impact of AR/VR on the educational process and the quality of decision-making by cadets. Particular attention is paid in their work to the issue of the didactic potential of feedback, which is generated by the simulation environment automatically in response to user actions. Thanks to this, teachers are able to introduce elements of formal assessment directly during the exercise. Complementing the focus on feedback and operational skills within the framework of the competency approach, Estrada et al. (2024) extend the application of educational simulations to the ethical dimension, aiming to form ethical and professional principles of activity of future specialists in conflict zones. As the results of this study show, students demonstrated a high level of acceptance of the analyzed concept, embodying a positive attitude towards immersive technologies as an innovative teaching method.

While the aforementioned authors focus on immersive environments, a parallel stream of research addresses the underlying intelligent infrastructure. In turn, Kurniawan et al. (2025) conducted a systematic review of the literature on the implementation of intelligent learning systems (ILS) in the educational process. The results showed that 81% of the analyzed works focused on the practical application of educational analytics tools to intensify learning, and 23% on the theoretical substantiation of the potential capabilities of this technology. A concrete manifestation of such intelligent systems is demonstrated in the study by Dutt and Chandra (2023), who narrow the focus to implementing AI algorithms within digital didactic tools. The authors describe generative systems as a powerful tool that allows changing the complexity of tasks and adapting them, taking into account the current level of knowledge of each student. This approach allows implementing the didactic principle of individualizing learning for further improvement of educational scenarios and development of adaptability of cadets.

At the same time, the research by Tanwar et al. (2024) broadens this technological spectrum by evaluating a wider range of solutions suitable for organizing scenario-

oriented learning, including robotics, artificial intelligence, the Internet of Things (IoT), and quantum computing. Crucially, their evaluation aligns with the core thesis of Grier (2012) and Bhange et al. (2024), as they conclude that AR/VR technologies still possess the greatest pedagogical potential for creating a realistic learning space, developing situational awareness, and practicing students' actions.

Vashisht (2024) arrived at a similar conclusion, validating these findings by demonstrating that VR, AR, and tactile interaction significantly increase the effectiveness of the learning process, improving the perception of educational information, accelerating the assimilation of actions, and forming psychological readiness for performing professional tasks. This work explicitly confirms that these technologies demonstrate a safe and didactically successful learning model through the prism of practical experience (experiential learning). A deeper pedagogical refinement of this model is described in the study by Alim et al. (2026), where it was found that scenario-based learning (SBT) increases the cognitive readiness of students to manage processes at the operational level. This becomes possible due to the use of modeling and educational simulations to develop strategic thinking and team interaction skills.

The practical execution of such scenario-based models is further reinforced by de Freitas et al. (2024), who investigated autonomous agent systems to build dynamic scenarios in simulation learning. Their results demonstrate that automated management of the interaction of environmental elements with given pedagogical scenarios increases the effectiveness of training of managerial personnel and the quality of interaction between different levels of management. Providing a technological parallel to this automated management, Kubola et al. (2024) developed scenario-oriented simulation training, which models complex situational tasks with a high level of realism, taking into account the physics of objects and analytical calculations. Their testing confirmed the high accuracy and convenience of simulation, which allows reducing costs for material and technical support and minimizing environmental risks.

In general, interactive simulations significantly accelerate the development of professional competencies of cadets due to the symbiosis of realistic modeling and a safe, adaptive educational environment. However, their integration into the professional training system requires further study and technological justification. In particular, it is important to study the aspect of combining interactive simulation-based learning with physical training. The issue of reducing the cost, increasing the mobility of systems, and their integration into existing educational processes remains relevant. Further research should assess how these innovative pedagogical technologies ensure the transfer of acquired knowledge to learning outcomes (transfer of learning) in real-world professional environments.

Methods and Materials

Research design

This study used the following sequential iterative quasi-experimental design (Figure 1). It allowed for a systematic assessment of the effectiveness of integrating immersive tools into the educational process.

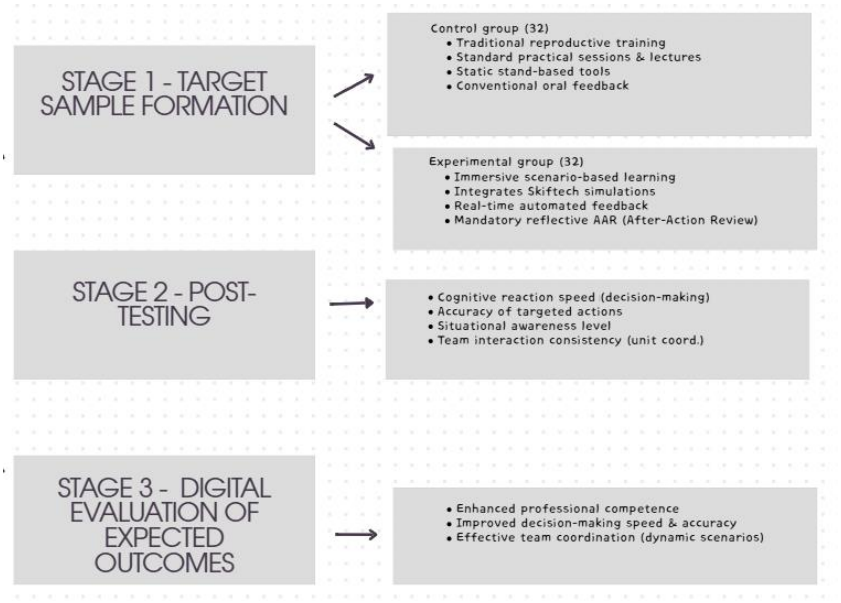


Figure 1. Research design
Source: developed by the authors

In general, the research procedure was divided into three stages:

1. The first iteration - includes an analytical search for optimal digital solutions for interactive learning. To select the optimal tool, the pedagogical criterion "ready-to-use" was used (readiness for immediate implementation without additional long-term adaptation of the educational environment).
2. The second iteration - creation of a general sample of participants, their division into groups. After that, a four-week educational experiment was introduced, which involved a symbiosis of several methodological approaches.
3. The third iteration - respondents completed a control complex situational task and statistical processing of the obtained data. After that, the experts assessed the dynamics of the development of professional competencies.

Methods

This study was conducted using the following methodology:

1. Focused search: controlled search for information on interactive tools and immersive simulation systems in order to identify modern and relevant solutions.
2. Comparative analysis: comparison of technical characteristics of relevant solutions for interactive tactical modeling with highlighting the advantages and disadvantages of each identified complex.
3. Assessment of effectiveness by the readiness for use parameter: determination of the most effective and balanced solution for interactive tactical training, which has a high coefficient of rapid deployment and immediate application.
4. Empirical assessment of effectiveness: determination of the effectiveness of the application of solutions for generating dynamic scenarios by checking the results of performing control tasks. The assessment is carried out for two groups, which are described in the "Sample" section. The main parameter by which the assessment is carried out is the time of performing the control task by the specified groups of cadets. This parameter is influenced by the following

indicators: (cognitive reaction speed, accuracy of targeted actions, level of situational awareness, consistency of team interaction).

Sample

The research sample consists of 64 cadets:

- Military Academy (Odesa) Department of Military Leadership;
- Military Academy (Odesa) Faculty of Training Specialists of the Airborne Assault Forces and Marine Corps;
- National Academy of Land Forces named after Hetman Petro Sahaidachny Institute of Psychological Support of Personnel;
- Kamianets-Podilskyi National University named after Ivan Ohienko, Department of Behavioral Sciences and Military Leadership.

A total of 64 individuals of the basic (identical) level of training participated in the study, who were divided into two groups (the study participants were selected in accordance with the standards of basic training in a proportional number relative to the involved educational institutions). The sample is limited, but sufficient for preliminary empirical testing:

1. Control group (CG) - a group undergoing training according to the traditional approved program, which provided for theoretical classes and classical practical skills development (32 cadets);
2. Experimental group (EG) - a group that mastered similar topics of the curriculum, but with the regular use of interactive immersive simulations (32 people).

Instruments

The study used an interactive tactical modeling complex - Skiftech Tactical Simulation System / Skiftech (Skiftech, n.d.). This system successfully combines software for creating dynamic scenarios and hardware laser components for capturing actions. This allows you to create a safe, but as realistic as possible learning environment.

Training procedure and structure

The main part of the experiment lasted 4 weeks. The training process of the experimental group participants was based on the principles of cyclical experiential learning (according to the Kolb model).

At the beginning, a preliminary briefing (Briefing / Scaffolding) was conducted, within the framework of which the cadets were introduced to the purpose of the lesson, the main theoretical principles and the task of the current scenario. In this case, the teacher played the role of a facilitator, explaining the criteria for the success of the actions.

After that, the cadets moved on to the immersive execution of the scenario (Simulation Immersion), when they directly interacted with the Skiftech digital simulation environment. The scenarios were complicated step by step and dynamically, which was done using algorithms. This required high concentration, rapid analysis of the situation and team interaction from the applicants.

An important stage of the experiment was pedagogical reflection and feedback. Debriefing / After-Action Review (AAR). It was thanks to the objective digital logs of

the Skiftech system that the teacher, together with the cadets, carefully analyzed the mistakes made. The applicants independently analyzed the reasons for ineffective decisions, which stimulated the development of critical and strategic thinking. After this, they were given the opportunity to go through the scenario again, taking into account previous experience and corrected errors.

To verify the effectiveness of the selected didactic model, a combined approach to assessing the results of cadets was used. It included automated quantitative data collection (digital logs of the Skiftech system) and qualitative expert analysis. The members of the expert group were 3 independent instructors with over 10 years of teaching experience. For expert assessment, standardized matrices of behavioral indicators using a 5-point Likert scale were used. According to the scale indicators, 1 is an unsatisfactory level, while 5 is an exemplary level).

The effectiveness of the didactic model was measured by the time the cadets completed the control task. This basic criterion was directly influenced by the following operational indicators:

- Cognitive reaction speed – was measured using a combined method. Skiftech digital logs determined the exact time (in milliseconds) from the moment the trigger appeared to the first physical action of the cadet.
- Accuracy of targeted actions – was determined automatically using Skiftech laser components. The percentage of effective shots was determined. Experts expanded these data by assessing the correctness of the technical execution of techniques.
- Level of situational awareness – was assessed by an expert diagnostic method. The commission determined the ability of cadets to navigate in space, predict the development of events, understand the meaning of the situation, etc.
- Consistency of team interaction – was assessed by an expert commission using the method of continuous monitoring of the synchronicity of actions, the speed of role redistribution, mutual insurance, etc.

For statistical analysis of the results, mathematical statistics methods were used including the calculation of mean values (M), standard deviations (SD), and the determination of statistical significance via Student's t-test (p-value). It allowed to ensure a higher degree of reliability of the conclusions. The structured breakdown of the pre-test and post-test dynamics for both the control (CG) and experimental (EG) groups is detailed in Table 3.

Ethical issues

The study fully complies with international ethical standards and was formally approved by the institutional review board (or ethics committee) of the participating military academy, ensuring alignment with institutional regulations. Since the sample was formed with the participation of cadets, strict confidentiality and data protection protocols were used at all stages of the experiment. All research data were fully anonymized to exclude any personal identifiers. Furthermore, the study did not involve or utilize any classified, restricted, or proprietary military information. The cadets participated on a voluntary basis, and before the start of the experiment, they received detailed oral and written instructions on the purpose, duration, and pedagogical nature of the tasks. Each participant signed a written consent to participate with a guaranteed opportunity to withdraw from the study at any stage. To ensure maximum data protection, the final results are presented exclusively in

an aggregated form, preventing the identification of any individual participant or specific training unit.

Results and Discusión

A search of open sources (focused search) identified a number of interactive immersive application tools for developing specialized professional competencies and decision-making skills in cadets within complex, high-stakes operational environments - Table 1.

Table 1.
Interactive simulation tools as digital learning environments for scenario-oriented cadet Training

Simulation system / Developer	Scenario type and didactic characteristics of the environment	Pedagogical function and application conditions	Expected learning outcomes	Reference
Virtual Battlespace (VBS3/VBS4) / Bohemia Interactive Simulations	Multi-user PC-based platform for modeling large-scale spatial scenarios, supporting VR/AR and AI integration for autonomous object management.	Organization of collective training, comprehensive analysis of multi-component operational situations, and practice of large-group interaction.	Development of strategic thinking, large-scale team coordination skills, and multi-level action planning.	Bohemia Interactive Simulations (2025)
DARWARS Ambush! / DARPA / BBN Technologies	Networked simulation environment designed for training under high cognitive load and unpredictable environmental changes.	Building stress resistance and crisis management skills; adapting leaders to decision-making under uncertainty and asymmetric risks.	Enhancing cognitive flexibility and accelerating decision-making during critical events.	Center for Digital Games Research (n.d.)
Dismounted Soldier Training System (DSTS) / Intelligent Decisions	Immersive VR platform utilizing head-mounted displays and motion capture systems for full user immersion into digital space.	Development of spatial orientation and small-group communication in a safe, high-fidelity experiential learning environment (*experiential learning*).	Attainment of personal situational awareness and real-time synchronization of team actions.	Bink et al. (2015)
Skiftech Tactical Simulation System / Skiftech	**Selected as the most adaptive solution.** Interactive field-based simulator utilizing wireless sensory tracking in real spaces with centralized data logging for analytics.	Field-based tactical modeling; intensification of practical training through objective digital feedback and reflective After-Action Review (AAR) debriefing.	Accelerating applied competency development (reaction speed, interaction precision) through immediate error analysis and scenario re-execution.	Skiftech (n.d.)
VirTra Military Training Systems / VirTra	Modular simulation platform featuring multi-channel immersive panoramic displays (180° to 300°) and analytical evaluation modules.	Collective response training, identification of critical situational markers under high cognitive load.	Development of peripheral perception, pattern recognition speed, and appropriate action algorithm selection.	VirTra (2025)
Military simulators and simulation systems / DB Logika LLC	Hardware-software simulation complex combining VR environments, haptic interfaces, and dynamic adjustments of time, weather, and terrain parameters.	Conducting joint complex real-time training exercises; individual and group skill building against autonomous AI-controlled opposing forces.	Enhancing student action adaptability; aligning individual skills with the overall group activity plan.	LOGIKA LLC (n.d)
InVeris / InVeris Training Solutions	Blended training ecosystem combining virtual simulators and real-world performance monitoring with embedded analytical assessment tools.	Cultivating individual and group operational readiness; modifying behavioral patterns via immediate feedback based on performance metrics.	Improving action execution precision and developing behavioral adaptation capabilities in variable conditions.	InVeris Training Solutions (n.d.)
Fully modular systems for tactical training / Trango Systems	Modular physical-virtual hybrid complex using lightweight, quickly reconfigurable structures	Practicing spatial coordination, tactical navigation, and team movement mechanics	Improving team maneuvering and orientation skills within complex	TRANGO Systems (n.d.)

	to alter the spatial layout of the training field.	within confined or dynamically changing spaces.	architectural configurations.	
Laser Shot / Laser Shot Inc.	Modular training system with integrated individual and crew equipment simulators, compatible with visualization displays.	Optimizing basic equipment handling proficiency and advancing collective interaction under standardized training conditions.	Achieving automaticity in core operational actions and enhancing movement coordination during group exercises.	Laser Shot, Inc. (n.d.)
VR Military Training for Defence & Security / Luminous Group Limited	Photorealistic immersive XR simulator for practicing action protocols in high-risk zones, medical evacuation, and complex equipment management.	Ensuring long-term knowledge retention and risk-free acquisition of critical protocols through automated performance metrics.	Forming distinct mental models of behavior in extreme situations with no physical risk to trainees.	Luminous Group Limited (2025)

Source: created by the authors

According to the results of the focused search (Table 1), it was found that modern interactive simulators play a key role in the accelerated development of cadets' tactical and decision-making skills, providing a high level of experiential realism, scenario variability, and adaptability to high-stress professional environments. Virtual platforms such as VBS4, DSTS, Luminous XR and InVeris Training Solutions integrate VR/AR, haptic feedback, motion capture (MoCap) and AI-driven scenarios, which enables trainees to navigate complex operational situations within a risk-free simulated environment. Laser-based systems such as Skiftech Tactical Simulation System and Trango Systems provide realistic field modeling of tactical engagements using authentic standard-issue equipment setups. Furthermore, complex response simulators (VirTra, Laser Shot) and modular training complexes (DB Logika LLC) utilize high-precision ballistic modeling, instant performance feedback, and automated After-Action Review (AAR) systems to optimize training efficiency. The systematic integration of interactive simulations into the specialized higher education framework significantly reduces the time required for professional competency acquisition, minimizes organizational costs, and ensures the rapid adaptability of small units to dynamic real-world settings.

To better understand the practical limitations of these tools, our findings must be contextualized within contemporary pedagogical debates. According to the publication by Joseph et al. (2024), educational progress in the course of traditional learning models may decrease due to the instability of external conditions and their unpredictability. Although the results of our study confirm the effectiveness of simulations in the accelerated development of skills, the lack of adaptation of the complexity of scenarios to the individual trajectory of the seeker may somewhat limit the long-term stability of the formed competencies. To overcome this limitation, our chosen architecture—the Skiftech environment—does not simply set a static task for the cadet, but instead involves him in a continuous cycle of variable scenario-oriented actions. In this case, the interpretation of the pedagogical mechanism is based on the concept of learning through experience (experiential learning — Kolb cycle).

While a basic comparative analysis of the considered propositions is made in Table 1, a more critical pedagogical screening is required to determine the most effective system in terms of the readiness parameter, as observed in Table 2.

Table 2.
Pedagogical potential of interactive simulation systems for scenario-oriented training of cadets

Simulation system / developer	Educational function	Pedagogical & operational advantages	Limitations for pedagogical use	Readiness
Virtual Battlespace (VBS3/VBS4) / Bohemia Interactive	Large-scale non-linear training; AI-driven dynamic scenarios; digital footprints for collective AAR.	Flexible custom trajectories; excellent scalability for large teams.	High interface complexity for beginners; requires extensive initial scaffolding.	★★★★☆
DARWARS Ambush! / DARPA / BBN Technologies	Stress-state modeling for adaptive behavior; real-time manual scenario adjustments by instructors.	Trains psychological resilience; quick scenario adaptation to group level.	Legacy UI reduces immersion; limited depth in automated learning analytics.	★★★☆☆
Dismounted Soldier Training System (DSTS) / Intelligent Decisions	Full sensory VR immersion for spatial coordination and team experiential learning.	High micro-interaction realism; direct link between motor actions and outcomes.	Risk of cybersickness limits duration; strict limits on simultaneous users.	★★★☆☆
Skiftech Tactical Simulation System / Skiftech	**Selected solution.** Real-space scenario learning; instant individual feedback; automated logs for AAR.	Complete didactic safety in real environments; objective evaluation; instant error-correction re-runs.	Cannot model abstract/fictional spaces; tracking depends on terrain topography.	★★★★★
VirTra Military Training Systems / VirTra	Panoramic screen training for situational awareness; embedded precision and reaction metrics.	Vast library of pre-configured scenarios; precise tracking for formative assessment.	Stationary setup limits macro-level movement and dynamic field interaction.	★★★★☆
Military simulators / DB Logika LLC	Multi-workstation networking for joint real-time complex scenarios.	Facilitates interdisciplinary sessions; flexible environmental modeling (weather, time).	High pedagogical complexity for instructors; difficult to align with linear plans.	★★★☆☆
InVeris / InVeris Training Solutions	Blended environment for step-by-step skill forming via automated performance tracking.	High precision in skill dynamics tracking; automated error-based feedback.	Narrow individual specialization; limited capacity for group tactical maneuvers.	★★★★☆
Fully modular systems / Trango Systems	Reconfigurable physical environments for active scenario learning and spatial reasoning.	Maximum flexibility prevents route habituation and rote memorization.	Low embedded digital analytics capacity; requires external video/manual evaluation.	★★★★★
Laser Shot / Laser Shot Inc.	Modular applied skill training with digital tools for structured AAR.	Ensures ergonomic authenticity; safe formation of stable core operational habits.	Oriented toward static exercises; limited potential for fluid strategic thinking.	★★★★☆
VR Training for Defence / Luminous Group Limited	High-risk critical scenario modeling for long-term knowledge retention.	Risk-free execution of life-threatening events; forms clear mental models for crises.	Strict dependence on individual VR tolerance; high mental load per session.	★★★☆☆

Source: created by the authors

The comparative analysis showed that Virtual Battlespace (VBS3/VBS4), Skiftech Tactical Simulation System, and VirTra Military Training Systems demonstrate the highest educational efficiency for the accelerated development of tactical competencies and decision-making skills. These platforms uniquely combine high contextual fidelity, structural flexibility, and immediate integration capabilities into existing instructional frameworks. Specifically, VBS4 provides sophisticated tactical modeling, collective interaction parameters, and deep scenario analysis utilizing GIS data and AI-driven synthetic entities; however, substantial computational resources and long-term configuration requirements bound its institutional adoption. Taking into account the readiness parameter, the Skiftech Tactical Simulation System is the most prepared for immediate use in cadets' training, as it does not require complex software modifications, making it the optimal solution for field-based experiential learning.

In accordance with the research design, an empirical test of the thoroughly selected interactive simulation (Skiftech) based on a defined sample of cadets was performed. The results of the study (Figure 2, 3) demonstrated a significant advantage of interactive simulations over traditional combat training methods. The analysis was conducted by comparing the performance of the CG and EG during training, performing the control task, as well as their dynamics at different stages.

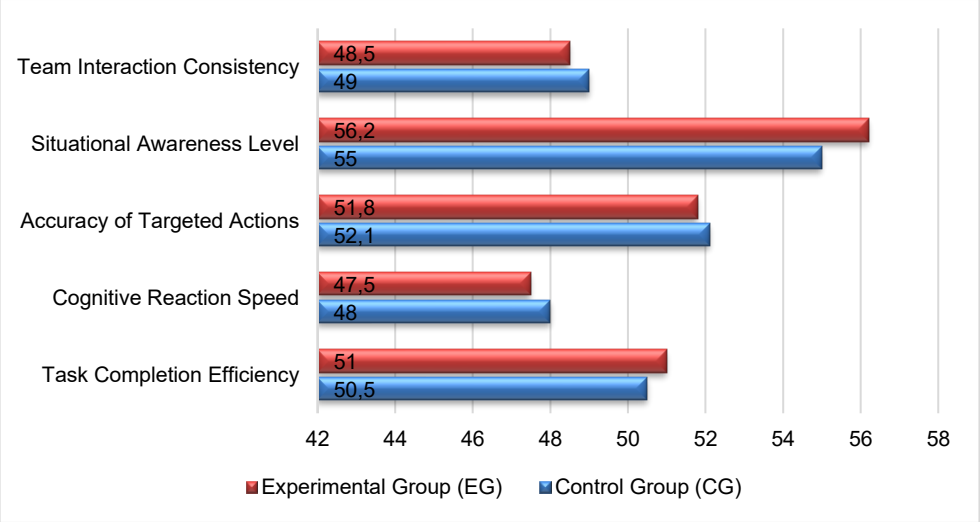


Figure 2. Initial equivalence of the control and experimental groups before the pedagogical Intervention.
Source: created by the authors.

The results of the comparative analysis of the input control indicators showed that both groups were equivalent at the start. All measured parameters (task completion time, cognitive response, situational awareness, team interaction) did not have statistically significant differences at the pre-test stage. Such balance allows us to objectively assess the net pedagogical impact of interactive modeling (in this study, the Skiftech complex) during the final assessment.

However, dynamic environments introduce unique visual and spatial constraints that directly impact these baseline metrics. Yoo and Ji (2025) have shown that AR interfaces improve situational awareness through collective information sharing, but that inconsistency in viewing directions can reduce it. The lack of adaptive visual cues in our current study may limit the speed of spatial analysis of learners in a dynamic learning space. Nevertheless, the pedagogical design of the selected simulator successfully compensated for this: when a student made a mistake while performing a task, the system showed him the consequences of this mistake in a safe-to-fail environment. Thus, the mistake is no longer perceived as an exclusively negative marker, but moves into the category of a dynamic asset, driving the subsequent shift in post-intervention outcomes.

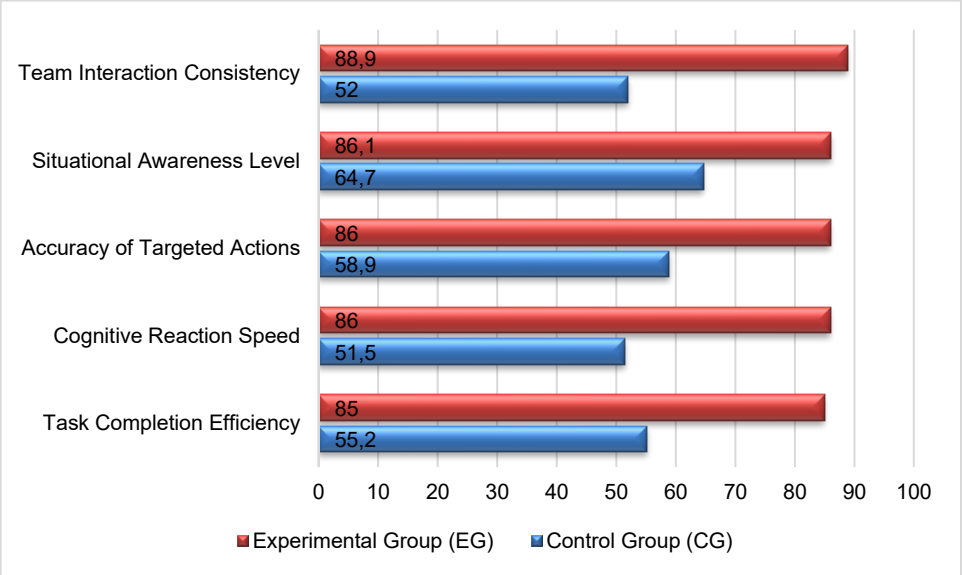


Figure 3. Learning outcomes of the control and experimental groups after the pedagogical intervention
Source: created by the authors

Empirical confirmation of the results of this experimental study reflected a significant difference in the vectors of development of competencies of cadets of the control (CG) and experimental (EG) groups. While the CG (traditional training) showed a slow linear increase (on average, a minimum of 4.7% for all parameters), in the EG (training with simulator integration) an exponential jump of the selected parameters was recorded.

This dramatic divergence between the two groups can be fundamentally explained by the nature of multi-sensory engagement. The authors Raman and Vyakarana (2024) note that the combination of the Internet of Things, virtual reality, and augmented reality (AR) in the educational space provides a highly interactive environment with instant feedback on aiming. The current study extends these findings by illustrating the following mechanism: the synchronization of sensory, tactile, and digital feedback creates an error-tolerant learning space. After detecting an error, the student proceeds to a cyclic repetition of critical phases in a safe environment, which increases the level of behavioral adaptation. This shift indicates that specialized simulation frameworks must evolve towards broader immersive ecosystems. In this context, Cheng et al. (2024) consider the concept of a professional (educational) metaverse as an integrated ecosystem that combines real and virtual spaces to intensify learning. Our study confirms the effectiveness of tactical simulations in the professional training of cadets, but also emphasizes that such systems retain pedagogical validity only if they go beyond the narrow scope of procedural training. To provide a precise mathematical foundation for these observed exponential improvements, the exact statistical breakdown is formalized in Table 3.

Table 3.
Dynamics of professional competence indicators in the control and experimental groups

Evaluation Metric / Parameter	CG Pre-test (M1±SD)	CG Post-test (M2±SD)	CG Growth Rate (%)	EG Pre-test (M3±SD)	EG Post-test (M4±SD)	EG Growth Rate (%)	Net Progress Difference (%)	Student's t-test (t)	p-value	Effect Size (Cohen's d)
Task completion time (s)	252.3±24.1	240.4±22.5	-4.72%	251.8±23.8	115.8±14.2	-54.01%	49.29%	26.43	<0.001	6.61
Cognitive reaction speed (%)	51.5±5.3	54.0±4.9	+4.85%	51.2±5.1	85.5±6.2	+66.99%	62.14%	22.52	<0.001	5.63
Accuracy of targeted actions (%)	56.2±5.8	58.9±5.4	+4.80%	55.9±5.6	81.6±5.9	+45.97%	41.17%	15.95	<0.001	3.99
Level of situational awareness (%)	58.5±6.1	61.3±5.7	+4.79%	58.2±5.9	77.4±6.0	+32.99%	28.20%	10.99	<0.001	2.75
Coherence of team interaction (%)	47.6±5.0	49.9±4.6	+4.83%	47.3±4.8	80.9±6.4	+71.04%	66.21%	22.18	<0.001	5.54

Note: Growth Rate calculated as (Post - Pre) / Pre x 100. For task completion time, a negative value indicates a positive didactic effect (speed optimization)
Source: created by the authors

Additionally, a comprehensive analysis of intra-group and inter-group dynamics was conducted (Table 3). The data obtained demonstrate that the most significant didactic progress was found within the “Team Interaction Consistency” metric, where the EG score increased from 47.3% to 80.9%, resulting in a relative increase of 71.04%, while the CG progress stagnated at +4.83%. At the same time, the integration of automated tracking in Skiftech reduced the task completion time for EG group cadets by 54.01% from 251.8 to 115.8 seconds, systematically proving the elimination of the gap between time and competence.

The correlation between minimized completion time and heightened group cohesion suggests that simulation shifts individual capacity into collective synergy. Sudiarno et al. (2024) have demonstrated that narrowly focused VR simulators (in particular, shooting simulators) can replace traditional forms of practical training, providing high accuracy, realism, and adaptation to the virtual environment. Our study demonstrates similar benefits of interactive simulation-based learning not only for isolated practice of individual operations, but also for modeling complex management and command tasks. Skiftech demonstrates that the simulation environment acts as a mirror, reflecting the systemic impact of group decisions, thereby shifting the educational focus from individual psychomotor skills to collective strategic intelligence. This structural shift towards strategic interaction is heavily dependent on cognitive engagement, which is often stimulated by game-like mechanics. Ivanjko et al. (2024) consider gamification as an effective tool for increasing engagement, motivation, and quality of learning through role-playing games, simulations, and strategic scenarios. Our study confirms the value of interactive simulations for improving flexibility of thinking in dynamic environments.

Ultimately, this flexible, gamified approach serves as a bridge for adapting students to high-stress professional ecosystems. Bekesiene and Varžinskas (2024) note that the successful development of professional competencies in JCATS largely depends on basic technological training and strategic thinking. Our study confirms that interactive simulations not only improve practical skills, but can also serve as an effective tool for adapting cadets to work in a technologically rich and informationally complex professional environment.

This baseline technological adaptation finds its ultimate application in close-quarters, collaborative maneuvers. Prasetyo and Rende (2024) investigate the capabilities of VR systems for practicing interaction in a confined space, emphasizing their potential for optimizing team communication and reflection. The results obtained are consistent with the results of this study, in particular, that interactive simulations are able to effectively reproduce multidimensional professional scenarios, providing not only individual learning, but also improving coordination and interpersonal interaction in small groups under conditions of high psychological stress.

Thus, it was found that interactive simulations have high pedagogical effectiveness in the process of accelerated formation of professional competencies of cadets, providing a safe environment for empirical learning, an increased level of situational awareness, and systemic integration of innovative technologies into the educational process of higher education. At the same time, it is necessary to take into account the adaptability of systems, dynamic modeling of situations, and standardized methods of assessing learning outcomes to ensure their long-term effectiveness. As demonstrated by our empirical data, the integration of scenario-oriented simulation training into complex educational systems guarantees a rapid development cycle, transferring acquired habits safely into the future officer's operational repertoire.

So, empirical data confirm that the use of the interactive simulation complex Skiftech Tactical Simulation System provides a significant acceleration and improvement of the development of practical skills of cadets. The use of this technology enables not only to increase the efficiency of the training process, but also to maintain the acquired skills, which confirms the appropriateness of introducing interactive simulators into the educational process.

Transferability of Results and Beyond-Military Applications

The pedagogical efficacy of combining interactive immersive simulations with automated digital analytical records, as demonstrated in this empirical evaluation, extends significantly beyond the boundaries of military cadet training. The core cognitive and behavioral mechanisms optimized within this study—specifically accelerated reaction speeds, enhanced situational awareness, minimized operational error rates, and synchronized team interaction under high stress—are fundamentally transferable to various complex civilian domains characterized by intense cognitive demand and high-stakes decision-making.

Firstly, this data-driven simulation framework holds immense potential for high-complexity medical surgical teams. In acute clinical and surgical environments, where rapid choices directly dictate patient outcomes, immersive VR/AR simulations can realistically replicate rare intraoperative crises, complex anatomical anomalies, or sudden systemic complications. Concurrently, the integration of embedded learning analytics allows for the precise tracking of procedural latency, instrument coordination, and stress-induced friction, enabling surgical units to refine critical non-

technical skills like communication and cognitive adaptability without risking patient safety.

Secondly, the model is applicable to rescue and fire services in civil disaster environments. First responders routinely operate under highly volatile, uncertain, and hazardous conditions that directly parallel tactical field scenarios. Utilizing modular physical-virtual hybrids or immersive digital setups allows rescue teams to safely navigate simulated structural collapses, chemical spills, or large-scale civilian evacuations. The application of centralized learning analytics provides objective, empirical data regarding spatial navigation efficiency, real-time hazard identification speed, and group resource coordination, ensuring teams can diagnose and rectify behavioral gaps before operational deployment.

Finally, these findings offer substantial implications for pilot training in commercial aviation. While aviation education has traditionally relied on high-fidelity simulators, the synthesis of advanced learning analytics with highly adaptive, gamified problem-sets can further optimize Crew Resource Management (CRM). By dynamically generating unpredictable multi-system hardware failures or extreme environmental anomalies, these simulations challenge the flight crew's collective situational awareness and strategic thresholds. Rooting the subsequent After-Action Review (AAR) in objective digital logs ensures that reflective debriefings target exact behavioral metrics, establishing a reliable, verified pathway for maintaining public safety and accelerating expert competency acquisition.

Limitations

The empirical component of the study was tested on a relatively small number of participants in the experiment. A relatively small number of solutions for interactive training of cadets were considered.

Recommendations

It is recommended to expand the sample of participants to increase the reliability of the results. It is also advisable to explore a wider range of interactive solutions for training cadets.

Conclusions

Within the framework of the theoretical and analytical stage of the study, 10 modern relevant digital solutions for interactive training of cadets of complex and extreme professions were analyzed and classified in detail. According to the results of a comparative analysis of technical and functional characteristics and an integral criterion of readiness for didactic implementation (ready-to-use), the Skiftech interactive tactical modeling complex was determined as the most adaptive tool for scenario-oriented experiential training in field conditions, which does not require the deployment of complex stationary infrastructure.

Empirical evaluation of the hypothesis regarding the feasibility and effectiveness of integrating immersive simulations into the process of accelerated formation of professional competencies of applicants was implemented on the basis of higher education institutions with a specialized training profile. The total sample size of the quasi-experiment was 64 cadets (control and experimental groups of 32 people, respectively). The pedagogical intervention led to a substantial optimization of tactical performance, manifested in a meaningful reduction of task completion time

and a marked acceleration of cognitive reaction speeds under stress. Furthermore, the simulation environment actively minimized operational errors, enhanced spatial analysis, and significantly strengthened team cohesion and synchronized interpersonal communication within units. These insights confirm that interactive simulations serve as a catalyst for transforming theoretical knowledge into stable, automated operational skills.

The scientific novelty of the study lies in developing a comprehensive pedagogical matrix for evaluating immersive systems and establishing the exact formative impact of interactive simulation environments on both the cognitive and practical components of cadets' competencies. Moreover, the study proposes a novel methodology for quantitative and qualitative assessment of trainee performance through the systematic analytics of the simulation's embedded digital logs.

The practical significance of the results consists in providing a verified technological choice (the Skiftech system) for optimizing practical training at training grounds and introducing a structured, reflection-based training procedure (from preliminary briefing to post-activity After-Action Review). The formulated methodological recommendations can be directly used by academic administration and instructors to modernize educational programs, update discipline syllabi, and implement automated formative assessment tools.

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Original Article

Chatbots en la educación superior: Mejorando la competencia digital de los estudiantes

Chatbots in higher education: Enhancing students' digital competence

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Resumen

El artículo presenta el contenido y revela la importancia de los chatbots en el entorno de la educación superior. Se consideran las categorías de chatbots con capacidades crecientes (sistemas basados en inteligencia artificial). Para desarrollar la competencia digital de los futuros especialistas y lograr la integración efectiva de los chatbots en el proceso educativo de la educación superior y en sus actividades profesionales, lo que mejora significativamente la calidad de la educación superior, las actividades profesionales y la vida de cada persona, realizamos un estudio experimental. Se utilizó la prueba t de Student para variables independientes con el fin de identificar diferencias entre los grupos experimental y de control, y la prueba de Fisher para comparar los resultados del diagnóstico. Al finalizar la etapa formativa del estudio experimental, todos los indicadores descritos difirieron de los resultados de la etapa de determinación del estudio experimental. En el grupo experimental, observamos cambios significativos en el alto nivel de formación de la competencia digital de los estudiantes, lo que introduce cualitativamente los chatbots en el proceso educativo de la educación superior y en las actividades profesionales de los futuros especialistas. En el grupo de control, también hay cambios, pero no significativos. El análisis de los resultados experimentales obtenidos demuestra la eficacia del innovador sistema desarrollado e implementado por nosotros y las condiciones pedagógicas propuestas para el fenómeno descrito.

Palabras clave: chatbots; categorías de chatbots; inteligencia artificial; entorno digital de la educación superior; competencia digital.

Abstract

The article presents the content and reveals the significance of chatbots in the higher education environment. The categories of chatbots with growing capabilities (systems based on artificial intelligence) are considered. To develop the digital competence of future specialists for the effective integration of chatbots into the educational process of higher education and into the professional activities of future specialists, which significantly improve the quality of higher education, professional activities, and the life of each person, we conducted an experimental study. Student's t-test was used for independent variables to identify differences between the experimental and control groups, and Fisher's multiple-test to compare the results of the diagnosis. Upon completion of the formative stage of the experimental study, all the outlined indicators differed from the results of the ascertaining stage of the experimental study. In the EG, we see significant changes in the high level of formation of students' digital competence, which qualitatively introduces chatbots into the educational process of higher education and into the professional activities of future specialists in students. In the control group, there are also changes, but not significant. Analysis of the obtained experimental results proves the

effectiveness of the innovative system developed and implemented by us and the proposed pedagogical conditions of the outlined phenomenon.

Keywords: chatbots; categories of chatbots; artificial intelligence; digital environment of higher education; digital competence.

Introduction

To ensure an adequate level of support and improve communication between students and teachers in distance learning, it is necessary to find effective tools, and modern trends in the digitalization of education are precisely necessary in this process. The use of AI chatbots is one of the promising solutions in this area, because they can automate several administrative and educational processes, increasing the availability of educational resources and reducing the burden on teachers.

The digital technology market offers a wide range of opportunities for the transformation of educational institutions of each type of activity. Today's realities have proven the significance and relevance of the process of digitalization of the educational process, when the educational process cannot do without digital methods. The effective operation of universities in general depends on such a process (Vanichvasin, 2022). In modern conditions, an urgent problem is determining the forms of transformation of education and real ways of involving new technical developments for productive growth and systematic improvement of the educational potential of a higher educational institution.

In the era of the Internet, virtual communication is considered the next stage aimed at the development of mediated forms of personal communication, the development of social communications of a person, the expansion of the cultural background and range of communication, methods of obtaining and attracting new sources, and the production of information (Zhang, 2023).

The modification of artificial intelligence is behind each of the listed features of virtual communication. The integration of artificial intelligence into the educational process is actively studied in world research. The integration of digital learning tools into the educational process is due to the personalization and accessibility of education, the completeness and speed of information processing, which is facilitated by the use of chatbots – virtual assistants.

Building on the identified research gap, this study addresses the insufficient empirical evidence regarding the effectiveness of AI-powered chatbots as pedagogical tools for developing students' digital competence in higher education. While previous studies have demonstrated the educational potential of chatbots, limited attention has been devoted to experimentally validating comprehensive pedagogical systems that integrate AI chatbots into university teaching and learning. Therefore, the objective of this study is to examine the effectiveness of integrating AI-powered chatbots into the higher education learning environment for enhancing students' digital competence.

The following hypotheses were formulated:

H_1: Students participating in the AI chatbot-supported educational intervention will demonstrate significantly higher levels of digital competence than students receiving traditional instruction.

H_0: There will be no statistically significant differences in the levels of digital competence between students participating in the AI chatbot-supported educational intervention and those receiving traditional instruction.

Literature Review

Modern scientific research indicates a growing interest in generative language models in the digital educational environment and in the use of chatbots, in particular in the context of assessing the results of educational interaction and their pedagogical feasibility.

Labadze et al. (2023), in a systematic review of literature sources, emphasize that the pedagogical advantages of chatbots in higher education are related to the support of teaching activities and personalization of learning, while the issues of accuracy, reliability, and ethical responsibility of their use in the educational process of higher education remain relevant.

A study by Knoth et al. (2025) found that, beyond static traditional learning support tools, educational chatbots can significantly increase students' skills in critically evaluating information.

Debets et al. (2025) note that chatbot evaluation is largely limited to subjective perception indicators, and many educational chatbots are integrated into student education without a proper pedagogical theoretical basis. Baig & Yadegaridehkordi conduct similar studies. The scientists point to the fragmentation of approaches in higher education to assessing the use of ChatGPT and prove the lack of consistency of methodological foundations in the studies (Baig & Yadegaridehkordi, 2024).

The empirical results of the study by Alenezi and Alenezi (2025) show the positive impact of chatbots on the growth of learning motivation and engagement of students in the educational space and on the development of their communication skills, which confirms the educational potential of such tools in various educational contexts.

A significant contribution to the formation of an analytical approach to assessment was made by Qiu et al. (2025), who proved the need to integrate data on the nature of interaction, learning outcomes, and level of involvement into a single system for analyzing education seekers. At the same time, Jauhiainen and Garagorry Guerra (2025) in their study show possible ways for pedagogically correct assessment of written works and prove the possibility of using generative language models in higher education, provided that certain methodological requirements and criteria are strictly observed.

As a social phenomenon, a chatbot is a computer program that imitates human communication using text or voice, helps automate tasks, and serves as an interlocutor that, working according to a given algorithm, conducts a dialogue with the user, fulfills requests, and responds to requests. Most chatbots work on popular messenger platforms: Viber, Telegram, Facebook Messenger, Skype, Slack. Chatbots allow people to communicate using electronic devices as if they were talking to a live agent.

To provide the highest level of personalization by collecting and processing data, chatbots can range from simple programs that clearly respond to a single instance to advanced virtual assistants that can improve and learn (Munaye et al., 2025).

Chatbots can be defined as software that generates natural language as output, accepts natural language as input, and participates in a conversation. Chatbots can be built into search engine functionality and operate as separate programs (Palshkov et al., 2026).

They are also capable of providing useful information and can multitask based on user requests. In particular, they can provide the latest news, posters, weather forecasts, word translation, currency exchange rates, help booking a ticket, choosing the right flight, ordering a taxi, etc.

Systems with growing capabilities based on artificial intelligence are one of the main categories of chatbots, which have many potential applications in production automation, decision support, training, communication, etc.

The chatbot industry, according to Bloomberg, is developing faster than the mobile application industry during its heyday. One example of technology currently used in (computer-mediated) communication is a chatbot, where artificial intelligence agents are increasingly performing the roles that people once served. Not all chatbots are designed based on artificial intelligence, such as machine learning. However, the advantage of chatbots based on artificial intelligence is that they become smarter through increased interaction and data with the user.

Many popular chatbots can entertain; educational chatbots help with learning foreign languages; they can work as quizzes, online games, puzzles, and send quotes, photos, etc.

Chatbots can be divided into simple and self-learning:

- Simple chatbots can interact with students in higher education through pictures and buttons or accept text commands, highlighting keywords, recognizing language or text, and translating them into commands. Simple chatbots respond according to a given program and may have instructions with keywords and a list of commands.
- Self-learning chatbots, adapting to the individual characteristics of users and analyzing dialogues and working on the principle of artificial intelligence, allow them to learn in the process of communicating with users (Rudolph et al., 2023).

Self-taught chatbots participate in dialogues with students on abstract topics and have several advantages: they do not require switching between different menu tabs; they allow convenient work in one window; they allow students to work even at low Internet speeds; they work with messengers on all platforms, and they consume little traffic. It is convenient to transfer information through chatbots.

AI is increasingly integrated into various aspects of learning in the modern educational space, particularly in higher education. AI systems contribute to improving knowledge assessment and learning quality, creating an individualized educational experience. Those countries that actively implement AI technologies have achieved significant progress in reforming educational processes (Ait Baha et al., 2024).

Multimedia elements, high-quality graphics, and animation make it possible to present a distance course in the form of dynamic images, which greatly facilitates the assimilation of the studied material. Chatbots with AI, contributing to improved communication between students and teachers and providing necessary

educational support, are becoming an important part of mobile applications for distance learning (Kohnke, 2023).

Chatbot structure can be of different types, which differ in purpose; format of contact (interface, communication, dialogue) with the user; algorithm of work; functional content; scope of application (Liu et al., 2022). Communication by selecting alternative query buttons is a common type of chatbot operation. This process is influenced by the selection of the response text that the student enters into the appropriate field. Based on the analysis of the functional and communication work of chatbots, the Master24 bot algorithm was developed to support students' research and provide educational consultations to higher education applicants (Alsanousi et al., 2023).

The chatbot is developed using artificial intelligence to support text and voice messages, significantly improving the personalization of communication and the psychological climate. To help students write their master's thesis, a chatbot can be created on the SendPulse website and activated on the Telegram channel to help students (Panok et al., 2025).

Recently, AI-based chatbots have become wildly popular worldwide: Jasper Chat, ChatSonic, Bard, DialogGPT, BingAI, Tabnin, etc., which is due to the ability of modern chatbots based on generative AI to exceed the capabilities and potential of human resources significantly (Pentina et al., 2023).

Chatbots can respond to user requests more conveniently and naturally, process large amounts of data faster and more accurately, have access to a wider range of data on the global Internet and knowledge sources, can adapt their responses accordingly, understand the context of the conversation, and provide personalized suggestions and recommendations to the interlocutor, which is an innovation today. (Adamopoulou & Moussiades, 2020).

The most popular are educational and psychological chatbots that provide support to students and psychological assistance. The psychoanalytic effect of chatbots is enhanced by dialogue with students and teachers, which simulates live communication. Examples of such chatbots are CareBot21, Aquabot25, Woebot23, Vik26, Wysa2224.

Therefore, the use of chatbots with artificial intelligence in the higher education environment is one of the promising solutions for automating several educational and administrative processes, increasing the availability of educational resources.

Methodology

Research Design

This study employed a quasi-experimental research design aimed at examining the effectiveness of an innovative educational system for developing the digital competence of future specialists through the integration of AI-powered chatbots into the higher education learning environment. The research consisted of two consecutive stages: the ascertaining stage, during which the initial level of students' digital competence was determined, and the formative stage, during which the proposed pedagogical intervention was implemented and evaluated.

Participants

The experimental study involved 80 undergraduate students from higher education institutions. Participants were divided into an experimental group (EG, n = 42) and a control group (CG, n = 38). The allocation of participants ensured sample homogeneity, which was confirmed statistically before the intervention. The experimental group studied using the proposed innovative system integrating AI-based chatbots into the educational process, whereas the control group followed the traditional instructional approach.

Instrument Validity and Reliability

The diagnostic questionnaire consisted of 10 open-ended questions designed to assess students' digital competence in the educational use of AI-powered chatbots. To establish content validity, the instrument was evaluated by a panel of seven experts in educational technology, pedagogy, and digital learning. Each expert independently assessed the relevance, clarity, and representativeness of every item using a four-point rating scale. The Scale Content Validity Index demonstrated excellent agreement among the experts (S-CVI = 0.93), confirming satisfactory content validity. The internal consistency of the questionnaire was examined prior to the experimental study using Cronbach's alpha coefficient. The obtained reliability coefficient (Cronbach's α = 0.86) indicates good internal consistency of the instrument. These psychometric characteristics confirm that the questionnaire provides reliable and valid measurements of students' digital competence and is suitable for research purposes.

Educational Intervention

The educational intervention was based on an author-developed pedagogical system designed to enhance students' digital competence through the educational use of artificial intelligence chatbots. The intervention incorporated contemporary AI tools, including ChatGPT, Microsoft Copilot, Gemini, and Perplexity AI, into classroom instruction, independent learning, research activities, and academic communication.

The implementation relied on three pedagogical conditions:

- Creation of a digital innovative educational environment.
- Development of students' digital competence through blended and distance learning.
- Methodological support based on AI-powered educational chatbots.

These pedagogical conditions were implemented only within the experimental group throughout the formative stage of the study.

Instruments

Students' digital competence was assessed using an author-developed diagnostic questionnaire consisting of ten open-ended questions evaluating theoretical knowledge and practical understanding of chatbot technologies, artificial intelligence, chatbot typology, educational applications, and digital competence.

The diagnostic framework assessed three structural components of digital competence:

- Motivational
- Cognitive
- Creative

Corresponding indicators were defined for each component, allowing students to be classified into three levels of competence development: high, sufficient, and low.

Data Collection Procedure

Data collection was conducted in two phases.

During the ascertaining stage, baseline measurements of students' digital competence were obtained for both groups. After the implementation of the educational intervention in the experimental group, identical diagnostic procedures were administered during the formative stage to evaluate changes in competence levels.

To ensure methodological rigor, all diagnostic instruments satisfied the requirements of validity, reliability, representativeness, objectivity, and clarity of administration.

Statistical Analysis

Statistical analysis was performed using inferential statistical methods.

Student's independent samples *t*-test was applied to verify the equivalence of the experimental and control groups before the intervention. The null hypothesis assumed no statistically significant differences between the two groups (p= 0.05).

To evaluate the effectiveness of the pedagogical intervention, Fisher's angular transformation criterion (φ*) was used to compare the proportions of students demonstrating high levels of digital competence before and after the formative experiment.

Descriptive statistics were additionally employed to analyse changes in competence levels across both groups. Statistical significance was established at $p < 0.05$.

Ethical Considerations

The study was conducted in accordance with the ethical principles of research involving human participants. Participation in the study was voluntary, and all participants were informed about the purpose of the research and the procedures involved. Informed consent was obtained from all participants prior to data collection. Participation was anonymous, confidentiality was maintained throughout the study, and the collected data were used exclusively for scientific purposes. Participants were informed of their right to withdraw from the study at any stage without any negative consequences.

Results and Discussion

To substantiate the digital competence of future specialists, we have identified its components, indicators, and levels.

The components of the formation of digital competence of future specialists have been selected and identified: motivational, cognitive, and creative.

We have identified indicators of the formation of digital competence of future specialists based on the analysis of the content characteristics of the components.

The motivational component is represented by indicators: motivation for professional activity, value orientations.

The set of theoretical knowledge about digital competence is an indicator of the cognitive component.

The creative component is represented by an indicator such as the ability to creative self-development.

The identified indicators are objects of qualitative and quantitative analysis. The selected indicators are sufficient and necessary to determine the level of formation of digital competence of students.

Having identified the components and indicators of digital competence, it is necessary to characterize the levels of its formation. We have identified the following levels: low, sufficient, high.

The completed definition of components, indicators, and levels of digital competence formation will contribute to the implementation of the goal of the process that we studied, which is reflected in the expected result – verification of the effectiveness of the developed system and pedagogical conditions for the formation of students' digital competence.

In accordance with the above, we have determined the following pedagogical conditions:

- Creation of a digital innovative educational environment in higher education.
- Ensuring the development of students' digital competence in the format of distance and blended learning.
- Educational and methodological support for students, taking into account the category of chatbots with the growing capabilities of the education system based on artificial intelligence.

All conditions are interconnected and interdependent.

Organization of experimental research.

An experimental study was conducted to verify the effectiveness of the proposed innovative system of training students for professional activity and the developed pedagogical conditions for the formation of students' digital competence to qualitatively introduce chatbots into the educational process of higher education and into the professional activity of future specialists. As a complex multi-component research method, a pedagogical experiment was used for this purpose, which is a controlled process of scientific and pedagogical activity, hierarchically organized and used by us for evidential verification and objective probability of the hypotheses and theoretical propositions under study, clarification of conclusions and certain assumptions.

The experimental study was carried out in a certain sequence:

- Preparation of the experiment.
- Actual experimental study.

We took into account the requirements when developing and selecting diagnostic tools: sufficient objectivity, compliance with the purpose of the study; reliability, validity, representativeness; clarity and unambiguousness of instructions within the framework of the experimental study and the process of its conduct.

Student's t-test was used for independent variables in order to identify differences between the experimental and control groups.

Fisher's multifactorial test was used to compare the results of the diagnosis.

At the ascertaining stage of the experimental study, in order to conduct and prepare the formative stage of the experiment and for comparison, statistical processing and analysis of the results of the study, the respondents of the experiment were divided into experimental and control groups. When distributing, the homogeneity of the sample was ensured, because the absence of differences between the experimental and control groups made it possible to obtain objective results already at the ascertaining stage of the experimental study.

The study used Student's t-test – the most optimal method (mathematical processing) for independent variables.

Student's t-test in the study made it possible to find out how much the indicators of one sample of subjects differ from another.

We used the results of the author's questionnaire as independent variables. The questionnaire consisted of 10 open-ended questions. 1 point was assigned for each correct answer. 10 is the maximum number of points.

The questionnaire was conducted at the ascertaining stage of the experiment to determine the level of formation of students' digital competence and showed the following results:

Table 1.
The level of formation of students' digital competence at the ascertaining stage of the experimental study

Level	Control Group (CG), n (%)	Experimental Group (EG), n (%)
High	7 (18.42%)	11 (26.19%)
Sufficient	31 (81.58%)	31 (73.81%)
Low	0 (0.00%)	0 (0.00%)
Total	**38 (100.00%)**	**42 (100.00%)**

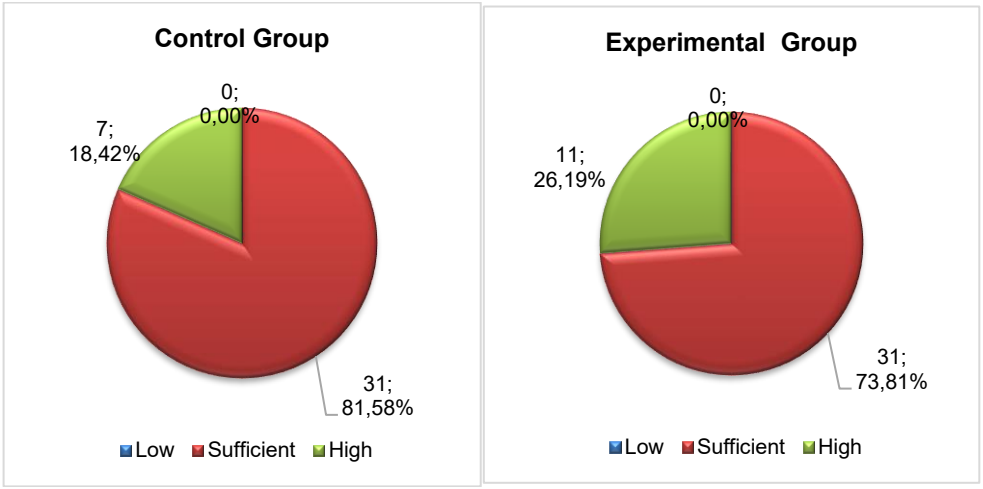


Figure 1. The level of formation of students' digital competence at the ascertaining stage of the experimental study.

18% (7 respondents of the CG) and 26% (11 respondents of the EG) correctly answered more than 8 questions of the questionnaire, the questions of which concerned the content and significance of chatbots in the educational environment of higher education; categories of chatbots with increasing capabilities of the system based on artificial intelligence; typologies of chatbots, chatbot structure, knew popular AI chatbots on a global scale, etc. The answers of these students were complete and reasoned. Respondents were aware of the importance of developing digital competence in professional activities.

82% (31 respondents of the CG) and 74% (31 respondents of the EG) have a sufficient level of theoretical knowledge about digital competence and current issues of chatbots with increasing capabilities of the system based on artificial intelligence, typologies of chatbots, chatbot structures, popular AI chatbots on a global scale.

So we see that the students who participated in the experiment did not show a low level at the ascertaining stage. However, they also showed a high level at a low position in both groups: EG and CG, which requires improving the system of preparing students for professional activity and the developed pedagogical conditions for the formation of students' digital competence in order to qualitatively introduce chatbots into the educational process of higher education and into the professional activity of future specialists.

We put forward a null hypothesis (H_0) that there is no dependence on the belonging of the survey results to the experimental or control group, and an alternative hypothesis (H_1) that there is a dependence.

We compared the results in two groups – EG and CG. For this purpose, we determined the number of points scored – the sum of the observed features according to formula 1.

$$x_{sum} = \sum_{i=1}^{v} (x_i \cdot n_i)$$

x_{sum} – the number of points scored is the sum of the observed features.
v – levels corresponding to the points scored.

x_i – level corresponding to the student's scores − each observed value of the attribute.
n_i – number of people who received x_i level.

According to formula 2, the average arithmetic value of the sum of the observed signs was calculated.

$$\bar{x} = \frac{x_{sum}}{m} = \frac{\sum_{i=1}^{v}(x_i \cdot n_i)}{m}$$

$\bar{x}$ – arithmetic mean value of an observed characteristic, equal to the sum (divided by the number of individuals in the group) of the observed characteristics.
x_{sum}– sum of observed features.
m – number of people in a group.
v – number of levels in the test.
x_i − the number of points scored by each participant – each observed value of the feature.
n_i – number of people who received the x_i level.

For the control group and for the experimental group, the arithmetic mean of the sum of the observed characteristics was determined.

According to formula 3, the calculation of the mean square error was performed based on the arithmetic mean value of the observed characteristic.

$$Q = \sqrt{\frac{\sum_{i=1}^{v}(x_i \cdot n_i - \bar{x})^2}{m}}$$

Q – root mean square error;
v – number of levels in the test;
x_i – the number of points scored by each participant – each observed value of the feature;
n_i – number of people who received the x_i level.
$\bar{x}$ – arithmetic mean of the observed feature;
m – number of people in a group.

Calculations were performed, and the values for the control group and the experimental group were obtained – the value of the mean square error.

Next, using formula 4, the value of the average errors in the answers to the test questions was calculated.

$$M = \frac{Q}{m}$$

M – the value of the average errors in respondents' answers to test questions.
Q – root mean square error.
m – number of people in a group.

The calculation of the mean error values for the experimental group and for the control group in the answers to the test questions yielded the following results.

The data obtained in the control and experimental groups on the values of the arithmetic mean of the observed features provide the possibility of calculating the Student's t-test – numerical value according to formula 5:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{M_1^2 + M_2^2}}$$

$\bar{x}_1$ – arithmetic mean value in the control group of the observed characteristic.
$\bar{x}_2$ – arithmetic mean value in the experimental group of the observed trait.
M_1 – value in the control group of mean errors.
M_2 – value in the experimental group of average errors.

We calculate the Student's t-test – a numerical value. This allows you to compare the obtained value of the Student's t-test with the tabular value to determine the level of reliability of the calculated t-value.

The calculated Student's t-test value, which is greater than or equal to the critical value, indicates that there is a statistical difference between the compared values. If the calculated Student's t-test value is less than the tabular value, then the difference between the compared values is not statistically significant.

For the selected level of reliability, the tabular value (p=0.05) and the number of degrees of freedom were selected. Using the number of degrees of freedom, we find the sample size in the Student distribution method. The number of freely selected observations shows the number of degrees of freedom after finding out the values that are important in this case. As a result of the calculations, we obtain the number of degrees of freedom according to formula 6:

$$U = m_1 + m_2 - 2$$

U – number of degrees of freedom.
m_1 – number of people in the control group.
m_2 – number of people in the experimental group.

The critical value of the Student's t-test is found for the selected (p=0.05) value level, taking into account (U=78) the calculated value of the degrees of freedom. It was found that the calculated t-value is less than the critical t-value when comparing the Student's t-criterion calculated by us (0.55<1.990). The obtained result confirms the hypothesis H_0, because it indicates that the test results are not dependent on whether respondents belong to the experimental or control group.

The calculation results obtained by the chosen method of mathematical statistics for Student's t-criteria – independent variables allowed us, as a result of the comparison of the test results for both studied samples, to conclude that the respondents of the experimental and control groups belong to the same general population, because the results do not differ.

Analysis and comparison of the levels of formation of students' digital competence at the ascertainment and formative stage of experimental research.

The results of the ascertaining stage of the experimental study showed the need to develop an innovative system for preparing students for professional activities and developed pedagogical conditions for the formation of students' digital competence

in order to qualitatively introduce chatbots into the educational process of higher education and into the professional activities of future specialists.

Therefore, we implemented such a system and pedagogical conditions in the EG, and the CG students studied according to the standard methodology.

Chatbots created on modern AI models were used in the EG educational process, which significantly facilitated students' learning by allowing respondents to quickly and accurately answer questions that arose during the mastering of professional material. Gemini from Google is an example of such a chatbot. It can offer additional resources for a deeper understanding of the topic and create interactive tasks and games. Studying at the university for EG students became more interesting, and not only more accessible, thanks to such tools. By adapting educational materials to the individual needs of each student, this technology contributed to better student learning, made it possible to set up personalized support, and to learn at a pace convenient for each individual. Thus, chatbots supported EG students even outside the traditional classroom, encouraged them to be more independent in their studies, and offered individual support to higher education students by adapting the proposed materials to their level of knowledge and needs. Chatbots automatically adjusted the pace of teaching in EG and provided additional resources or explanations for deeper mastery of professional material. They provided continuous support to students, helped them overcome difficult tasks thanks to an individualized approach, and reduced their dependence on the teacher.

An effective tool for EG students was ChatGPT, which can generate answers to questions in various fields of knowledge and conduct dialogues in natural languages thanks to the ChatGPT language model, which assisted EG students in the learning process and made it possible to use the chatbot effectively.

Another effective example is Microsoft Copilot, which is based on GPT-4 and was developed in collaboration with OpenAI by Microsoft Corporation. To automate everyday tasks, this tool uses natural language. It allows you to focus on visualization, editing, and text creation in various environments (Windows 10 and 11 operating systems), including the Microsoft 365 service, Android and iOS mobile platforms, and the Microsoft Edge web browser. Copilot is an indispensable, convenient, and useful tool for increasing productivity in education.

An important chatbot is Google's Gemini, which uses artificial intelligence to translate text, generate creative content, and answer user questions, and is based on Google’s LaMDA language model. Gemini promotes interactive learning by creating learning tasks and exercises, providing students with additional explanations and resources for a deeper understanding of the material, and also increases the efficiency of the educational process in higher education.

For processing text queries, Perplexity AI is of great importance in the professional training of students – an innovative tool capable of using Internet sources, generating answers, and citing relevant links. This opens up new opportunities for students and teachers, making it effective for information processing and search, which is especially important when analyzing information and research.

The use of chatbots based on artificial intelligence has the potential to increase the efficiency of the educational process, helping to change the student’s thinking and behavior. Ease of use and personalization are considered the most useful factors in student-teacher interaction, as communication is crucial to achieving goals.

Therefore, for modern education, chatbots are an important component of the methodology. Effective communication skills in higher education, such as social dialogue, empathy, and immediacy, can be embedded in digital systems through social interaction signals and communication strategies, contributing to strong relationships between the learning system and the user. Chatbot-based interventions are one of the most innovative forms that can significantly expand access to professional education.

In the EG, the chatbot made it possible to explain to the EG students the problems they need at the moment and what is relevant for them. In addition to its educational and reference function, the educational chatbot system included feedback for students, because each chain was recorded and tracked. Based on the number of links and open reference buttons, it was possible to determine the systematicity of the work on the research, the level of implementation of the considered questions, track the activity of the participants in the educational chat, and the pace of task processing. Chatbots using AI for EG students significantly facilitated student communication, contributed to the development of individual learning trajectories, increased motivation and overall success, significantly facilitated the advisory work of teachers, and allowed them to pay more attention to the creative aspects of the work done.

For EG students, two formats for implementing the educational process were proposed: a channel for supporting educational actions and quick communication – Telegram-bot (convenient for short consultations and home training); Web-bot (browser interface) as an environment for extended work. This approach strengthened the educational activity of EG students, rather than replacing it, and corresponded to the competency-based logic of assessment.

The architecture of the educational bot in the educational environment provided three key characteristics: manageability (the teacher set the framework), verifiability (reproduction of the process of obtaining an answer), and security (responsible and private use).

As a result of introducing modern digital technologies in the EG to form the digital competence of future specialists, we concluded that the use of chatbots significantly improves the quality of higher education. The functions of chatbots make student learning more exciting, facilitate access to educational resources, provide students with individualized support, and improve their communication.

We have developed and implemented pedagogical conditions for the formation of students' digital competence in the EG. In accordance with the above, we have defined the following pedagogical conditions:

- Creation of a digital innovative educational environment in higher education.
- Ensuring the development of students' digital competence in the format of distance and blended learning.
- Educational and methodological support for students, taking into account the category of chatbots with the growing capabilities of the education system based on artificial intelligence. All conditions are interconnected and interdependent.

The formative stage of the experimental study was aimed at determining the respondents' levels (high, sufficient and low) of students' digital competence formation in order to qualitatively introduce chatbots into the educational process of higher education and into the professional activities of future specialists and to verify the effectiveness of the proposed innovative system of training students for

professional activities and the developed pedagogical conditions of the outlined phenomenon.

Upon completion of the formative stage of the experimental study, all the outlined indicators differed from the results of the ascertaining stage of the experimental study.

Let us analyze the results of the obtained data.

The results of the correlation of the levels of students' digital competence formation at the ascertaining and formative stages are presented in Table 2. As can be seen from the table, a low level of students' digital competence formation was not detected either at the ascertaining stage, at the research stage, or at the formative stage of the experiment.

Table 2.
Correlation of the levels of students' digital competence formation at the ascertaining stage and the formative stage of the experimental study

Level	Control Group (CG), n (%)	Experimental Group (EG), n (%)
Before the experiment		
High	7 (18.42%)	11 (26.19%)
Sufficient	31 (81.58%)	31 (73.81%)
Low	0 (0.00%)	0 (0.00%)
After the experiment		
High	13 (34.21%)	37 (88.10%)
Sufficient	25 (65.79%)	5 (11.90%)
Low	0 (0.00%)	0 (0.00%)
Total	**38 (100.00%)**	**42 (100.00%)**

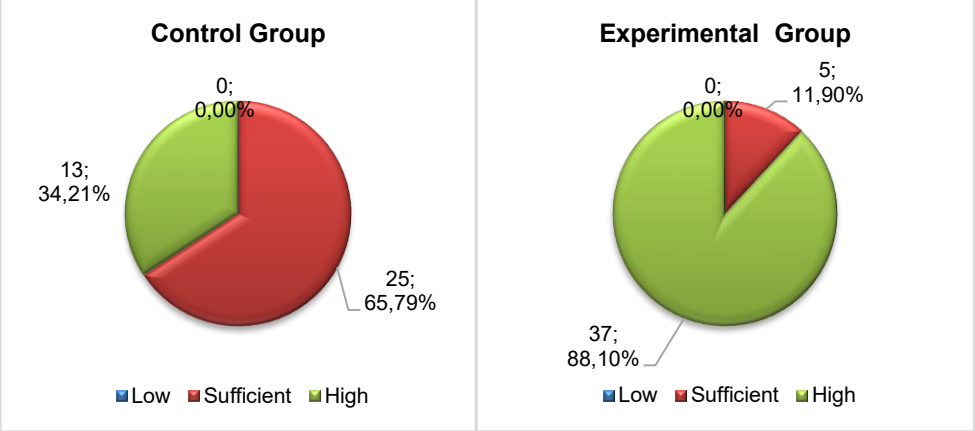


Figure 2. Distribution of Students by Levels of Digital Competence Formation After the Experiment

In the EG, we see significant changes, with an increase in the high level of digital competence formation among students for the qualitative implementation of chatbots in the educational process of higher education and in the professional activities of future specialists. In the control group, there are also changes, but not significant.

The number of students with a high level of digital competence formation in the CG increased from 18.42% (7 students) at the ascertaining stage to 34.21% (13

students) at the formative stage. The proportion of students with a high level of digital competence in the control group increased from 18.42% (7 students) before the intervention to 34.21% (13 students) after the intervention, representing an increase of 15.79 percentage points (34.21% − 18.42% = 15.79 percentage points).

In the EG, the proportion of students with a high level increased from 26.19% (11 students) at the ascertaining stage to 88.10% (37 students) at the formative stage, representing an increase of 61.91 percentage points. At the same time, the proportion of students with a sufficient level in the EG significantly decreased from 73.81% (31 students) to 11.90% (5 students). In contrast, in the CG, the proportion of students with a sufficient level decreased from 81.58% (31 students) at the ascertaining stage to 65.79% (25 students) at the formative stage, representing a decrease of 15.79 percentage points. Thus, the changes in the CG were considerably less pronounced than those observed in the EG.

Individuals with a low level of formation of students' digital competence for qualitative implementation of chatbots in the educational process of higher education and in the professional activities of future specialists in the experimental group were also not identified, as in the CG.

Analysis of the obtained experimental results proves the effectiveness of the innovative system of training students for professional activities developed and implemented by us and the proposed pedagogical conditions for the formation of students' digital competence for qualitative implementation of chatbots in the educational process of higher education and in the professional activities of future specialists in the educational process of group.

We used the multifunctional Fisher criterion to determine the effectiveness of the results obtained in the experimental group.

The dynamics in the levels of formation of digital competence of students to introduce chatbots into the educational process of higher education and into the professional activities of future specialists made it possible to formulate the following hypotheses:

H_0: The number of respondents in the experimental group at the ascertaining stage of the experimental study with a high level of development is less than at the final stage of the experimental study, which proves that the formative stage of the experimental study is effective.
H_1: The number of respondents in the experimental group at the ascertaining stage of the experimental study with a high level of development is not significantly greater or the same as at the final stage of the experimental study, which proves that the formative stage is not effective in the experimental study.

Referring to the table of Fisher's exact test φ* critical values, we determine the percentages of the "effect" of the value φ* in each of the groups.

The empirical value of φ* is determined by formula 7:

$$\varphi^*_{emp} = (\varphi_1 - \varphi_2) \times \sqrt{\frac{n_1 \times n_2}{n_1 + n_2}}$$

φ_1 – angle corresponding to the larger % fraction.
φ_2 – angle corresponding to the smaller % fraction.

n_1 – number of total observations in sample 1.
n_2 – number of total observations in the sample of 2.

Substituting the post-test data into Formula (7), the empirical value of Fisher's angular transformation criterion was calculated as φemp = 5.30. Since φemp exceeded the critical value (φ*crit = 2.31, p < 0.01), the null hypothesis was rejected. Therefore, the difference between the experimental group (88.10%, 37/42 students) and the control group (34.21%, 13/38 students) after the intervention was statistically significant, confirming the effectiveness of the proposed educational intervention.

To compare the identified levels and their final results of the formation of students' digital competence, we used Fisher's multifactorial criterion. Thus, the indicators of (empirical) high and sufficient levels after the formative stage of the study are greater than the critical value (2.31), adopted in psychology as the level of statistical significance.

The scientific validity and reliability of the conclusions and provisions of the study were ensured by the reliability and validity of standardized psychodiagnostic methods.

Thus, the results of the experiment showed positive dynamics in the levels of formation of students' digital competence for qualitatively introducing chatbots into the educational process of higher education and into the professional activities of future specialists, so we have reason to assert that the assumption expressed regarding the need for the proposed innovative system of training students for professional activities and the developed pedagogical conditions for the formation of students' digital competence was confirmed.

Conclusions

This study investigated the effectiveness of integrating AI-powered chatbots into the higher education learning environment for enhancing students' digital competence. The findings demonstrate that the proposed pedagogical system, based on the creation of an innovative digital educational environment, blended learning, and methodological support through AI-powered chatbots, contributes significantly to the development of students' digital competence.

The quasi-experimental study confirmed that the experimental and control groups were statistically equivalent before the intervention (Student's $t = 0.55$, $p > 0.05$), ensuring the comparability of the groups. Following the implementation of the intervention, the proportion of students demonstrating a high level of digital competence increased from **26.19% to 88.10%** in the experimental group, whereas the corresponding increase in the control group was from **18.42% to 34.21%**. Fisher's angular transformation criterion confirmed the statistical significance of the post-test differences between the groups ($\varphi emp = 5.30 > \varphi crit = 2.31$, $p < 0.01$), providing empirical evidence for the effectiveness of the proposed educational intervention.

The study contributes to the growing body of research on artificial intelligence in higher education by providing experimental evidence that the systematic pedagogical integration of AI-powered chatbots enhances students' digital competence beyond the outcomes achieved through traditional instruction. Unlike studies that primarily examine learners' perceptions or isolated chatbot applications,

the present research evaluates a comprehensive pedagogical model implemented under controlled educational conditions.

The practical significance of the study lies in the possibility of integrating AI-powered chatbots such as ChatGPT, Microsoft Copilot, Gemini, and Perplexity AI into university teaching, independent learning, research activities, and academic communication. The proposed pedagogical conditions may be adapted for higher education institutions seeking to improve students' digital competence and promote the responsible educational use of artificial intelligence technologies.

Several limitations should be acknowledged. The study was conducted within a relatively limited sample of undergraduate students from higher education institutions, which may restrict the generalizability of the findings. In addition, the intervention evaluated short-term learning outcomes, whereas the long-term sustainability of digital competence development was beyond the scope of the present research.

Future research should investigate the long-term effects of AI-supported learning environments, compare different categories of educational chatbots across academic disciplines, examine their influence on additional learning outcomes such as critical thinking, problem-solving, and self-regulated learning, and validate the proposed pedagogical model using larger, multicenter, and cross-cultural samples.

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Original Article

El componente interactivo de la transformación digital en la educación superior: Un estudio experimental

The interactive component of digital transformation in higher education: An experimental study

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Resumen

La transformación digital de la educación superior ha generado nuevas oportunidades para potenciar la participación estudiantil mediante entornos de aprendizaje interactivos. Este estudio examinó la efectividad de un sistema pedagógico diseñado para mejorar la participación interactiva del estudiante mediante la integración de tecnologías digitales en la educación superior. Se empleó un diseño cuasiexperimental con 174 estudiantes de pregrado, divididos en un grupo de control (n = 86) y un grupo experimental (n = 88). Se realizó un cuestionario, observación y entrevista para evaluar la disposición de los estudiantes para la interacción interactiva en parámetros motivacionales, de actividad y reflexivos. El grupo experimental contó con un sistema especialmente diseñado que combinaba estrategias de aprendizaje, plataformas de comunicación digital, herramientas de evaluación interactiva, tecnologías de colaboración en línea y aplicaciones de realidad virtual y aumentada. Los resultados mostraron una gran mejora en la disposición de los estudiantes para la interacción interactiva en el grupo experimental en comparación con el grupo de control. También se observaron cambios en todas las dimensiones (motivación para el aprendizaje, participación colaborativa y prácticas reflexivas). El análisis estadístico demostró la efectividad de la intervención. La prueba de chi-cuadrado de Pearson (χ^2) mostró diferencias entre los grupos, mientras que la prueba t de Student confirmó la fiabilidad de los resultados. En consecuencia, se demostró que las tecnologías digitales pueden mejorar eficazmente la interacción interactiva de los estudiantes y fomentar la participación activa en un entorno de educación superior transformado digitalmente.

Palabras clave: interacción educativa interactiva; estudiantes; digitalización; educación superior; herramientas digitales.

Abstract

The digital transformation of higher education has created new opportunities to enhance student engagement through interactive learning environments. This study examined the effectiveness of a pedagogical system designed to enhance interactive student engagement by integrating digital technologies in higher education. A quasi-experimental design was employed, involving 174 undergraduate students divided into a control group (n = 86) and an experimental group (n = 88). A questionnaire, observation and interview were conducted to assess students' readiness for interactive interaction on motivational, activity and reflective parameters. The experimental group had a specially designed system that combined learning strategies, digital communication platforms, interactive assessment tools, online collaboration technologies and virtual and augmented reality applications. The results showed

a great improvement in students' readiness for interactive interaction in the experimental group compared to the control group. Changes were also observed on all dimensions (motivation for learning, collaborative participation and reflective practices). Statistical analysis proved the effectiveness of the intervention. Pearson's chi-square (χ^2) test showed differences between groups, while Student's t-test confirmed the reliability of the results. As a result, it turned out that digital technologies can effectively improve students' interactive interaction and support active participation in a digitally transformed higher education environment.

Keywords: interactive educational interaction; students; digitalization; higher education; digital tools.

Introduction

The contemporary education system is undergoing profound social, technological, and organizational transformations. One of the key drivers of these changes is digitalization, which permeates all sectors of society and significantly influences the functioning of higher education institutions (HEIs). As education becomes increasingly integrated into the digital ecosystem, traditional approaches to organizing teaching, learning, and institutional management require fundamental reconsideration.

Global trends in higher education and institutional governance are increasingly oriented toward comprehensive digital transformation. This process extends beyond the adoption of digital technologies for teaching and learning to encompass the digitalization of educational, research, administrative, and managerial processes across the entire institution. Without a comprehensive digital transformation strategy, higher education institutions cannot effectively ensure the quality of educational provision, support remote administrative operations and document management, or maintain competitiveness in an evolving academic environment. Consequently, the absence of such transformation negatively affects students, faculty members, and administrative staff alike.

Traditional approaches to the automation of higher education management have largely exhausted their potential and no longer meet the demands of contemporary digital ecosystems. Conventional automated systems for learning management, administration, and record-keeping address only isolated institutional functions while fragmenting the information environment into separate, function-specific domains. These disconnected systems operate independently rather than as components of an integrated digital infrastructure, limiting data interoperability and institutional efficiency. Such fragmentation hinders the implementation of comprehensive digitalization initiatives and prevents the development of fully integrated digital universities. Consequently, new conceptual approaches to the digital transformation of higher education institutions are required – approaches capable of integrating all institutional processes, software solutions, and information resources within a unified digital ecosystem that supports the development of sustainable digital universities.

Accordingly, a significant scientific and practical challenge lies in developing innovative methods and models for the digital transformation of higher education institutions through the integration of institutional functions, procedures, and information repositories into a unified, concentric information technology framework that supports the digital transformation of educational activities.

Recent research has demonstrated that digital technologies create favorable conditions for collaboration, communication, and active learning in higher education. Nevertheless, most existing studies have focused primarily on evaluating individual digital tools or isolated instructional approaches. Considerably less attention has been devoted to understanding how these technologies can be systematically integrated into a coherent pedagogical framework that consistently enhances students' readiness for interactive educational engagement. Consequently, empirical evidence regarding the effectiveness of comprehensive pedagogical systems that combine digital technologies with collaborative learning, formative assessment, reflective practice, and project-based learning within a unified instructional model remains limited.

Against this background, the present study aims to provide empirical evidence of the educational value of a pedagogically structured approach to digital transformation in higher education.

The aim of this study was to examine whether the systematic pedagogical integration of digital technologies can enhance students' readiness for interactive educational engagement in higher education. To achieve this, the study evaluated the effectiveness of an author-developed pedagogical system that combines collaborative learning, digital communication tools, formative assessment, reflective activities, and immersive technologies within a digitally transformed learning environment.

Literature Review

Recent research has demonstrated that the successful digital transformation of higher education depends on the integration of digital technologies with student-centred pedagogical approaches. Studies by Chiang and Wu (2021), Onyishi and Sefotho (2020), Meşe and Mede (2023), Ramírez Hernández et al. (2025), Saqib et al. (2021), Surjawan et al. (2025), and Hashim et al. (2022) highlight the importance of collaborative learning, digital competence, interactive educational environments, and institutional digital transformation for improving student engagement and learning outcomes.

The theoretical foundations of modeling open systems in the field of science and education, pedagogical systems for the formation and development of competencies, cloud-based learning support systems, as well as the implementation of interactive methodological systems are thoroughly substantiated in the works of Meşe and Mede (2023), who investigated the issues of digitalization of the educational environment, the development of cloud technologies and methodological learning systems.

Current studies suggest that students' engagement in digital learning depends on more than access to technology alone. Their readiness to contribute, assurance in their own skills, and the method instruction is systematized all play an central role. The authors Ramírez Hernández et al. (2025), Saqib et al. (2021), Surjawan et al. (2025), and Hashim, et al. (2022) examine the interrelationships in digital transformation, digital agility, and the implementation of smart technology models. They outline the main challenges and opportunities that universities face when implementing new technologies. They explore a comprehensive analysis that outlines the critical elements of effective smart management, including resource management, institutional collaboration, and increasing digital competencies among teachers, emphasizing the importance of implementing digital transformation to

increase the effectiveness of the educational process in higher education institutions.

While important study has examined digital learning technologies and interactive pedagogical approaches, central gaps persist. Most existing studies focus on individual digital tools, teaching methods, or learner characteristics. Comparatively little attention has been paid to the development and experimental validation of integrated pedagogical systems that combine digital technologies, interactive instructional strategies, and purposeful development of students' readiness for active participation. Addressing this gap is particularly important in the context of ongoing digital transformation in higher education. Therefore, the present study aims to investigate the effectiveness of a comprehensive pedagogical system designed to enhance students' readiness for interactive engagement within digitally transformed higher education environments.

Methodology

Research Design

A quasi-experimental pretest–posttest control group design was employed to evaluate the effectiveness of the proposed pedagogical system for enhancing students' interactive educational engagement in digitally transformed higher education. Before the intervention, all participants completed baseline measurements using the same assessment instruments to establish the initial equivalence of the experimental (EG, n = 88) and control groups (CG, n = 86). Pearson's chi-square test revealed no statistically significant differences between the groups across the motivational, activity-based, and reflective dimensions of interactive readiness ($p > .05$ for all comparisons), confirming their initial homogeneity and ensuring the comparability of subsequent experimental results.

Participants

The participants were 174 undergraduate students from higher education institutions. The sample included a control group (CG, $n = 86$) and an experimental group (EG, $n = 88$). While the control group studied according to the standard curriculum, students in the experimental group completed a learning program based on the proposed pedagogical system, which integrated collaborative activities and interactive digital technologies into the educational process. Comparing the two groups allowed the effectiveness of this approach in developing students' readiness for interactive educational engagement to be assessed.

Instruments

Information about students' readiness for interactive educational engagement was gathered from three sources: questionnaire responses, classroom observations, and semi-structured interviews. Using these methods made it possible to obtain a broader picture of students' learning experiences and participation.

The questionnaire consisted of 30 items distributed across three dimensions: motivational readiness (10 items), activity-based readiness (10 items), and reflective readiness (10 items). Responses were recorded using a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Higher scores indicated greater readiness for interactive educational engagement.

Previous to the key study, the questionnaire was led with 32 undergraduate students who did not participate in the experiment. Internal consistency demonstrated satisfactory reliability (Cronbach's α = 0.91 for the overall scale; motivational dimension α = 0.88; activity-based dimension α = 0.90; reflective dimension α = 0.86). Content legitimacy was recognized through expert assessment by five specialists in higher education pedagogy and digital learning, who complete the importance, precision, and representativeness of all questionnaire items. Minor linguistic revisions were introduced following the pilot testing without changing the theoretical structure of the instrument.

Observation Protocol

Quantitative and social indicators were considered in the students' interactive participation. An observation checklist was developed with 12 behavioral indicators to assess participation in collaborative discussions, peer interaction, initiative during group activities, use of digital tools for collaborative learning, and response to formative feedback.

The indicators were rated on a four-point scale from 0 (not observed) to 3 (consistently demonstrated). Two independent observers rated approximately 20% of the training sessions. Inter-rater agreement reached Cohen's κ = 0.84, indicating the reliability of the observational coding.

Experimental Procedure

The study had two stages. The first was to establish the initial level of readiness for interactive educational participation in a digital environment. The result is that most participants did not yet have a sufficiently high level of readiness, most participants demonstrated a low or moderate level of success. Therefore, the results confirmed the need to introduce different approaches to learning that should promote more active participation and interaction throughout the educational process.

The second stage showed that the experimental group completed the curriculum made on the proposed pedagogical system, while the control group continued their studies on the regular curriculum used in their institutions. The intervention was introduced into regular courses and was not conducted as a separate course. The main objective was to increase student engagement through the use of digital technologies together with interactive teaching methods.

Throughout the experiment, students worked on collaborative projects, discussed them in groups, solved various practical tasks in teams and communicated through online learning environments. Digital platforms, shared online workspaces, interactive assessment services, educational games and virtual and augmented reality applications were actively introduced into classroom activities when they supported learning objectives and encouraged active participation.

The pedagogical system was guided by three interrelated principles:

- Involved creating a digital learning environment in which students were encouraged to take initiative, work independently, and participate actively in educational activities.
- Focused on enriching learning experiences through the use of virtual and augmented reality technologies where appropriate.

– Emphasized continuous interaction supported by digital communication and learning tools, enabling students to exchange ideas, collaborate on educational tasks, and develop skills through sustained peer interaction.

Interview Procedure

After the experimental phase, semi-structured interviews were conducted with 24 students, including 12 participants from the experimental group and 12 from the control group. The interviews covered students' learning through digital technologies, their participation in collaborative activities, changes in motivation, approaches to independent learning, and their overall perceptions of engagement during the course.

The interview data were analysed using thematic analysis. Each transcript was independently reviewed by two members of the research team, who brainstormed and assigned preliminary codes. After comparison, the research team members agreed on one common coding scheme. This resulted in four main themes: motivation to learn, participation in collaborative activities, digital learning experiences, and reflective self-regulation. Any differences in coding were discussed together until a common interpretation was reached.

Data Analysis

Quantitative data were processed using statistical methods and Pearson's chi-square (χ^2) test. This allowed us to compare the levels, their distribution, and readiness in the experimental and control groups before and after the introduction of the pedagogical system. The primary analysis did not show any differences between the groups, which indicates comparable initial conditions. After the intervention, statistically significant differences were made, which indicates a good effect of the proposed educational approach.

Qualitative data that we obtained as a result of classroom observations and interviews were made by us together with statistical results. These data were used to explain the quantitative results and for a broader understanding of the students' educational experience.

Ethical Considerations

The conduct of the experiment is permitted by the scientific councils of the universities in order not to violate ethical considerations in institutions of higher education. Ethical requirements were taken into account at each stage of the study. Before the start of the experiment, all participants were informed about its purpose, procedure, and use of the collected data. Respondent participation was voluntary, and each student could withdraw from the study without any consequences. To protect the confidentiality of the participants, their personal information was removed from the research materials before analysis.

Limitations

The study was conducted with the participation of undergraduate students from a limited number of higher education institutions. The effectiveness of the system was evaluated at a specific educational institution and during a short period of the experiment.

Results and Discussion

Among the innovations is the possibility of implementing high-quality interactive educational interaction of students through the digitalization of higher education even in the absence of direct contact between the student and the teacher; increasing the degree of visibility of educational material, giving it the properties of interactivity and dynamism, making any sources of information available to students, presented in any form convenient for the education student; the ability to perceive professional educational material that is inaccessible without digital means (virtual excursions, virtual experiments, communication with historical figures, modeling of phenomena and processes, etc.); activation of all cognitive mental processes (perception, sensations, imagination, thinking, memory, attention) in higher education students; creation of an emotional bright attitude towards educational digital information by adding elements of competition and game; provision of innovations for all participants in the educational process for implementing high-quality interactive educational interaction of students.

Digital educational tools are universal for implementing high-quality interactive educational interactions with students. They can be used effectively in distance learning (where they are indispensable and mandatory) and in offline learning, provided that appropriate multimedia interactive devices are available. A modern specialist, regardless of the profile, must have a sufficient level of digital educational tools and apply them methodically correctly in their work, be competent with the help of these tools in organizing interactive interaction of participants in the educational process.

Digital tools that provide opportunities for organizing interactive educational interactions.

A high level of interactive educational interaction through the digitalization of higher education is ensured by an orientation to the value system and personal motivation of all those involved in this process.

A high level of interactive educational engagement among students in the educational process, enabled by the digitalization of higher education, is associated with acquiring knowledge that forms the basis of professional skills.

Digitalization involves saturating the educational environment with systems and devices for electronic communication, and the widespread use of information and communication technologies and multimedia educational technologies, which entails significant changes in the organization of the educational process (Chiang & Wu, 2021).

To do this, the teacher offers students interactive electronic didactic materials and can create them themselves using online services and various software tools. Many digital platforms have already developed lessons and certain templates. Examples of such platforms include WorldWall, Quizlet, Kahoot!, Liveworksheets, and Prosvita (Jennek et al., 2019; Knaut et al., 2022).

Active use of communication tools: social networks (Viber, Telegram, WhatsApp), e-mail, provides opportunities for maintaining interactive learning interaction between students in the digital educational environment. At the same time, the organization within the platform of independent activity requires constant pedagogical support and modern approaches. Otherwise, there is a risk of reducing educational tasks to reproductive fulfillment (Liou et al., 2023).

The possibility of parallel student interaction, joint work on content, and saving results for further use in professional activities – all of this provides a new level of organization in the virtual space of the educational process. One such tool is diagrams – knowledge maps that reflect the relationships between concepts and ideas (Yuen et al., 2023).

Ready-made knowledge map templates are provided by the online service MindMeister. The Thinglink tool is focused on creating interactive didactic materials: interactive labels are added to images that open tests, text, audio, and video elements. This is how thematic posters, multimedia summaries, videos, and interactive maps are created.

Educational materials in PDF format are converted into interactive digital tasks by the Liveworksheets, JPG, or DOCX service.

The Quizlet platform is an effective tool for working with lexical material (Tajik et al., 2024).

The integration of artificial intelligence (AI) is attracting special attention in teaching. Such technologies, by providing personalized learning, transform the educational environment. AI algorithms allow you to create adaptive tasks tailored to a particular student's needs, which positively affect the assimilation of the material (Moallemi, 2024).

The state of students' preparation for organizing interactive educational interaction.

To determine the indicators of readiness for organizing interactive educational interaction, observations, questionnaires, and individual interviews were used. Using the questionnaire, we identified students' readiness to organize interactive educational interactions.

Questioning students at the ascertaining stage of the study allowed us to conclude that mainly during the organization of interactive educational interaction, significant attention is paid to pedagogical partnership, the introduction of ideas of humanism, and active cooperation of all participants in the educational process of higher education, but there were also such students (41.1%) who were not motivated enough for such activities.

In order to objectively clarify the formation of students' readiness to organize educational interactive interaction, the following criteria and their indicators have been defined:

- Motivational, the essence of which is the awareness by students of humanistic value orientations, cooperation, partnership pedagogy, the significance of the ideas of child-centrism, and the prospects of the ability to organize educational interactive interaction in the educational environment.
- Activity that ensures students master methodological and didactic skills and knowledge to carry out professional activities based on subject-subject interaction.
- Reflective-evaluative, which characterizes the ability of respondents to model and organize educational interactive interaction; students' desire for professional growth, self-improvement, and self-development.

Thus, we consider the proposed criteria and outlined indicators of students' readiness to organize interactive educational interaction through the digitalization of higher education.

The study characterized four levels of students' readiness to engage in interactive educational interaction: high, sufficient, average, and low.

In Table 1 and Fig. 1, we present the results of measuring students' readiness to organize interactive educational interactions at the ascertaining-experiment stage in the experimental and control groups.

Table 1.
Results of measuring the level of students' readiness to organize interactive educational interaction at the stage of the ascertaining experiment in the experimental and control groups

Levels	Control Group	Experimental Group
	Motivational component	
Low	27.7%	27.8%
Average	45.7%	44.0%
Sufficient	17.7%	19.0%
High	8.9%	8.3%
	Activity component	
Low	28.1%	28.9%
Average	43.7%	42.2%
Sufficient	21.1%	21.7%
High	7.1%	7.2%
	Reflective and evaluative component	
Low	32.6%	32.9%
Average	39.0%	38.5%
Sufficient	23.3%	23.6%
High	5.1%	5.0%

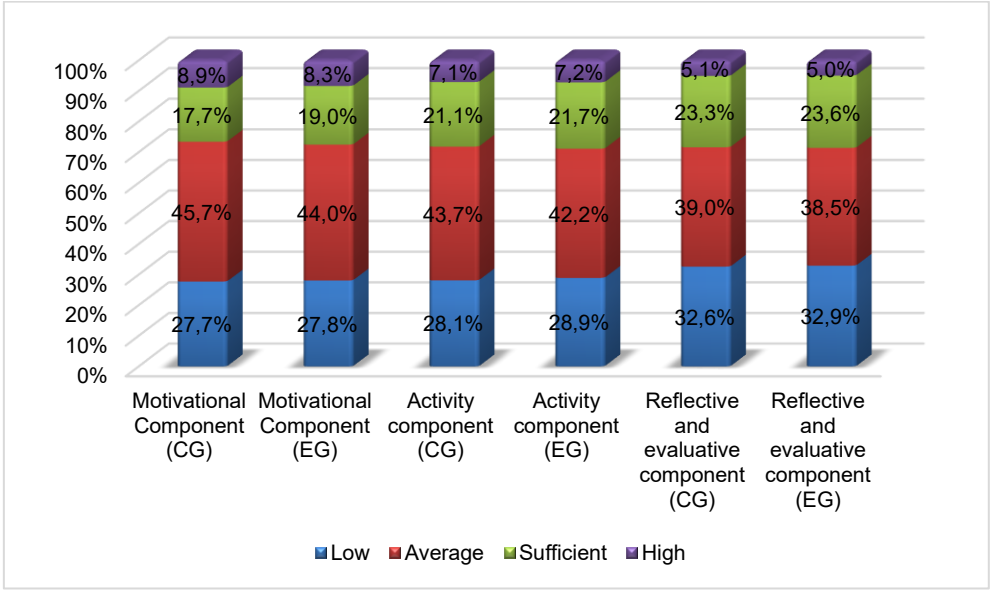


Figure 1. Results of measuring the level of students' readiness to organize interactive educational interaction at the stage of the ascertaining experiment in the experimental and control groups

Thus, the basis for further research and solution of the outlined problem was the study of the motivational, activity, and reflective-evaluative components of students' readiness to organize interactive educational interaction, which indicates the need to improve students' professional training.

In general, the study of the state of students' preparation for organizing interactive educational interaction allowed us to state the need to develop an author's system and pedagogical conditions for updating this process, which will ensure the formation of students' readiness for organizing interactive educational interaction through the digitalization of higher education, as an important prerequisite for conducting a formative experiment.

Let us reveal the methods and techniques of interactive educational interaction of students that were used in EG in the developed educational system in the process of teaching professional disciplines:

- Group thematic discussions that used technologies to process discussion questions influenced the positions and opinions of EG students and enabled the adoption of optimal, productive collective decisions.
- By creating speech situations, situational modeling technologies, such as “Professional Dialogue”, “Communication in the Educational Process”, etc., were implemented in order to form and develop professional speech skills.
- Visual dictation − for analyzing the spelling aspect of professional speech − as an interactive teaching method during student interaction, which allowed them to acquire knowledge of the norms of the written form of professional speech.
- Business games − for solving specific tasks and modeling specific situations by students, for training professional skills by practicing professional techniques and performing various professional roles in order to facilitate the acquisition of communicative tactics using mobile applications.
- Implementation of interactive educational interaction of students during collective and group learning.
- Field trips − the method of an active form of conducting classes (interactive excursions) was implemented in the form of an excursion, which made it possible to study realities in natural conditions and conduct observations, which were a favorite interactive activity of students. In such classes, students interactively modeled situations, interacted with each other, exchanged information, evaluated their own actions and those of others, and immersed themselves in the real atmosphere of business cooperation – interactive educational interaction while solving the problem.
- The use of the mind map method during terminological work contributed to the expansion of students' communicative abilities: the formation of linguistic guesswork, the systematization and consolidation of material, and the development of students' productive lexical skills.

All digital interactive technologies used during interactive educational interactions by EG students were divided into hardware and software.

We included devices with touch screens, computers – interactive boards, technical means for immersion in virtual reality, tablets, smartphones, interactive panels, interactive tables/desks, as well as specific multimedia means for rehabilitation, development, relaxation, learning in the process of outdoor games – interactive floor/wall, etc.

Because there are many interactive digital software tools, we divided them into certain categories:

- Interactive visual aids, interactive presentations, diagrams, maps, posters, infographics.
- Interactive online boards – which allowed all participants in the EG educational process to work together on the same information via the Internet in real time (to conduct joint brainstorming sessions, create virtual moodboards, and systematize information in the form of mind maps).
- Interactive books, textbooks, textbook supplements, manuals that contained interactive tasks, quests, exercises, tests, games, as well as animation, audio, video, and other elements, and were not just electronic books;
- Interactive videos are videos (video lessons), while watching which EG students performed interactive exercises added to them
- Interactive websites – sites whose content, during interactive educational interactions with students, is formed in real time based on data received from the user – contain various elements of interaction: interactive tasks, feedback forms, game elements, and online surveys.
- Interactive applications – programs that were installed on a mobile device or a computer and allowed users to learn educational material more effectively and develop professional skills through practical application of knowledge, training, and interaction.
- Interactive games – computer programs that allowed students to create their own game world, interact interactively with the game world and perform professional tasks aimed at achieving the set didactic goal.
- Webquests – interactive, based on the use of Internet resources, quests with elements of a role-playing game, in the process of which EG students independently obtained the knowledge necessary to perform the tasks set.
- Technologies of virtual reality (VR) and augmented reality (AR) allowed EG students to supplement the real world with computer-modeled objects (AR) and interact with the digital environment (VR).
- Means of interactive survey – EG students were offered online services, programs for creating quizzes, tests, games, and questionnaires, with the help of which information from students was quickly collected, presented in a convenient graphic form, and reflection was carried out.

Also, in order to organize effective interactive educational interaction of EG students, the following digital and software hardware tools were offered:

- "Interactive floor/wall" – a multimedia system that has software and allowed EG students to work in groups, pairs, collective competitions and games, which will be aimed at the development of coordination, concentration of attention, general motor skills, visual stimulation, contributed to the development of important communicative and social skills in the process of joint interactive educational interaction – the ability to enjoy joint activities, respect game partners, establish friendly relationships.
- Software platforms for video conferences (Google Meet, Zoom, Skype, WebEx, Microsoft Teams) enabled oral communication among EG participants, demonstrations and discussions of various materials, and the organization of online, collective group work.
- Software tools for performing joint educational tasks, collective projects form relationships of responsible interdependence, when each member of the group tries to perform their part of the task as best as possible, understanding that the overall success of their group depends on it.

- Quests and didactic games made it possible to organize emotionally rich, interactive educational interactions among EG students in groups, face-to-face or in pairs, add a competitive element to learning, involve all participants in active cooperation, and increase interest in the educational material.
- Software tools for interactive survey (Wordwall, Kahoot!, Mentimeter, Edpuzzle, Socrative, OnlineTestPad, Puzzlecup, Plickers, Google Forms) allowed EG students to determine the degree of assimilation of the educational material quickly, the level of understanding of the material, or collect information from the group at once, conduct reflection, determine the general emotional mood, and visualize the results.
- The use of the E-front network project enabled the directing of educational activities to improve self-education and the use of the Internet to acquire the skills of a scientific researcher.

By implementing the system proposed by the EG for preparing students for the organization of interactive educational interaction through digitalization of higher education, we saw real positive results of the educational process in higher education: students of higher education learn more quickly how to perform an effective search for the necessary professional information, learn how to work safely on the Internet, know more about the development of the Internet network, and know how to clearly work with social services that are used in the process of communication and learning. We made the following conclusions: the use of digital technologies in the system of preparing students for the organization of interactive educational interaction in the form of Internet projects allows, during interactive educational interaction, to solve the educational tasks of organizing joint activities through the digitization of higher education with students of higher education and with teachers and Internet resources, to create conditions for the development of professional competences, to promote the ability to work in interaction and to expand the boundaries of educational spaces.

For EG students, we defined and characterized the pedagogical conditions that contributed to the formation of students' readiness for the organization of interactive educational interaction:

- Creation of a student-centered digital environment while preparing students for the organization of interactive educational interactions.
- The focus of the teacher's activities on virtual (VR) and augmented reality (AR) technologies is to interact with the digital environment (VR) and teach students to supplement the real world with computer-modeled objects (AR), taking into account the practice-oriented nature of preparing students for the organization of interactive educational interaction
- Involving students in the organization of joint activities with teachers and Internet resources through digitalization of higher education, creating conditions for the development of professional competencies, promoting the ability to work in interaction, and expanding the boundaries of educational spaces during their training.

Analysis of the results of the experimental study.

The experimental data obtained on positive changes in the formation of students' readiness to organize interactive educational interaction through the digitalization of higher education indicate the effectiveness of the developed system and pedagogical conditions.

The generalized results on the levels of formation of students with the specified readiness at the formative stage of the experiment are presented in Table 2 and Fig. 2.

Table 2.
Results of measurements of the level of students' readiness to organize interactive educational interaction at the stage of the formative experiment through the digitalization of higher education in the experimental and control groups (%)

Levels	Control Group	Experimental Group
	Motivational component	
Low	19.9%	3.3%
Average	40.0%	20.7%
Sufficient	29.3%	37.3%
High	10.8%	38.7%
	Activity component	
Low	20.0%	5.5%
Average	40.3%	21.8%
Sufficient	29.8%	41.6%
High	9.9%	31.1%
	Reflective and evaluative component	
Low	28.8%	6.4%
Average	32.7%	15.9%
Sufficient	29.6%	40.0%
High	8.9%	37.7%

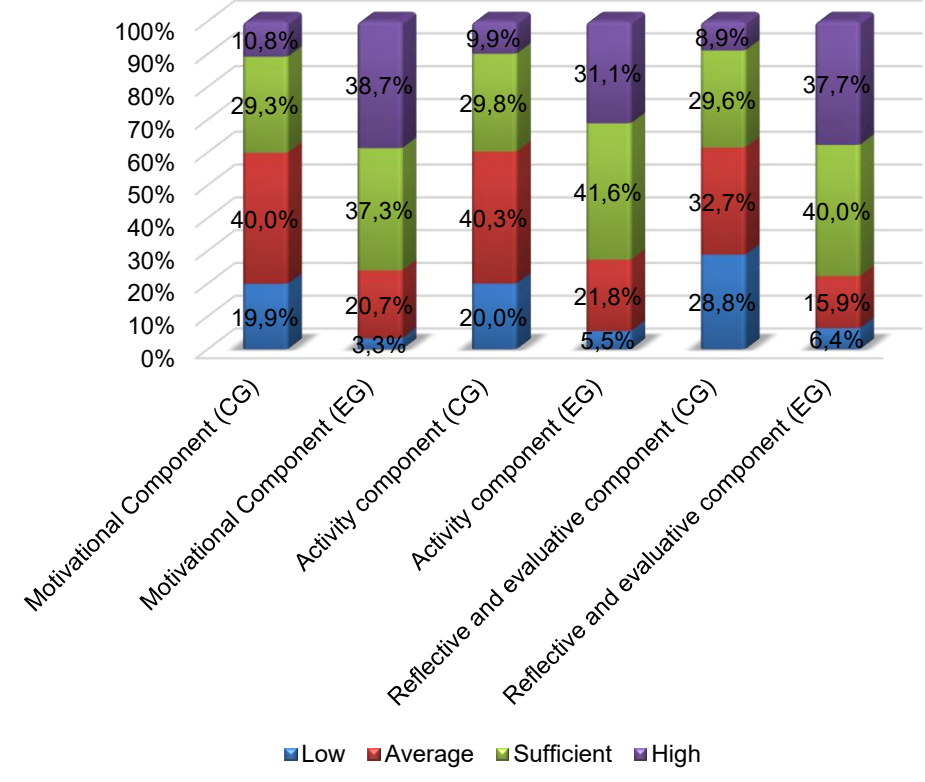


Figure 2. Results of measurements of the level of students' readiness to organize interactive educational interaction at the stage of the formative experiment through the digitalization of higher education in the experimental and control groups.

Analysis of experimental data at the stage of the formative experiment through the digitalization of higher education showed significant qualitative changes in the EG at low and average levels of students' readiness to organize interactive educational interaction, and this was due to a slight decrease in the number of students during the pedagogical experiment in the CG. Sufficient and high levels of students' readiness to organize interactive educational interactions through the digitalization of higher education also demonstrated significant positive qualitative changes in both the EG and the CG, though insignificant in the latter.

Comparative analysis of the values of the average absolute value of qualitative changes in the level of students' readiness to organize interactive educational interaction in the experimental and control groups allowed us to say that the positive dynamics of qualitative changes in the CG is due to the traditional professional training of students, and in the EG – the result of students' professional training according to the developed system and implemented pedagogical conditions.

Using mathematical statistics methods, the results of the experimental study were confirmed, in particular through the calculation of the non-parametric Pearson χ^2 criterion.

To evaluate the effectiveness of the proposed pedagogical system, post-intervention outcomes were compared between the experimental and control groups using Pearson's chi-square (χ^2) test. The analysis revealed statistically significant differences in the distribution of students' readiness levels in favour of the experimental group ($p < .001$), indicating that the observed improvements were unlikely to have occurred by chance.

The comparison confirmed statistically significant differences between the experimental and control groups. Pearson's χ^2 test showed large advantages in the distribution of readiness levels ($p < 0.001$), while Student's t-test had large differences in mean scores between the groups ($t = 12.79$, $p < 0.001$). In this regard, we emphasize that together these results have strong statistical evidence confirming the effectiveness of the proposed pedagogical system.

The baseline assessment did not have statistically significant changes between the experimental and control groups on the motivational, activity and reflective criteria of interactive educational interaction (χ^2, $p > 0.05$), which confirms the initial equivalence of the groups.

After the intervention, we had statistically significant differences in favor of the experimental group. Some students showing sufficient and high levels of readiness increased on all three criteria, while others with low readiness decreased significantly. Pearson’s chi-square test showed that these differences were statistically significant ($p < 0.001$), which has the effectiveness of the proposed pedagogical approach.

Large changes were observed in the motivational dimension, where students showed greater readiness and interaction with digital support. Improvements were also seen in activities reflecting their confidence in using digital technologies for communication, teamwork and collaborative problem solving. In addition, students in the experimental group showed high levels of reflective readiness, indicating better self-esteem, self-regulation and more critical reflection on their learning experience.

Qualitative results

The qualitative results complemented the quantitative results and provided additional evidence for the implementation of the pedagogical intervention.

Observations showed that students in the experimental group became more active in learning together. During the intervention, students frequently participated in group discussions, demonstrated greater initiative in completing joint tasks, and took greater responsibility for collective decision-making. Compared with the control group, teachers also had more frequent peer interaction, more balanced participation in teams, and higher levels of collaboration.

Qualitative data show that positive changes were associated not only with the use of digital technologies, but also with their introduction into the educational process. In the experimental group, digital tools improved collaborative learning, project activities, ongoing feedback, and reflective practice. But in the control group, digital technologies were used mainly to provide educational content and support regular educational activities.

The results of the study show that collaborative digital tasks improved active participation, forced students to exchange ideas, work together to solve real educational problems. Continuous formative assessment allowed students to assess their improvement and respond to feedback during the learning process, while project-based learning strengthened students' autonomy, linking theoretical knowledge with practice. Reflective activities also had the advantage of developing self-regulation and critical evaluation of individual and group activities.

Thus, the qualitative results highlight the improvements that were identified in the quantitative analysis.They indicate that the effectiveness of the intervention was determined by the pedagogical organization of the learning process rather than by the introduction of digital technologies themselves. Digital tools served as instructional resources that facilitated collaboration, communication, feedback, and reflective learning within a structured educational environment.

These results are consistent with previous studies emphasizing that digital technologies produce stronger educational outcomes when incorporated into student-centred instructional approaches rather than used as independent technological solutions. Similar conclusions have been reported by Chiang and Wu (2021), who highlighted the importance of collaborative learning environments, and by Krishan and Al-rsa'i (2023), who demonstrated that technology-supported instruction enhances student motivation when integrated into appropriate pedagogical practices. The present findings also support the conclusions of Meşe and Mede (2023), who emphasized the role of learner readiness, self-regulation, and collaborative learning in digitally supported education.

By comparing previous studies that assessed individual digital tools, our study demonstrates the effectiveness of an integrated pedagogical system that incorporates collaborative learning, project-based activities, formative assessment, reflective practice, and digital technologies within a single learning framework. This approach explains the observed improvements in students' motivational, performance, and reflective readiness for interactive educational engagement.

Conclusions

The study presented that this pedagogical system improved the development of students' readiness for interactive educational participation in a digital learning environment. After the intervention, the experimental group showed a better level of motivational, activity and reflective readiness than the control group, while qualitative data highlighted greater participation in collaborative learning, peer interaction and reflective practice. The results show that the educational significance of digital technologies depends on their purposeful integration into the educational process, rather than on their use as independent learning tools.

The study improves the contribution to the current research on digital transformation in higher education, which has empirical evidence that the combination of collaborative learning, formative assessment, project-based activities, reflective practice and digital technologies in a single pedagogical structure creates good conditions for increasing student engagement. The results of the study emphasize that instructional design plays a major role in improving the educational effectiveness of digital learning environments.

This pedagogical framework has a place in higher education to support the development of student-centered courses, improve different teaching methods, and integrate digital technologies into professional training programs.

We had several limitations in determining the results. The study included students from a small number of higher education institutions, and the impact of the intervention was demonstrated over a relatively short period of time.

Further research should investigate the long-term effectiveness of integrated pedagogical systems in different academic disciplines and institutional settings. Future studies may also examine the use of artificial intelligence–supported learning environments and analyse their influence on student engagement, self-regulation, academic achievement, and professional competence development.

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Original Article

Fomento de la competencia digital entre estudiantes de filología de educación superior

Fostering digital competence among philology students in higher education

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Resumen

La transformación digital de la educación superior ha incrementado la necesidad de desarrollar competencias digitales entre los futuros filólogos. Este estudio tuvo como objetivo evaluar la efectividad de un sistema pedagógico para el desarrollo de competencias digitales en estudiantes de filología mediante una intervención cuasiexperimental. La investigación empleó un diseño cuasiexperimental con 126 estudiantes de filología de pregrado, incluyendo un grupo experimental (n = 62) y un grupo de control (n = 64). La intervención constó de tres etapas: de evaluación, formativa y de control. Los datos se recopilaron mediante un cuestionario estructurado de competencias digitales desarrollado a partir del Marco Europeo de Competencias Digitales para la Ciudadanía (DigComp 2.2). La competencia digital se evaluó según tres dimensiones (motivacional, de contenido y de actividad), y se utilizó la prueba χ^2 de Pearson para determinar la significación estadística de las diferencias observadas entre los grupos. Los resultados demostraron que el sistema pedagógico propuesto mejoró significativamente la competencia digital de los estudiantes en el grupo experimental en comparación con el grupo de control. Según el criterio motivacional, la proporción de estudiantes con un alto nivel de competencia digital aumentó del 8,1% al 40,3%, mientras que la proporción con un nivel bajo disminuyó del 40,3% al 4,8%. Se observaron cambios positivos similares para el criterio de contenido (nivel alto: del 8,1% al 41,9%; nivel bajo: del 38,7% al 4,8%) y el criterio de actividad (nivel alto: del 9,7% al 50,0%; nivel bajo: del 50,0% al 4,8%). El análisis estadístico confirmó la significancia de las mejoras observadas. El estudio concluye que la integración de recursos educativos digitales, tecnologías de inteligencia artificial y enfoques pedagógicos interactivos mejora eficazmente la competencia digital de los estudiantes de filología.

Palabras clave: competencia digital; estudiantes de filología; inteligencia artificial; educación superior e intervención pedagógica.

Abstract

The digital transformation of higher education has increased the need to develop digital competence among future philologists. This study aimed to evaluate the effectiveness of a pedagogical system for developing digital competence in philology students through a quasi-experimental intervention. The research employed a quasi-experimental design involving 126 undergraduate philology students, including an experimental group (n = 62) and a control group (n = 64). The intervention included three stages: ascertaining, formative, and control. Data were collected using a structured Digital Competence Questionnaire developed on the basis of the European Digital Competence Framework for Citizens (DigComp 2.2). Digital competence was evaluated according to three dimensions (motivational, content, and activity), and Pearson's χ^2 test was used to determine the statistical significance of the observed between-group differences. The findings demonstrated that the proposed pedagogical system significantly improved students' digital competence in the experimental group compared with the control group. According to the motivational criterion, the proportion of students with a high level of digital competence increased from 8.1% to 40.3%, while the proportion with a low level

decreased from 40.3% to 4.8%. Similar positive changes were observed for the content criterion (high level: 8.1% to 41.9%; low level: 38.7% to 4.8%) and the activity criterion (high level: 9.7% to 50.0%; low level: 50.0% to 4.8%). Statistical analysis confirmed the significance of the observed improvements. The study concludes that integrating digital educational resources, artificial intelligence technologies, and interactive pedagogical approaches effectively enhances the digital competence of philology students.

Keywords: digital competence; philology students; artificial intelligence; higher education; and pedagogical intervention.

Introduction

The digital transformation of higher education has fundamentally changed the requirements for the professional preparation of future philologists. Digital competence has become a core professional competence, encompassing not only the ability to use digital technologies but also to critically evaluate digital information, create digital content, collaborate in online environments, and effectively integrate artificial intelligence (AI) tools into professional practice. Consequently, higher education institutions are expected to provide learning environments that systematically develop these competencies alongside subject-specific knowledge (Díaz-Noguera et al., 2022).

Despite these advances, the existing literature reveals several important limitations. First, most studies investigate digital competence among university students in general or focus primarily on pre-service teachers, while considerably less attention has been paid to students of philological specialties whose professional activities require the integration of digital communication, language technologies, AI-assisted translation, digital content creation, and intercultural interaction (Horváthová, 2023). Second, previous research has predominantly examined individual digital tools or isolated instructional approaches rather than comprehensive pedagogical systems capable of fostering digital competence through coordinated educational interventions (Falloon, 2020). Third, although artificial intelligence has recently become an important component of digital education, empirical evidence regarding its systematic integration into the professional training of Although digital competence has become a strategic priority in higher education, preliminary diagnostic assessments conducted at the participating Ukrainian higher education institutions before the intervention revealed several persistent challenges (Redecker, 2017).

Most philology students demonstrated only basic digital skills, while experiencing difficulties in the pedagogically meaningful use of digital educational resources, critical evaluation of AI-generated content, collaborative online learning, and discipline-specific digital communication. The baseline assessment further indicated that digital technologies were primarily employed for information retrieval and routine academic tasks rather than for authentic professional activities such as AI-assisted translation, multilingual content creation, corpus analysis, or collaborative language projects. These institutional observations suggested a discrepancy between the digital demands of contemporary philological professions and the competencies developed through existing instructional practices (Hazari, 2024).

This empirical context highlights the need for comprehensive pedagogical interventions tailored specifically to philological education. While previous studies have identified the importance of digital competence in higher education, they have rarely examined how integrated pedagogical systems can address the specific professional requirements of future philologists within the context of Ukrainian

universities. Consequently, the present study is motivated not only by an identified research gap in the international literature but also by documented educational needs observed in the participating institutions prior to the implementation of the intervention.

The scientific contribution of this study lies in providing experimental evidence for the effectiveness of an integrated pedagogical system that combines digital educational resources, artificial intelligence technologies, collaborative learning, project-based activities, and competency-based assessment to foster digital competence among philology students. Unlike previous investigations focusing on isolated technologies, this study evaluates a comprehensive instructional model implemented under authentic educational conditions in Ukrainian higher education institutions.

Accordingly, the purpose of this study was to evaluate the effectiveness of an integrated pedagogical system for developing digital competence among philology students through a quantitative quasi-experimental intervention.

Literature Review

Current scholarship recognizes digital competence as one of the key learning outcomes in higher education; however, most empirical studies have concentrated on teacher education, engineering, STEM disciplines, or multidisciplinary university populations (Falloon, 2020; Haleem et al., 2022; Ng et al., 2023). Comparatively little attention has been devoted to philology students, although their future professional activities increasingly depend on digital communication, corpus linguistics, computer-assisted translation, multilingual content creation, artificial intelligence, and online intercultural collaboration.

Recent research in Computer-Assisted Language Learning (CALL) demonstrates that digital technologies substantially improve language acquisition when they are integrated into pedagogically meaningful learning activities rather than used as isolated technological tools (Beatty, 2013; Hubbard & Levy, 2016). Digital language learning environments promote learner autonomy, collaborative interaction, critical thinking, and authentic communication, all of which constitute essential components of professional philological education.

An important direction of contemporary philological education is corpus linguistics. Corpus-based language learning enables students to investigate authentic language use, analyze lexical and grammatical patterns, develop translation strategies, and improve academic writing through evidence-based linguistic analysis (Boulton & Cobb, 2017; McEnery & Hardie, 2011). Corpus technologies therefore represent one of the essential digital competencies required of future philologists.

Another rapidly developing area concerns computer-assisted translation (CAT) and language technologies. Professional translators increasingly rely on translation memory systems, terminology databases, machine translation, and post-editing tools rather than traditional translation methods. Research demonstrates that integrating CAT technologies into university curricula significantly improves students' professional readiness and digital competence (Bowker & Fisher, 2010; O'Hagan, 2019). Consequently, digital competence for philology students should include the ability to critically evaluate AI-generated translations, manage multilingual resources, and effectively combine human expertise with intelligent language technologies.

The emergence of generative artificial intelligence has fundamentally transformed language education. Large Language Models such as ChatGPT are increasingly employed for academic writing, language practice, automated feedback, translation support, vocabulary development, and discourse analysis. Nevertheless, recent studies emphasize that effective educational use of generative AI requires AI literacy, critical evaluation of generated outputs, ethical awareness, and responsible academic practice (Kasneci et al., 2023; Tlili et al., 2023; Zawacki-Richter et al., 2019). Rather than replacing traditional linguistic training, AI should support higher-order cognitive processes and professional decision-making.

Although these studies demonstrate the educational potential of digital technologies, they mainly investigate individual tools or separate technological solutions. Comprehensive pedagogical systems integrating artificial intelligence, corpus technologies, collaborative digital environments, project-based learning, authentic professional tasks, and competency-based assessment remain insufficiently investigated, particularly within philological education. Consequently, there is limited experimental evidence regarding the effectiveness of integrated pedagogical system for systematically developing discipline-specific digital competence among future philologists.

The conceptual framework of the present study combines the European Digital Competence Framework for Citizens (DigComp 2.2) (Vuorikari et al., 2022) with competence-based pedagogical theory. DigComp 2.2 served as the theoretical basis for defining the domains of student digital competence (information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving). In contrast, DigCompEdu (Redecker, 2017) was applied exclusively as a pedagogical framework guiding the design of instructional activities implemented by university teachers during the intervention. Thus, DigComp 2.2 informed competence assessment, whereas DigCompEdu supported instructional design.

Based on this theoretical synthesis, digital competence was operationalized through three interconnected dimensions. The motivational dimension reflects students' readiness to engage with digital technologies, professional attitudes toward innovation, and motivation for continuous digital development. The content dimension encompasses theoretical knowledge of digital resources, artificial intelligence, corpus technologies, language technologies, and multilingual communication. The activity dimension represents the practical application of these competencies through authentic professional tasks, including corpus analysis, AI-assisted translation, multilingual content creation, collaborative online interaction, and critical evaluation of AI-generated information. Together, these dimensions establish a theoretically coherent model linking pedagogical theory, DigComp 2.2 domains, and the profession-specific digital competencies required of future philologists.

Methodology

Research Design

This study employed a quasi-experimental quantitative research design aimed at evaluating the effectiveness of an integrated pedagogical system for developing digital competence among undergraduate philology students.

The study was conducted between September 2022 and May 2025 and consisted of three stages.

Ascertaining stage (September–October 2022): baseline assessment of students' digital competence and verification of group equivalence.

Formative stage: during the overall study period, preparatory activities, curriculum planning, teacher training, and organizational support were carried out. The educational intervention itself was implemented as a standardized 16-week programme (64 contact hours) during one academic semester.

Control stage (immediately after completion of the 16-week intervention): participants completed the post-intervention assessment using the same Digital Competence Questionnaire. Additional organizational activities related to data verification, statistical analysis, and reporting continued until May 2025
.

Research Setting and Participants

The research was carried out in three Ukrainian higher education institutions offering bachelor's degree programs in Philology (specialties: English Philology, Germanic Philology, and Translation Studies). Participants were second- and third-year undergraduate students because these semesters include courses involving digital language resources, translation technologies, academic communication, and project-based learning.

A total of 126 students participated in the study: 62 students in the experimental group (EG) and 64 students in the control group (CG). Group assignment was based on existing academic groups; therefore, random assignment was not possible, which justifies the quasi-experimental design.

Inclusion criterio

- Enrolment in a bachelor's program in Philology or Translation Studies.
- Second or third year of study.
- Regular attendance of language and methodology courses.
- Consent to participate in the research.

Exclusion criterio

- Students on academic leave.
- Students who participated in less than 80% of intervention sessions.
- Incomplete questionnaire data.

Table 1.
Demographic characteristics

Characteristic	EG (n = 62)	CG (n = 64)
Mean age (SD)	20.4 (1.1)	20.6 (1.2)
Female	48 (77.4%)	50 (78.1%)
Male	14 (22.6%)	14 (21.9%)
English Philology	32	33
Germanic Philology	14	15
Translation Studies	16	16

No statistically significant differences were found between groups at baseline regarding age, gender distribution, academic specialization, or initial digital competence ($p > .05$).

Sample Size and Statistical Power

An a priori power analysis was conducted using GPower 3.1 for a chi-square test with a medium effect size (w = 0.30), alpha = .05, and power = .80. The required minimum sample size was 108 participants. The final sample of 126 students exceeded this threshold and was considered sufficient to detect statistically significant differences between groups.

Quantitative Instruments
Digital Competence Questionnaire

The main instrument was a 32-item questionnaire developed on the basis of the European Digital Competence Framework for Citizens (DigComp 2.2) (Vuorikari et al., 2022). Items were distributed across three theoretically justified dimensions.

Table 2.
Structure of the Questionnaire Based on the DigComp 2.2 Framework

Dimension	Items	Example
Motivational (Readiness and professional attitudes)	10	I am motivated to use AI tools for language learning and professional development.
Content (Knowledge of digital and AI resources)	11	I understand the principles of corpus-based language analysis.
Activity (Practical application in authentic tasks)	11	I can critically evaluate AI-generated translations and revise them when necessary.

Responses were recorded on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Total scores ranged from 32 to 160.

Table 3.
Classification of competence levels

Level	Score range
Low	32–74
Medium	75–117
High	118–160

Cut-off points were established using a percentage-based interpretation of the maximum possible score (<47%, 47–73%, ≥74%).

The questionnaire comprised three dimensions containing different numbers of items, competence levels were classified separately for each dimension using the same percentage-based approach that was applied to the total questionnaire score. Specifically, scores below 47% of the maximum possible score for a given dimension were classified as low, scores between 47% and 73% as medium, and scores of 74% or higher as high. Accordingly, the score ranges were as follows:

- Motivational dimension (10 items; score range 10–50): Low = 10–23; Medium = 24–36; High = 37–50.
- Content dimension (11 items; score range 11–55): Low = 11–25; Medium = 26–40; High = 41–55.

– Activity dimension (11 items; score range 11–55): Low = 11–25; Medium = 26–40; High = 41–55.

These predefined score ranges were applied consistently throughout the study to classify participants' competence levels for each dimension and to generate the categorical distributions presented in the Results section.

Content Validity and Reliability

The questionnaire underwent expert validation by seven specialists in educational technology, digital pedagogy, applied linguistics, and language education. Experts evaluated each item for relevance, clarity, and representativeness using a 4-point scale.

Item-level Content Validity Index (I-CVI): 0.86–1.00
Scale-level Content Validity Index (S-CVI/Ave): 0.94

A pilot study involving 30 philology students not included in the main sample was conducted to test clarity and reliability. Minor wording revisions were introduced after the pilot phase.

Cronbach's alpha coefficients reported below refer to the final study sample (N = 126).

Table 4.
Internal Consistency of the Questionnaire Scales (Cronbach's α)

Scale	α
Motivational	0.88
Content	0.90
Activity	0.89
Total questionnaire	0.91

During the implementation of the intervention, teachers conducted classroom observations and maintained reflective notes regarding students' participation and engagement. Informal discussions with students were also used to monitor the instructional process and identify possible organizational difficulties. These procedures served exclusively to support the implementation of the intervention and were not designed as independent sources of research data. Therefore, they were not subjected to formal qualitative analysis and are not reported in the Results section.

Educational Intervention

The intervention lasted 16 weeks (64 contact hours) and was implemented by three university teachers previously trained to ensure procedural consistency.

Table 5.
Structure of the 16-Week Educational Intervention

Module	Hours	Main tools
Digital information literacy	12	Google Scholar, Zotero
Corpus linguistics	14	AntConc, Sketch Engine
AI-assisted translation	14	DeepL, ChatGPT, MateCat
Collaborative multilingual projects	12	Google Workspace, Padlet, Canva
Digital ethics and AI evaluation	12	Case studies, reflective journals

Instructional sequence

Each module followed a standardized sequence:

- Introduction and modeling (15 min).
- Guided practice (25 min).
- Collaborative task (30 min).
- Reflection and formative feedback (20 min).

Fidelity of implementation

To ensure consistent implementation:

- Teachers used common lesson plans.
- Researchers conducted monthly monitoring meetings.
- 20% of sessions were audited using a fidelity checklist.
- Average fidelity score was 91%.

The control group studied according to the standard curriculum without the systematic integration of AI tools, corpus technologies, collaborative digital projects, or gamified activities.

Data Analysis

Data were analyzed using IBM SPSS Statistics 29.0. Descriptive statistics (frequencies, percentages, means, and standard deviations) were first calculated to summarize participants' demographic characteristics and digital competence scores.

The primary outcome variable was students' level of digital competence, classified into three ordinal categories (low, medium, and high) according to the predefined questionnaire score ranges.

Because the study employed a quasi-experimental design with experimental and control groups, Pearson's chi-square (χ^2) test of independence was used to compare the distributions of competence levels between the experimental and control groups at each measurement point (baseline and post-intervention). The χ^2 test was not used as a measure of correlation but as a test of association between group membership and competence level. For each analysis, the χ^2 statistic, degrees of freedom (df), exact p value, and Cramer's V were reported to indicate both statistical significance and effect size. Effect sizes were interpreted according to Cohen's recommendations (0.10 = small, 0.30 = medium, 0.50 = large).

To assess baseline comparability, Pearson's chi-square tests of independence were used to compare the distributions of competence levels between the experimental and control groups. No statistically significant baseline differences were detected across the motivational, content, or activity dimensions (all $p > .05$), indicating that the groups had similar initial distributions of digital competence. Post-intervention Pearson's chi-square tests were subsequently conducted to determine whether the distributions of competence levels differed significantly between the groups following implementation of the pedagogical system.

The study included repeated measurements of the same participants; however, the available dataset used for inferential analysis consisted of aggregated categorical distributions rather than individual paired observations. Consequently, paired statistical procedures for repeated measurements (e.g., McNemar's test, Stuart–Maxwell test, generalized estimating equations, or ordinal mixed-effects models) could not be validly applied. This represents a methodological limitation and should be considered when interpreting the findings.

Statistical analyses were performed exclusively on questionnaire-derived quantitative data. Classroom observations and informal student discussions were used only to facilitate implementation of the intervention and were not analysed using formal qualitative procedures. Consequently, no qualitative findings are presented in the Results section.

Statistical significance was established at $p < .05$ for all quantitative analyses.

All quantitative ratings and competence levels reported in this study were derived exclusively from the Digital Competence Questionnaire. Classroom observations, teachers' reflective notes, and informal student discussions were used solely to support the implementation and monitoring of the educational intervention. These procedures were not standardized research instruments, were not included in the statistical analyses, and did not contribute to the calculation of students' competence scores. Consequently, no weighting procedure across multiple data sources was applied, as all reported quantitative outcomes were based exclusively on questionnaire data.

Ethical Considerations

According to the institutional regulations of the participating universities, formal ethical committee approval was not required for this educational study involving voluntary participation, anonymous questionnaire data, and no medical or psychological intervention. Participation was voluntary, written informed consent was obtained from all participants, questionnaire responses were anonymized prior to analysis, and participants were informed of their right to withdraw from the study at any time without academic consequences.

Results and Discussion

The effectiveness of the proposed pedagogical system was evaluated by comparing the distribution of digital competence levels between the experimental and control groups at the ascertaining and post-intervention stages. Digital competence was assessed according to three dimensions: motivational, content, and activity. Baseline analyses confirmed that no statistically significant differences existed between the groups before the intervention ($p > .05$), indicating their initial equivalence. The post-intervention findings are presented below.

The results of assessing respondents' digital competence levels at the control stage of the experiment, using the motivational criterion, are presented in Table 6.

Table 6.
The level of digital competence formation of respondents at the control stage of the experiment by the motivational criterion

Levels	Experimental Group (n = 62)		Control Group (n = 64)	
	Ascertaining Stage	Control Stage	Ascertaining Stage	Control Stage
High	5 (8.1%)	25 (40.3%)	5 (7.8%)	6 (9.4%)
Average	32 (51.6%)	34 (54.8%)	34 (53.1%)	34 (53.1%)
Low	25 (40.3%)	3 (4.8%)	25 (39.1%)	24 (37.5%)

Source: own research

The descriptive distributions indicate that, at the post-intervention assessment, a larger proportion of students in the experimental group achieved a high level of motivational digital competence and a smaller proportion remained at the low level compared with the control group. Because the available data consisted of aggregated categorical frequencies rather than paired individual observations, these descriptive differences should not be interpreted as statistically significant within-group improvements.

At baseline, no statistically significant differences were observed between the experimental and control groups ($p > .05$), confirming their initial equivalence. Following the intervention, Pearson's chi-square test demonstrated statistically significant between-group differences in motivational competence, $\chi^2(2) = 27.95$, $p < .001$, with Cramer's $V = 0.47$, indicating a moderate-to-large effect size.

Table 7.
The level of digital competence formation of respondents at the control stage of the experiment by the content criterion

Levels	Experimental Group (n = 62)		Control Group (n = 64)	
	Ascertaining Stage	Control Stage	Ascertaining Stage	Control Stage
High	5 (8.1%)	26 (41.9%)	5 (7.8%)	6 (9.4%)
Average	33 (53.2%)	33 (53.2%)	34 (53.1%)	35 (54.7%)
Low	24 (38.7%)	3 (4.8%)	25 (39.1%)	23 (35.9%)

Source: own research

Descriptive comparisons show that the post-intervention distribution of content competence levels differed between the experimental and control groups, with a greater proportion of students classified at the high level in the experimental group. These descriptive differences should not be interpreted as evidence of statistically significant within-group change because paired individual data were unavailable.

At baseline, no statistically significant differences were found between the groups ($p > .05$). Following the intervention, Pearson's chi-square test demonstrated statistically significant differences in the distribution of content competence levels between the experimental and control groups, $\chi^2(2) = 27.92$, $p < .001$, with Cramer's $V = 0.47$, indicating a moderate-to-large effect size.

Table 8.
The level of digital competence formation of respondents at the control stage of the experiment by the activity criterion

Levels	Experimental Group (n = 62)		Control Group (n = 64)	
	Ascertaining Stage	Control Stage	Ascertaining Stage	Control Stage
High	6 (9.7%)	31 (50.0%)	6 (9.4%)	8 (12.5%)
Average	25 (40.3%)	28 (45.2%)	26 (40.6%)	36 (56.3%)
Low	31 (50.0%)	3 (4.8%)	32 (50.0%)	20 (31.3%)

Source: own research

Descriptive statistics indicate that the experimental group demonstrated a more favourable post-intervention distribution of activity competence levels than the control group. However, because only aggregated frequencies were available, these results should be interpreted as between-group differences rather than statistically verified within-group improvements.

Between-group differences in the distribution of digital competence levels were evaluated using Pearson's chi-square (χ^2) test of independence. Effect sizes were estimated using Cramer's V.

Baseline differences between the groups were not statistically significant ($p > .05$). After completion of the intervention, Pearson's chi-square test showed significant between-group differences in the activity criterion, $\chi^2(2) = 27.10$, $p < .001$, with Cramer's V = 0.46, indicating a moderate effect size.

Post-intervention differences between the experimental and control groups were examined using Pearson's chi-square test of independence, with Cramer's V used to estimate effect size. Statistically significant between-group differences were identified across all three dimensions of digital competence (motivational: $\chi^2(2) = 27.95$, $p < .001$, Cramer's V = .47; content: $\chi^2(2) = 27.92$, $p < .001$, Cramer's V = .47; activity: $\chi^2(2) = 27.10$, $p < .001$, Cramer's V = .46). The experimental group exhibited more favourable post-intervention distributions of self-reported digital competence levels than the control group across all three dimensions.

Because the inferential analyses were based on aggregated categorical data rather than paired individual observations, these findings should be interpreted as statistically significant between-group differences at the post-intervention measurement, rather than as statistically verified within-group changes over time. Overall, the results suggest a positive association between participation in the proposed pedagogical system and students' self-reported digital competence, but they do not by themselves establish definitive causal effectiveness.

The findings demonstrate that the proposed pedagogical system significantly improved the digital competence of philology students across the motivational, content, and activity dimensions. The most substantial progress was observed in students' ability to apply digital technologies in authentic professional contexts, indicating that the intervention promoted not only theoretical knowledge but also practical digital competence. These findings suggest that sustainable competence development is achieved through the systematic integration of digital educational resources, artificial intelligence (AI) tools, collaborative learning, and competency-based instructional strategies rather than through the isolated use of individual digital technologies.

The results are consistent with previous studies reporting that digital technologies enhance student engagement, learning motivation, and academic performance in higher education (Haleem et al., 2022). Similar to these studies, the present research confirms that technology-supported learning environments create favourable conditions for developing digital competence. Likewise, the multidimensional improvements identified in this study support the conceptual frameworks proposed by Falloon (2020), who argue that digital competence encompasses content, technological, communicative, and ethical dimensions rather than simple technical proficiency.

However, the present findings also extend previous research in several important respects. Many earlier investigations primarily evaluated the effectiveness of individual digital tools, online platforms, or isolated instructional technologies. Although such studies reported positive effects on students' digital literacy and motivation, they often demonstrated improvements limited to specific competencies or short-term educational outcomes. In contrast, the current study examined an integrated pedagogical systems that combine AI-supported learning, digital educational resources, collaborative activities, project-based learning, and continuous formative assessment. The positive changes observed simultaneously across all three competence dimensions suggest that comprehensive pedagogical design may produce broader and more sustainable educational effects than isolated technological interventions.

The findings also address an important gap in the literature concerning discipline-specific digital competence. Existing empirical evidence has largely focused on pre-service teachers, engineering students, or multidisciplinary university populations, whereas philology students have received comparatively limited scholarly attention despite the increasing digitalization of language professions. Unlike many previous studies, the present research demonstrates that digital competence in philological education should incorporate AI-assisted language technologies, digital communication, multilingual content creation, collaborative online interaction, and critical evaluation of AI-generated information. Consequently, the proposed pedagogical system expands current understanding of digital competence by adapting its development to the professional requirements of future philologists.

Several factors may explain the positive outcomes observed in the experimental group. First, the intervention integrated multiple complementary instructional approaches rather than relying on a single educational technology. Second, AI-supported learning activities enabled students to receive immediate feedback, personalise learning processes, and engage with authentic professional tasks. Third, collaborative learning promoted communication, reflection, and peer support, facilitating deeper knowledge construction. Finally, continuous formative assessment encouraged students to monitor their own learning progress and progressively develop higher levels of digital competence. These pedagogical mechanisms likely acted synergistically, explaining the greater improvements observed in comparison with traditional instructional approaches.

The educational implications of these findings are significant. The results indicate that higher education institutions should move beyond teaching isolated digital skills and instead adopt integrated pedagogical system that combine digital educational resources, AI technologies, collaborative learning environments, and authentic profession-oriented tasks. Such an approach better prepares future philologists for professional activities requiring digital communication, computer-assisted translation, digital content creation, intercultural collaboration, and responsible use of artificial intelligence. Furthermore, the proposed pedagogical system may serve

as a practical framework for curriculum redesign, professional development of university teachers, and modernization of digital learning environments within humanities education.

Despite these positive findings, several limitations should be acknowledged. The study involved students from a limited number of higher education institutions, which may restrict the generalisability of the results to other educational contexts. In addition, the intervention evaluated medium-term educational outcomes; therefore, further longitudinal studies are needed to determine whether the observed improvements remain stable over time. Future research should also investigate the effectiveness of the proposed pedagogical system in other humanities disciplines, compare different AI-supported instructional models, and examine additional factors influencing the long-term development of digital competence.

Overall, the study contributes to the growing body of evidence supporting integrated approaches to digital competence development. By providing experimental evidence from the context of philological education, it extends existing theoretical models and demonstrates that the combination of pedagogically grounded digital technologies, artificial intelligence, and collaborative learning strategies represents a promising direction for the digital transformation of higher education.

These findings suggest that integrating digital educational technologies into university curricula can substantially improve students' professional readiness for technology-rich educational environments. The proposed pedagogical system may therefore be recommended for implementation in higher education institutions preparing future specialists.

One limitation of this study is that classroom observations and informal student discussions were employed solely as supportive pedagogical procedures during the implementation of the intervention and were not subjected to systematic qualitative analysis. Consequently, the conclusions are based primarily on quantitative questionnaire data. Because the quantitative findings were based exclusively on questionnaire data, future studies should employ validated observation protocols, structured interviews, and performance-based assessment rubrics as additional sources of evidence. Such triangulation would enable cross-validation of the questionnaire results and provide a more comprehensive assessment of students' digital competence.

Conclusions

This study examined the implementation of an integrated pedagogical system designed to support the development of digital competence among undergraduate philology students within a quantitative quasi-experimental research design. The intervention combined digital educational resources, artificial intelligence technologies, collaborative learning activities, and competency-oriented instructional strategies in order to enhance students' motivational, content, and activity dimensions of digital competence.

The questionnaire-based findings demonstrated more favourable post-intervention distributions of digital competence levels in the experimental group than in the control group. Pearson's χ^2 analyses identified statistically significant between-group differences across the motivational, content, and activity dimensions following implementation of the intervention. These findings indicate that the proposed

integrated pedagogical system was associated with higher levels of self-reported digital competence among students in the experimental group.

The study contributes to the literature by providing empirical evidence on the application of an integrated pedagogical system in philological education, an area that has received comparatively limited attention in previous research. The results also demonstrate the potential of combining digital educational resources, artificial intelligence tools, collaborative learning, and competency-oriented instruction within the professional preparation of future philologists.

From a practical perspective, the proposed integrated pedagogical system may serve as a useful framework for curriculum modernization in higher education institutions preparing future philologists. The integration of artificial intelligence technologies, authentic professional tasks, collaborative digital environments, and competency-oriented assessment offers a promising approach to supporting students' readiness for professional activity in digitally transformed educational and linguistic contexts.

The findings suggest that integrating digital educational resources, artificial intelligence technologies, collaborative learning activities, and competency-oriented instructional strategies may support the development of students' digital competence in higher education. However, these conclusions should be interpreted in light of the study's methodological limitations, including reliance on self-report questionnaire data, the use of aggregated rather than paired individual observations, and the absence of long-term follow-up or independent performance-based measures.

Consequently, although the results indicate the potential educational value of the proposed integrated pedagogical system, additional research employing longitudinal designs, paired individual analyses, performance-based assessments, and multiple validated data collection methods is required to confirm the durability, generalisability, and broader applicability of the observed effects.

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Original Article

Preparación del profesorado para la integración de la IA: Cerrando la brecha entre la competencia digital y el uso pedagógico de la IA

Teacher readiness for AI integration: Bridging the gap between digital competence and pedagogical use of AI

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Resumen

El objetivo del estudio fue desarrollar y validar un modelo estructural de la preparación del profesorado de educación superior para la integración pedagógica de la inteligencia artificial, que constaba de seis componentes interrelacionados: competencia digital, actitudes pedagógicas hacia la IA, autoeficacia, prácticas reales de uso de la IA, apoyo institucional y barreras percibidas. El estudio se llevó a cabo dentro del marco de una estrategia cuantitativa utilizando un diseño descriptivo correlacional. Al mismo tiempo, los datos se recopilaron mediante un cuestionario mixto entre 278 docentes de educación superior. Se utilizaron estadísticas descriptivas, análisis de correlación, análisis factorial confirmatorio (AFC) y modelado estructural (MEE) para analizar los datos. Los resultados indicaron características psicométricas satisfactorias del instrumento desarrollado (α = .76–.89; CFI = .96; RMSEA = .041). Los datos también confirmaron la existencia de una brecha entre el nivel de competencia digital del profesorado y las prácticas reales de uso de la IA. El modelado estructural mostró que la autoeficacia es el predictor más fuerte del uso pedagógico de la IA (β = .42). Sin embargo, el impacto de la competencia digital está mediado principalmente por la autoeficacia y las actitudes pedagógicas. La relevancia práctica del estudio radica en que la herramienta APRS desarrollada puede ser utilizada por las instituciones de educación superior para diagnosticar la preparación del profesorado y diseñar programas de desarrollo profesional específicos.

Palabras clave: inteligencia artificial en la educación; competencia digital; educación superior; autoeficacia; modelado estructural; preparación docente.

Abstract

The study aimed to develop and validate a structural model of higher education teachers' readiness for pedagogical integration of artificial intelligence, which consisted of six interrelated components: digital competence, pedagogical attitudes towards AI, self-efficacy, real practices of using AI, institutional support and perceived barriers. The study was conducted within the framework of a quantitative strategy using a descriptive correlational design. At the same time, the data were collected based on a mixed questionnaire among 278 higher education teachers. Descriptive statistics, correlation analysis, confirmatory factor analysis (CFA) and structural modeling (SEM) were used to analyze the data. The results indicated satisfactory psychometric characteristics of the developed instrument (α = .76–.89; CFI = .96; RMSEA = .041). The data also confirmed the existence of a gap between teachers' levels of digital competence and their actual use of AI. Structural modeling showed that self-efficacy is the strongest predictor of pedagogical use of AI (β = .42). However, the impact of digital competence is mainly mediated by self-efficacy and pedagogical attitudes. The practical significance of the study is that the developed APRS tool

can be used by higher education institutions to diagnose the readiness of teaching staff and design targeted professional programs.

Keywords: artificial intelligence in education; digital competence; higher education; self-efficacy; structural modeling; teacher readiness.

Introduction

The active use of artificial intelligence (AI) in the first quarter of the 21st century has changed the nature of professional activity in the educational sphere. The introduction of generative models, intelligent learning systems, automated assessment tools and personalized learning have become an important part of the educational space of higher education institutions (HEIs) around the world. However, it has been proven that the effectiveness of integrating AI into the educational process is determined by the availability of technologies and the readiness of teaching staff to use them meaningfully, methodically justified. Accordingly, the phenomenon of readiness is one of the least studied constructs of modern pedagogical science. In addition, teachers' readiness to use AI is multidimensional. In particular, it covered the level of digital competence, that is, the skills to navigate the technological environment and critically evaluate digital tools. On the other hand, readiness for AI integration also requires a structured pedagogical dimension, in particular, an understanding of when, how and for what educational purpose it is appropriate to use artificial intelligence in teaching practice. Modern research has shown that digital literacy alone does not guarantee the effective implementation of educational technologies (Guppy et al., 2022). The authors have proven that the decisive role was played by teachers' attitudes towards AI, their self-efficacy, pedagogical beliefs and the level of institutional support (Buchan et al., 2024).

In addition, despite the significant attention of the scientific community to the topic of AI in education, most of the existing research is focused on the student perspective. Therefore, there is little research conducted in the teaching environment. In addition, many scientists have drawn attention to the fact that the study of individual technological tools (Gutierrez et al., 2022). Accordingly, the analysis of the readiness of scientific and pedagogical workers as a holistic category is ignored. In addition, it should be recognized that the connection between the measured level of digital competence and the actual pedagogical use of AI is mostly postulated theoretically, but rarely verified empirically in large-scale quantitative studies. This raises the main question: does a higher level of digital competence of a teacher really lead to a more frequent and pedagogically appropriate use of artificial intelligence tools?

The answer to this question required the development of a theoretically grounded and empirically validated toolkit — a model that would reflect the structure of teachers' readiness for AI integration and allow measuring its key components. It is this gap that the proposed study seeks to fill.

Therefore, the aim of the article will be to develop and analyze a structural model of the readiness of HEI teachers for the pedagogical integration of AI. This model will reflect the relationship between digital competence, pedagogical attitudes, self-efficacy regarding AI and practices of its use. The tasks are as follows:

1. To characterize the profile of digital competence of HEI teachers and identify which components of readiness for integration were the most developed in the studied sample.

2. To find out whether there is a gap between the level of digital competence of teachers and the intensity of their pedagogical use of AI.
3. To determine which factors predict the actual frequency and pedagogical appropriateness of using AI in teaching practice.
4. To establish whether the profiles of readiness for AI integration differ depending on the demographic and professional characteristics of teachers.

Theoretical Framework or Literature Review

Digital competence of higher education teachers: status and challenges

The digital competence of teaching staff is one of the most studied constructs in modern educational science, however, the operationalization of this phenomenon and its measurement remain a subject of debate. A systematic literature review by Basilotta-Gómez-Pablos et al. (2022) indicated that despite the attention paid to the study of digital competence of higher education teachers, most studies contain significant variability between its individual components. In particular, the authors indicated that technical skills are better developed than the pedagogical application of digital tools. Cobena et al. (2023) found that effective improvement of digital competence requires systematic, long-term interventions that are focused on practical application. Masoumi and Noroozi (2025) specified this conclusion for novice teachers and indicated the need to integrate the development of digital competence into initial teacher training programs. Regalado-Pezua et al. (2025) identified that digital competencies have become important drivers of digital transformation in the Ibero-American educational space. However, their development in this region has been uneven. In addition, Rodríguez-Cisneros et al. (2026) demonstrated the existence of such an unevenness using the example of technical and technological education in Ecuador, in which a significant part of teachers had only a basic level of digital competencies. In addition, Alderete (2025) analyzed the dynamics of gaps in access, use and mastery of ICT in Latin American countries during 2008–2022. The author indicated that the gap in the use and pedagogical mastery of technologies increased even with improved physical access to them.

Integration of artificial intelligence into pedagogical practice in higher education

The problem of qualitative integration of AI into higher education is becoming relevant in the international scientific discourse. In particular, Flores and Chiappe (2025) found that teachers' readiness to integrate AI is determined by various training factors and digital competencies. In particular, the authors highlighted that pedagogical attitudes and experience in the practical application of technologies play a decisive role. In addition, Gutierrez et al. (2022) analyzed scenarios for the use of AI in e-learning in the Latin American space. The authors identified new competencies of graduates that should be formed in an AI-saturated educational environment. The authors also proved that there are currently special requirements for the pedagogical training of teachers. In addition, Deroncele-Acosta et al. (2025) in a review of research on generative AI in higher education pointed out the potential of these technologies for the development of transversal competencies. The researchers also emphasized that the realization of this potential depends on the pedagogical skills of the teacher and his readiness for the meaningful use of AI.

In addition, Molina-Soria et al. (2026) described the process of combining AI and formative assessment in teacher education. The authors concluded that despite the obvious synergistic potential, most teachers were unprepared for such integration due to a lack of technical knowledge. Also, Patiño Barriga et al. (2025) formed an

AI-oriented model to stimulate international cooperation in open education and indicated the need for systemic institutional solutions to support pedagogical innovations based on AI. This work became important for this study. In addition, Nnaji et al. (2026) pointed to the experience of Nigerian universities and determined that AI-oriented digital transformation of HEIs requires technological and managerial and pedagogical restructuring.

An important aspect of AI integration has been the issue of pedagogical innovation and the transformation of traditional approaches to teaching. Cano et al. (2026) identified that the most effective approaches consist of technological solutions and a rethinking of pedagogical roles and methods. Godinez-Flores et al. (2025) identified the need for educational transformation based on digital humanities as a conceptual framework for understanding the place of AI in pedagogical practice. Furthermore, Patiño Barriga et al. (2025) identified that gamification and AI have become important catalysts for such transformation, as they have reduced psychological barriers and increased teachers' motivation to master new technologies.

2.3. Professional development of teachers in the field of digital technologies. Osorio Vanegas et al. (2025) identified a consistent trend: the most effective professional development programs are based on the principles of practice-oriented learning, peer support and reflection. At the same time, Basantes-Andrade et al. (2025) confirmed that effective digital integration required targeted methodological training. In addition, Masoumi and Noroozi (2025) specified the conditions for the effective development of digital competence of novice teachers and highlighted the role of mentoring, institutional support for practical experimentation.

At the same time, Hernandez-Pozas (2025) analyzed the transformation of the roles of students and teachers in the context of a continuous process of digital learning. The authors also determined that the traditional dichotomy “digital immigrant - digital native” is an oversimplification. In particular, real digital competence and readiness to use AI were determined mainly by the experience of purposeful learning. Rodas-Coloma et al. (2026) identified the pedagogical potential of new digital platforms and pointed out the importance of critical pedagogical reflection of any technological tools, which is especially relevant in the context of AI. Regalado-Pezua et al. (2025) also indicated that digital competences have become an important organizational resource, the development of which requires a strategic management approach at the HEI level. The digital competence component in the proposed model was based primarily on the European conceptual frameworks DigComp and DigCompEdu. DigComp defined digital competence through such areas as information literacy and data work, communication and collaboration, digital content creation, security and problem solving. DigCompEdu specified such areas according to the professional activities of teachers and covered work with digital resources, organization of teaching and learning, digital assessment, empowering learners and promoting the development of their digital competence. In this study, the mentioned framework was used to distinguish between the general technological literacy of teachers and their ability to pedagogically appropriate use of digital and AI-based tools. Such a distinction was fundamental, since the possession of digital skills in itself did not guarantee the regular, conscious and methodologically justified use of AI in teaching. The proposed APRM model combined complementary, rather than competing, theoretical approaches (Al-Abdullatif, 2024). DigCompEdu explained the structure of teachers’ professional digital competence. The TPACK (Technological Pedagogical Content Knowledge) model allowed us to determine the extent to which technological knowledge was integrated with pedagogical and

subject knowledge. Technology acceptance models explained the role of perceived usefulness, ease of use, attitudes, and behavioral intentions. Self-efficacy theory revealed teachers' confidence in their own ability to perform pedagogical tasks with the help of AI. Institutional support and perceived barriers complemented these individually focused approaches, as they took into account the organizational, technical, ethical, and psychological conditions under which teachers' readiness was or was not realized in actual pedagogical practice (Ayanwale et al., 2024). This is confirmed by the studies of Flores and Chiappe (2025) and Cobena et al. (2023). At the same time, technology acceptance models identified the role of perceived usefulness and ease of use in shaping behavioral intentions towards new technologies. The integration of these theoretical approaches allows us to formulate the basic theoretical position of the study: a teacher's readiness for pedagogical integration of AI is a dynamic construct that is formed at the intersection of individual characteristics and organizational context (institutional support).

Accordingly, the six APRM constructs reflected interrelated levels of readiness for pedagogical integration of AI. Digital competence characterized the teacher's available technological resource; pedagogical attitudes reflected the assessment of the educational appropriateness of AI; self-efficacy determined subjective confidence in the ability to apply AI (Collie et al., 2024); AI use practices represented the behavioral realization of readiness; institutional support reflected the favorableness of the organizational environment; perceived barriers and anxiety captured factors that could inhibit the transition from competence and positive intentions to actual pedagogical behavior.

Despite the significant body of research on teachers' digital competence and AI integration in higher education, a review of the existing literature has identified a number of gaps. In particular, most of the existing work has defined digital competence and AI readiness as separate, autonomous constructs, and has not examined the mechanisms of their interaction. In particular, Basilotta-Gómez-Pablos et al. (2022), Cobena et al. (2023), and Masoumi and Noroozi (2025) have focused exclusively on digital competence and have not considered how it is transformed. Flores and Chiappe (2025) are one of the few exceptions, but their study did not verify the mediation mechanisms between competence and behavior through structural modeling. In addition, there is a lack of research that offers a validated instrument to comprehensively measure teachers' readiness for pedagogical integration of AI. This work will fill these gaps.

Methodology

Research design

The work is based on a quantitative strategy using a descriptive correlational design and cross-sectional data. This design was important for studying the structure of the latent construct - teachers' readiness for pedagogical integration of artificial intelligence. This design was also chosen from the point of view that it is important for verifying the connections between AI components. The study did not involve experimental intervention, since the main goal was to build and statistically validate the measurement model.

Participants

278 teachers of higher education institutions participated in the study. The inclusion criteria were: having experience in teaching at a higher education institution for at least one academic year and directly implementing the educational process at the

time of the study. The selection of participants was implemented based on the method of purposive sampling with elements of snow sampling - by contacting university departments and distributing invitations to participate through academic networks. The main characteristics of the participants are presented in Table 1.

Table 1.
Demographic and Professional Characteristics of the Sample (N = 278)

Characteristic	Category	n	%
Gender	Female	178	64.0
	Male	95	34.2
	Other / Prefer not to say	5	1.8
Age	Under 30	24	8.6
	31–40	87	31.3
	41–50	96	34.5
	51–60	54	19.4
	Over 60	17	6.1
Academic degree	No degree	18	6.5
	Master's	72	25.9
	PhD (Candidate of Sciences)	134	48.2
	Doctor of Sciences / Professor	54	19.4
Teaching experience	Up to 5 years	38	13.7
	6–10 years	64	23.0
	11–20 years	98	35.3
	Over 20 years	78	28.1
Prior AI/digital training	Yes	143	51.4
	No	135	48.6

Teacher readiness model for AI integration

The theoretical basis of the study was the author's structural model of the readiness of teachers of higher education institutions for the pedagogical integration of artificial intelligence (AI Pedagogical Readiness Model, APRM). This model was formed on the basis of the intersection of the conceptual provisions of the DigComp digital competence framework, the TPACK model and Bandura's self-efficacy theory. The model consisted of six interrelated latent constructs:

1. Digital competence - the level of technological literacy of the teacher and confidence in working with digital tools;
2. Pedagogical attitudes towards AI - the teacher's basic beliefs about the educational value and appropriateness of using artificial intelligence;
3. Self-efficacy towards AI - subjective confidence in the ability to effectively apply AI in the educational process;
4. AI use practices - the frequency and pedagogical focus of using AI tools in teaching activities;
5. Institutional support - perceived availability of technical infrastructure, training and organizational encouragement from the HEI;
6. Perceived barriers and anxiety - subjective obstacles of a technical, ethical and psychological nature that hinder the integration of AI.

Procedure and tools

Data collection was implemented during November 2025 - March 2026 based on a mixed questionnaire. In particular, some participants filled out the questionnaire in electronic form via the Google Forms platform, others in paper format during face-

to-face meetings at departments of higher education institutions. The use of two data collection formats is due to the desire to minimize selection bias and cover teachers with different levels of digital engagement. Before starting to fill out the questionnaire, each participant received an information letter with a detailed explanation of the purpose, objectives and procedure of the study, guarantees of anonymity and confidentiality of the data obtained. Participation in the study was exclusively voluntary; all participants confirmed their consent before starting to fill out the questionnaire.

The main research instrument was the author's questionnaire "Teachers' Readiness Scale for Pedagogical Integration of Artificial Intelligence". This tool was developed specifically for this study. The questionnaire consists of two parts. The first part consisted of questions about the demographic and professional characteristics of the participants and their experience of digital training or education in the field of AI. The second part consisted of statements distributed across six scales according to the components of the author's APRM model: digital competence, pedagogical attitudes towards AI, self-efficacy in using AI, real-life practices of AI application, institutional support and perceived barriers and anxiety about AI. All statements were formulated in the format of a five-point Likert scale.

The formation and development of the instrument was carried out in several consecutive stages. In particular, at the first stage, an analysis of existing validated instruments in related fields was conducted - scales of digital competence, readiness to use educational technologies and attitudes towards AI. At the same time, in the second stage, the content validity of the instrument was ensured through expert assessment: seven specialists in the field of educational technology, higher education pedagogy and applied statistics independently assessed each statement according to the criteria of relevance, clarity of formulation and correspondence to the theoretical construct. Statements that did not gain a sufficient level of agreement between experts (content validity index CVI < 0.78) were reformulated or even excluded from the instrument. In the third stage, the instrument was pilot tested on a small sample (n = 30 teachers who were not included in the main sample) in order to check the clarity of the statements, the average time of completion and a preliminary assessment of the internal consistency of the scales. Based on the results of the piloting, a number of editorial clarifications were made to the instrument. The final version of the questionnaire was tested for reliability (Cronbach's α) and construct validity (confirmatory factor analysis) on the data of the main sample. This confirmed its psychometric suitability for use in the study.

Data analysis

Statistical data analysis was implemented using the IBM SPSS Statistics 26 and IBM AMOS 26 software packages.

First, descriptive statistics were used and reliability assessment was performed. Descriptive statistics indicators were calculated for the scale and the total sample: mean values (M), standard deviations (SD), minimum and maximum values, as well as skewness and kurtosis indicators to check the normality of the distribution. The internal consistency of each scale was assessed using Cronbach's α coefficient; $\alpha \geq 0.70$ was considered acceptable, and $\alpha \geq 0.80$ was considered good. Additionally, the average variance and reliability indicators (CR ≥ 0.70) were calculated as criteria for convergent validity of the constructs.

Next, a correlation analysis was performed. Pearson's correlation analysis was used to establish relationships between the six components of the model. Bivariate

correlations between individual scales and statistical significance ($p < .05$; $p < .01$) were tested. Confirmatory factor analysis (CFA) was also implemented. Confirmatory factor analysis using the Maximum Likelihood Estimation method was used to verify the factor structure of the instrument and assess the correspondence of the theoretical model to the empirical data. The quality of the model fit was determined by a set of indices: absolute ($\chi^2/df < 3.0$; RMSEA < 0.08; SRMR < 0.08) and incremental (CFI ≥ 0.95; TLI ≥ 0.95). Structural modeling (SEM) was also performed. Structural modeling was used to test the causal relationships between the latent variables of the model and identify significant predictors of the pedagogical use of AI. Standardized regression coefficients (β), their statistical significance ($p < .05$), and the explanatory power of the model (R^2) on the dependent variable — real-world AI practices — were assessed. To test indirect effects (in particular, mediational relationships through self-efficacy), the bootstrap resampling method was used (n = 5000 samples, 95% confidence interval). The overall quality of the structural model was assessed using the same fit indices as in CFA.

Results and Discussion

Profile of digital competence and readiness of teachers for AI integration

The results of descriptive statistics indicated that the average readiness indicator for the sample was M = 3.12 (SD = 0.61). This indicator corresponded to the average level on the five-point Likert scale. At the same time, the analysis of the profiles of individual components indicated variability between scales, that is, there is an uneven development of different aspects of teachers' readiness for pedagogical integration of artificial intelligence.

The highest indicators are noticeable on the digital competence scale (M = 3.74, SD = 0.58). This determined a sufficient level of technological literacy among teachers of higher education institutions. The indicators of pedagogical attitudes towards AI (M = 3.52, SD = 0.63) were also relatively high: most participants had a positive attitude towards the potential of artificial intelligence in education. The indicators of institutional support (M = 3.18, SD = 0.72) and self-efficacy regarding AI (M = 3.09, SD = 0.69) were at an average level. The lowest indicators were recorded on the scale of real practices of using AI (M = 2.61, SD = 0.79) - this result became important for interpretation and indicated the presence of a gap between digital competence and real pedagogical use of AI. The internal consistency indicators of all scales are acceptable (Cronbach's α from 0.76 to 0.89).

Table 2.
Descriptive Statistics and Reliability Coefficients for APRM Scales

Scale	M	SD	Min	Max	Skewness	Kurtosis	α
Digital Competence	3.74	0.58	1.80	5.00	−0.41	0.18	.83
Pedagogical Attitudes toward AI	3.52	0.63	1.50	5.00	−0.29	−0.12	.81
AI Self-Efficacy	3.09	0.69	1.17	5.00	−0.18	−0.31	.84
AI Use Practices	2.61	0.79	1.00	5.00	0.34	−0.22	.87
Institutional Support	3.18	0.72	1.00	5.00	−0.21	−0.08	.76
Perceived Barriers & AI Anxiety	3.41	0.74	1.17	5.00	−0.11	−0.41	.89
Overall Readiness	**3.12**	**0.61**	**1.42**	**4.83**	**−0.09**	**−0.19**	**.91**

Note. M = mean; SD = standard deviation; α = Cronbach's alpha. Scale range: 1–5.

The obtained data are clearly illustrated in Figure 1, which presents a comparative profile of the average values for the six scales of the model. At the same time, Figure 2 shows a radar diagram of the component profile of readiness for the sample as a whole.

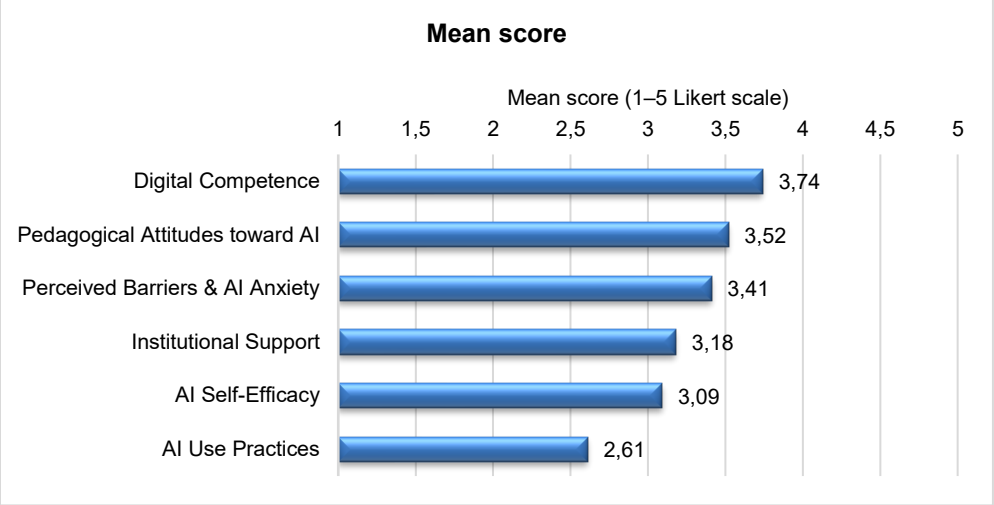


Figure 1. Mean Scores of AI Pedagogical Readiness Components (N = 278)

As can be seen from Figure 1, the highest average indicators were recorded for the Digital Competence component (M = 3.74, SD = 0.58). This determined a relatively high level of digital training of respondents. At the same time, lower values were found for AI Self-Efficacy (M = 3.09, SD = 0.69) and especially for AI Use Practices (M = 2.61, SD = 0.79). Such indicators indicated insufficient integration of AI use practices into professional activities.

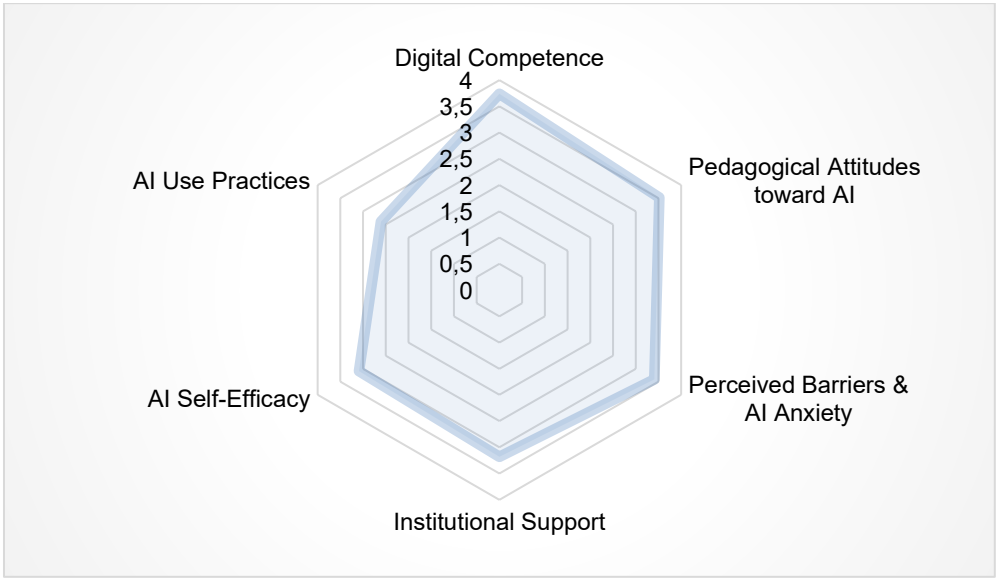


Figure 2. Competency Profile of AI Pedagogical Readiness (N = 278)

As can be seen from Figure 2, the AI pedagogical readiness profile had an asymmetrical structure: the most strongly developed components were Digital Competence and Pedagogical Attitudes toward AI. The weakest were the indicators of AI Use Practices and AI Self-Efficacy. Comparison with the reference contour of

the neutral level (3.0) showed that most indicators were at an above-average level. However, the practical application of AI and confidence in one's own abilities to work with it remained insufficiently formed.

Relationships between the components of the readiness model

The data from the correlation analysis (Pearson's r) for the six components of the APRM model are shown in Table 3. Thus, all the identified correlations were significant at the $p < .01$ level. This indicator indicated the interconnectedness of the constructs within the proposed model.

The strongest positive relationship with actual practices of using AI was found for self-efficacy regarding AI ($r = .61$, $p < .001$). Thus, the teacher's subjective confidence in his own ability to use AI became a strong correlate of his actual activity. A noticeable relationship was also recorded between pedagogical attitudes and practices of using AI ($r = .54$, $p < .001$) and between digital competence and practices ($r = .47$, $p < .001$). However, although digital competence correlated moderately with actual practices, its relationship with self-efficacy was higher ($r = .63$, $p < .001$). This situation indicated an indirect, rather than direct, role of digital literacy in shaping AI usage practices. It is also worth noting that institutional support was also positively associated with practices ($r = .43$, $p < .001$). However, perceived barriers and anxiety about AI had a negative relationship with actual practices ($r = -.38$, $p < .001$). This indicated the restraining role of subjective barriers. The discriminant validity test using the Fornell-Larker criterion indicated that the AVE of each construct exceeded the square of its correlation with any other construct in the model. Such data indicated sufficient differentiation of the measured latent variables.

Table 3.
Pearson Correlation Matrix for APRM Scales

Scale	1	2	3	4	5	6
1. Digital Competence	—					
2. Pedagogical Attitudes toward AI	.51**	—				
3. AI Self-Efficacy	.63**	.58**	—			
4. AI Use Practices	.47**	.54**	.61**	—		
5. Institutional Support	.39**	.44**	.48**	.43**	—	
6. Perceived Barriers & AI Anxiety	−.31**	−.29**	−.42**	−.38**	−.33**	—

Note. ** $p < .01$

Confirmatory factor analysis data

The study conducted a confirmatory factor analysis (CFA) using the maximum likelihood method. The obtained data indicated a satisfactory fit of the model to the data according to the set of indices: $\chi^2(df) = 412.3$ ($df = 284$), $\chi^2/df = 1.45$, CFI = .96, TLI = .95, RMSEA = .041 (90% CI [.032, .049]), SRMR = .053. In particular, all the obtained values met the recommended acceptance thresholds. This confirms the adequacy of the proposed six-factor structure of the readiness model.

The standardized factor loadings of all statements were statistically significant ($p < .001$) and exceeded the recommended threshold of 0.50, varying in the range from 0.54 to 0.81. The average variance extracted (AVE) values for all six factors exceeded the critical value of 0.50 (from 0.52 to 0.64). At the same time, the composite reliability (CR) values were 0.70 (from 0.76 to 0.89). This confirmed the convergent validity of all constructs of the model. The data from the CFA fit indices and psychometric indices of the scales are summarized in Table 4.

Table 4.
Confirmatory Factor Analysis: Factor Loadings, AVE, and Composite Reliability

Scale	No. of Items	Factor Loadings Range	AVE	CR	α
Digital Competence	6	.57 – .79	.54	.83	.83
Pedagogical Attitudes toward AI	6	.54 – .76	.52	.81	.81
AI Self-Efficacy	6	.61 – .81	.59	.86	.84
AI Use Practices	6	.58 – .80	.57	.88	.87
Institutional Support	6	.54 – .74	.52	.79	.76
Perceived Barriers & AI Anxiety	6	.59 – .81	.64	.89	.89

Note. AVE = Average Variance Extracted; CR = Composite Reliability; α = Cronbach's alpha. Model fit: $\chi^2/df = 1.45$; CFI = .96; TLI = .95; RMSEA = .041; SRMR = .053.

Structural modeling

To determine the causal relationships between the latent variables of the APRM model and the predictors of real AI practices, structural modeling (SEM) was used. The overall fit of the structural model to the data is satisfactory: $\chi^2/df = 1.52$, CFI = .95, TLI = .94, RMSEA = .044 (90% CI [.035, .053]), SRMR = .057. These data met the recommended acceptance criteria.

The standardized regression coefficients for the direct effects on the dependent variable — real AI practices — are shown in Table 5. In particular, as can be seen in the table, the strongest direct predictor was self-efficacy regarding AI ($\beta = .42$, $p < .001$). This determined the important role of the teacher's subjective confidence in shaping his practical activity in the field of AI. At the same time, pedagogical attitudes towards AI ($\beta = .31$, $p < .001$) and institutional support ($\beta = .19$, $p < .01$) also had a significant positive impact. Perceived barriers and anxiety towards AI had a significant negative direct impact on practices ($\beta = -.22$, $p < .001$). Such indicators indicated the deterrent function of this component. In contrast, the direct impact of digital competence on actual practices of using AI was statistically insignificant ($\beta = .11$, $p = .09$).

Testing indirect effects using bootstrap resampling (n = 5000) indicated that digital literacy had an indirect effect on AI use practices through self-efficacy ($\beta = .26$, 95% CI [.18, .35], $p < .001$) and through pedagogical attitudes ($\beta = .14$, 95% CI [.08, .21], $p < .01$). Thus, the relationship between digital literacy and actual pedagogical use of AI was mainly mediated through the development of self-efficacy and the formation of positive attitudes. The formed model explained 58% of the variance of the dependent variable ($R^2 = .58$).

Table 5.
Structural Model: Standardized Path Coefficients for Predictors of AI Use Practices (N = 278)

Predictor	β	SE	p	95% CI
AI Self-Efficacy	.42	.06	< .001	[.31, .53]
Pedagogical Attitudes toward AI	.31	.07	< .001	[.18, .44]
Perceived Barriers & AI Anxiety	−.22	.05	< .001	[−.32, −.12]
Institutional Support	.19	.06	.001	[.08, .30]
Digital Competence (direct)	.11	.07	.090	[−.02, .24]
Digital Competence → Self-Efficacy → Practices	.26	.04	< .001	[.18, .35]
Digital Competence → Attitudes → Practices	.14	.03	.003	[.08, .21]

Note. β = standardized regression coefficient; SE = standard error; CI = confidence interval. R^2 = .58.

Figure 3 shows the structural model of AI pedagogical readiness with standardized path coefficients between the main latent variables. The data from the SEM analysis indicated that the strongest direct effect on AI Use Practices was AI Self-Efficacy (β = .42, p < .001). This determined the crucial role of respondents' confidence in their own abilities to use AI technologies.

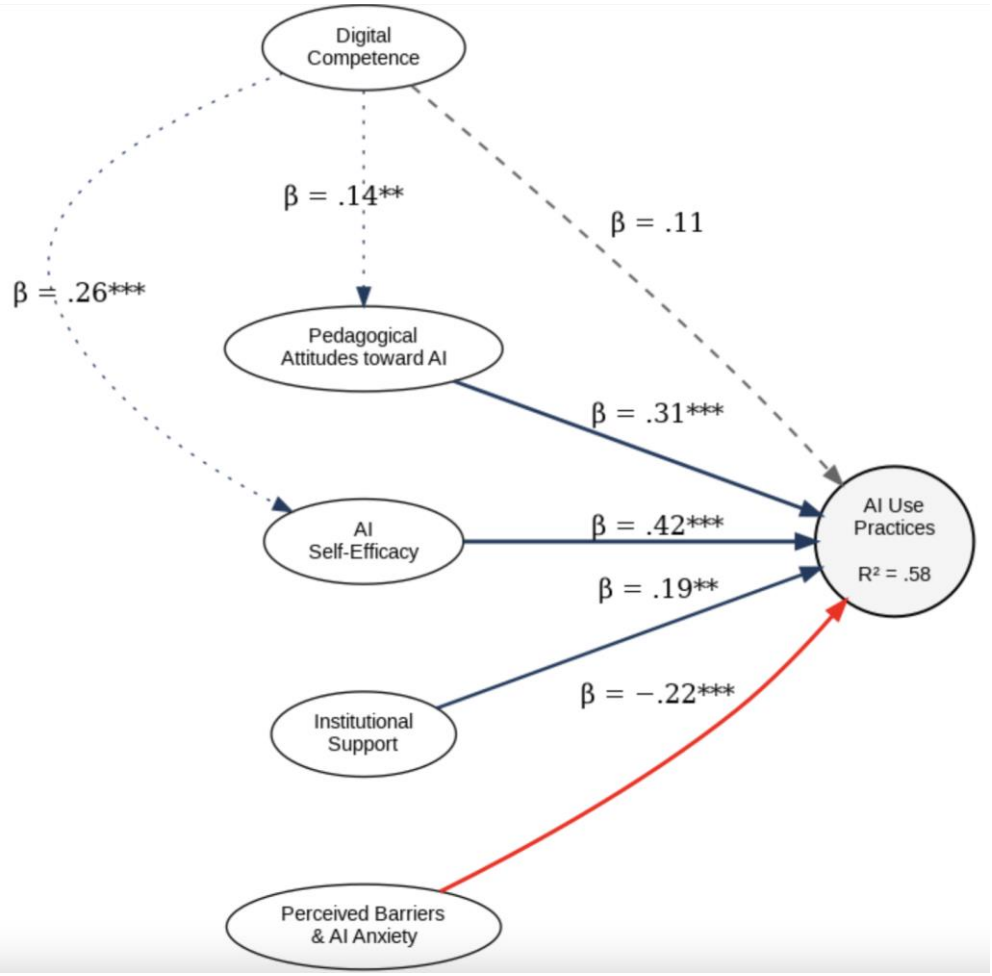


Figure 3. Structural Model of AI Pedagogical Readiness: standardized odds

Differences in readiness profiles depending on teacher characteristics

An important part of the study was to determine the readiness profiles for AI integration depending on the demographic and professional characteristics of the participants. To do this, a comparative analysis was conducted using one-way analysis of variance (ANOVA) for variables with three or more groups and Student's t-test for independent samples for dichotomous variables. Note that the effect size was estimated using η^2 (for ANOVA) and Cohen's d (for t-test). The results of the comparative analysis by key characteristics are presented in Table 6.

Analysis of variance indicated significant differences in the overall readiness index depending on teaching experience ($F(3, 274) = 8.43$, $p < .001$, $\eta^2 = .08$). At the same

time, post-hoc analysis (Tukey HSD) indicated that teachers with less than 5 years of experience had higher scores on the scales of real-world AI practices and self-efficacy. In contrast, more experienced teachers had higher scores on digital competence. However, this difference did not reach statistical significance ($p = .12$).

The presence of prior digital training indicated significant differences between teachers who had prior digital training experience and those who did not. For example, teachers with prior AI training had higher scores on self-efficacy ($t(276) = 6.84$, $p < .001$, $d = 0.82$), real-world AI practices ($t(276) = 7.21$, $p < .001$, $d = 0.87$).

Analysis of variance did not indicate statistically significant differences in the overall readiness score depending on the scientific degree ($F(3, 274) = 1.94$, $p = .12$, $\eta^2 = .02$). Only on the scale of pedagogical attitudes towards AI was there a trend towards higher scores among doctors of science. However, this indicator did not reach the accepted threshold of significance.

In addition, the t-test did not indicate statistically significant gender differences in any of the components of the model ($p > .05$ for all scales).

Table 6.
Group Differences in AI Pedagogical Readiness by Demographic and Professional Characteristics (N = 278)

Variable	Group Comparison	Scale	Statistic	p	Effect Size
Teaching experience	F(3, 274) = 8.43	Overall Readiness	ANOVA	< .001	$\eta^2 = .08$
	≤5 yrs > >20 yrs	AI Use Practices	Tukey HSD	< .01	—
	≤5 yrs > >20 yrs	AI Self-Efficacy	Tukey HSD	< .01	—
Prior AI/digital training	Yes vs. No	AI Self-Efficacy	t(276) = 6.84	< .001	d = 0.82
	Yes vs. No	AI Use Practices	t(276) = 7.21	< .001	d = 0.87
	Yes vs. No	Perceived Barriers	t(276) = −4.13	< .001	d = −0.50
Academic degree	F(3, 274) = 1.94	Overall Readiness	ANOVA	.120	$\eta^2 = .02$
Gender	Male vs. Female	All scales	t-test	> .05	n.s.

Note. n.s. = not significant. Effect sizes: η^2 (ANOVA); d = Cohen's d (t-test). Small effect: $\eta^2 = .01$, $d = 0.20$; medium: $\eta^2 = .06$, $d = 0.50$; large: $\eta^2 = .14$, $d = 0.80$.

Teacher readiness for AI integration

The results obtained made it possible to determine the readiness of HEI teachers for the pedagogical integration of artificial intelligence as a multidimensional construct. In particular, all components were in complex interdependencies and did not reduce to the sum of technological skills. Active research searches have generated significant interest in the role of AI in higher education (do Lago et al., 2026; Selmi et al., 2025; Khumalo et al., 2025). This, in turn, has highlighted the need to study the capabilities of technologies and the real readiness of teaching staff for their meaningful application.

The absence of significant gender and degree differences indicated that readiness to integrate AI is determined primarily by individual experiences of interaction with technology and institutional space.

AI literacy

The study indicated a noticeable asymmetry between the relatively high level of digital competence and low indicators of real practices of using AI. This became the central result of the study.

The teacher had to assess the reliability of the generated content, adapt it to educational goals, anticipate possible ethical risks, and maintain control over the learning outcomes.

It has also become important to work with psychological barriers and anxiety about AI. This should become an independent and necessary component of such programs (Patiño Barriga et al., 2025).

Digital competence in higher education

This gap was generally consistent with the conclusions of Basilotta-Gómez-Pablos et al. (2022), who indicated that the digital competence of higher education teachers cannot always be transformed into innovative pedagogical practice. At the same time, structural modeling data indicated that digital competence became a necessary, but not sufficient, condition for active pedagogical use of AI. It was shown that its impact on practices was mainly mediated, in particular through self-efficacy and pedagogical attitudes.

The revealed indirect nature of the relationship between digital competence and AI practices was explained by the fact that general digital skills created only a potential opportunity for the application of technology. They did not automatically determine the pedagogical behavior of the teacher. The teacher could confidently use digital platforms, create content and work with information. However, he was not convinced of his own ability to integrate AI into specific educational scenarios (Mah & Groß, 2024).

Thus, digital competence in the proposed model performed the function of a basic resource, while self-efficacy and pedagogical attitudes acted as mechanisms that transformed this resource into real practice.

This explained why teachers with similar levels of digital competence demonstrated significantly different intensities of AI use in teaching.

DigCompEdu and TPACK

The results obtained have implications for the development of professional development systems for academic staff. In particular, AI training programs should not be limited to the formation of technical skills.

However, despite the importance of the results obtained, the study has a number of limitations. In particular, the use of a self-report method may lead to socially desirable responses, especially regarding digital competence scales and AI usage practices.

The transition from technological competence to practical use probably occurred only when the teacher perceived AI as a pedagogically useful tool and had sufficient confidence that he could apply it without losing the quality of teaching, control over the educational process or professional autonomy.

The leading role of self-efficacy could be related to the specifics of the pedagogical use of AI, which involved technical mastery of the tool and decision-making under conditions of uncertainty.

In addition, Godinez-Flores et al. (2025) and Hernandez-Pozas (2025) pointed out the need to rethink pedagogical roles in the context of digital transformation. This situation involves not only technical, but also conceptual retraining of teachers.

Technology Acceptance Model (TAM)

The mediation mechanism made it possible to expand existing theoretical models of technology adoption in education and supplement them with the role of self-efficacy as the main transmission mechanism between competence and behavior.

Such data were consistent with the position of Hernandez-Pozas (2025) on the transformation of teachers' roles in the context of digitalization of education.

The significant negative impact of perceived barriers (β = −.22) can be compared with the observations of Molina-Soria et al. (2026). In particular, these authors recorded that the combination of AI and assessment in teacher education is hampered primarily by psychological and organizational barriers.

The positive role of institutional support (β = .19) was consistent with the findings of Khumalo et al. (2025) and Alaba and Ajibola (2026). These autho rs indicated that the successful integration of AI into HEIs is determined mainly by organizational and managerial factors. At the same time, individual characteristics of teachers took a secondary place (Kurebay et al., 2023). At the same time, this study, on the contrary, proved that experience in using technology is important.

The relatively weaker direct relationship of institutional support with AI practices did not mean that the organizational context was secondary. Rather, institutional support created favorable conditions. However, its effect was realized through individual mechanisms.

The availability of access to tools, training, methodological recommendations, and administrative support did not guarantee the use of AI if the teacher did not have positive pedagogical beliefs or doubted his own ability to apply the technology. Therefore, institutional support in APRM was appropriate to consider as a contextual resource, the effectiveness of which depended on its transformation into personal experience, confidence, and pedagogically sound intentions.

Teacher self-efficacy

The indicator of self-efficacy regarding AI became the strongest direct predictor of real practices (β = .42). This result can be compared with the findings of Deroncele-Acosta et al. (2025). These authors indicated that the subjective confidence of teachers played an important role in shaping their ability to integrate AI for the development of transversal competencies.

The article proves that they should purposefully develop teachers' self-efficacy based on practical experience of applying AI in educational scenarios.

Under such conditions, it was confidence in one’s own ability to manage these processes that could determine behavior more than the formal level of digital skills (Wang et al., 2023).

Professional development for AI integration

The most practical result of the comparative analysis was the large effect size of prior training in the field of AI. This indicated that targeted training can indeed change the behavior of teachers. This view is supported by research in the field of technology-enriched learning (Ogwo, 2026; Salas-Pilco et al., 2022).

Higher education administrations should also consider institutional support as a strategic factor in the readiness of teaching staff. Institutional support should develop technical infrastructure, encourage innovation, and allocate time for the development of new technologies (do Lago et al., 2026; Cano et al., 2026). In addition, the verified APRS tool can be used by higher education institutions as a diagnostic tool to assess the current state of teacher readiness and plan targeted professional development activities (Deroncele-Acosta et al., 2025; Feitosa et al., 2025; Selmi et al., 2025).

It is also worth noting that the cross-sectional design did not allow conclusions to be drawn about causal relationships over time. At the same time, the structural relationships between the components of the model that were identified were correlational in nature.

Conclusions

Thus, the diagnostics of the readiness profile indicated an asymmetry between the components of the model. In particular, teachers demonstrated a relatively high level of digital competence and positive pedagogical attitudes towards AI, but real practices of its use were the least developed component of readiness. Thus, there is a real gap between technological literacy and its pedagogical implementation in higher education practice.

The data from structural modeling indicated that digital competence became a necessary, but not sufficient condition for the pedagogical application of AI. Its impact on real practices was realized mainly indirectly - on the basis of the development of self-efficacy ($\beta = .26$) and the formation of positive pedagogical attitudes ($\beta = .14$). This finding became fundamentally important for the design of professional development programs for teachers.

The article proves that self-efficacy towards AI was the strongest direct predictor of real practices of using AI ($\beta = .42$). However, perceived barriers and anxiety had a negative impact ($\beta = -.22$). These results identified specific areas for effort to increase readiness: developing self-efficacy, addressing psychological barriers, and creating a supportive organizational environment.

Previous AI training experience was the most important demographic predictor of readiness with a large effect size. This indicated that readiness to integrate AI is an acquired rather than an innate characteristic.

Overall, the study indicated that bridging the gap between digital competence and pedagogical use of AI requires a systemic approach that involves developing self-efficacy, transforming pedagogical beliefs, and creating a supportive institutional environment. The proposed APRM model and the verified APRS tool provided the necessary theoretical and diagnostic foundation for this. Therefore, the results can serve as a basis for developing scientifically sound professional development programs for scientific and pedagogical workers.

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Original Article

Recursos digitales para mejorar la competencia pragmática de los estudiantes en el aprendizaje de lenguas extranjeras

Digital resources for enhancing students' pragmatic competence in foreign language learning

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Resumen

Se revelan el contenido y los componentes de la competencia pragmática de los estudiantes al aprender una lengua extranjera. Se fundamenta el contenido de la competencia sociopragmática y pragmalingüística. Se identifican las principales tareas de los recursos digitales que aseguran el desarrollo de la competencia pragmática en términos de contenido. Los resultados de la etapa de evaluación del experimento mostraron un nivel insuficiente de formación de la competencia pragmática de los estudiantes, lo que permitió establecer factores que influyen en la formación y el desarrollo de la competencia pragmática de los estudiantes, delinear una serie de problemas prácticos y teóricos, desarrollar un sistema, determinar y fundamentar las condiciones pedagógicas e implementar un curso especial. Después de la etapa formativa del experimento, los indicadores del alto nivel de formación de la competencia pragmática de los estudiantes que utilizan recursos digitales al aprender una lengua extranjera aumentaron significativamente en los estudiantes del grupo experimental; en consecuencia, los indicadores del bajo nivel disminuyeron significativamente. En el grupo de control, estos cambios no son significativos. De este modo, los resultados de la fase formativa del experimento confirmaron la eficacia del sistema desarrollado para la formación de la competencia pragmática mediante el uso de recursos digitales en el aprendizaje de una lengua extranjera, las condiciones pedagógicas propuestas y fundamentadas, y el curso especial desarrollado e implementado.

Palabras clave: competencia pragmática; estudiantes; aprendizaje de un idioma extranjero; recursos digitales; plataformas digitales.

Abstract

The content and components of pragmatic competence of students when learning a foreign language are revealed. The content of sociopragmatic and pragmalinguistic competence is substantiated. The main tasks of digital resources that ensure the development of pragmatic competence are identified in terms of content. The results of the ascertaining stage of the experiment showed an insufficient level of formation of pragmatic competence of students, which made it possible to establish factors that influence the formation and development of pragmatic competence of students, outline a range of practical and theoretical problems, develop a system, determine and substantiate pedagogical conditions, and implement a special course. After the formative stage of the experiment, the indicators of the high level of formation of pragmatic competence of students using digital resources when learning a foreign language significantly increased in EG students; respectively, the indicators of the low level significantly decreased. In CG, these changes are not significant. Thus, the results of the formative stage of the experiment confirmed the effectiveness of the developed system for the formation of pragmatic

competence using digital resources when learning a foreign language, the proposed and substantiated p edagogical conditions, and the developed and implemented special course.

Keywords: pragmatic competence; students; learning a foreign language; digital resources; digital platforms.

Introduction

The digital transformation of higher education has substantially changed approaches to foreign language teaching, creating new opportunities for the development of students' communicative competence (Harvey Arce & Cuadros Valdivia, 2020). Universities increasingly integrate digital learning environments, online communication platforms, artificial intelligence tools, and authentic multimedia resources into language instruction. Despite these advances, the development of pragmatic competence remains one of the least systematically addressed components of university foreign language education.

Content and components of students' pragmatic competence when learning a foreign language. Sociopragmatic and pragmatic competence. The main goal of high-quality foreign language learning is the formation of students' pragmatic competence using digital resources, necessary for the successful performance of professional and academic activities in a foreign language environment. Pragmatic competence is a systemic, complex formation, among which the main ones are linguistic, sociolinguistic, and pragmatic models.

In order to be able to interpret and achieve a communicative goal, using communication models, necessary interaction schemes, adhering to the logical organization of thoughts, a certain register and style of speech, and etiquette norms, it is the pragmatic competence of students when learning a foreign language that involves independently generating statements and coherent discourses. The correct choice of the conditions of the communicative act, communication strategies, and language units depending on the context is especially important for the effective interaction of students in professionally oriented communication, which is status-regulated by its nature.

Pragmatic competence is a combination of sociopragmatic and pragmatic linguistic competences and, in the context of learning a foreign language, means the ability to act correctly in communicative foreign language situations (Mugford, 2022).

Therefore, the study of pragmatics of business speech in learning a foreign language should be integrated at all levels by creating communicative situations in the form of cases, projects, discussions, business and role-playing games, and problem situations, developed based on authentic materials (multimedia, audio, video, Internet resources) (Jacome Paredes et al., 2025).

Traditionally, pragmatics was oriented towards intercultural pragmatics within the framework of the study of a foreign language as a research field, which led to one-sided and relatively narrow attention to socio-pragmatic aspects and related speech acts. Within the framework of a broad definition of pragmatics, this concept, at the junction of pragmatics and grammar, is based on the example of pragmalinguistic aspects of language use.

In general, pragmatic competence is formed only in the process of developing socio-cultural and linguistic competence; therefore, it is often not singled out as a separate

educational aspect. However, the lack of knowledge of pragmatics in professional communication in a foreign language can lead to significant communicative failures (Niño Molina & Torres Sánchez, 2026). Unlike errors in grammar, vocabulary, and pronunciation, which are quite expected for a person who speaks a non-native language, errors are often perceived in speech behavior as deliberate rudeness, inappropriateness, and make a negative impression on the interlocutor.

Pragmatic competence is a combination of sociopragmatic (refers to the assessment of the social distance between communicants, and the norms of language use and social rules in a particular group), which includes the study of the features of embodiment in the expression of speech acts, which are intended to greet, complain, apologize, invite, request, make proposals, etc. and pragmatic linguistic competence (studies the ways of using language in order to embody a certain communicative intention in a message), which involves familiarization with the mastery of communicative strategies and communication theory, and sociopragmatic competence.

Blogs and social networks are popular today. Many students maintain their own page on a social network. The use of social networks by a teacher allows for continuous learning of a foreign language, taking students' foreign language learning beyond classroom lessons. Therefore, digital resources should be used to form students' pragmatic competence (Palshkov et al., 2026).

Students can listen to native speakers of a foreign language using the YouTube Internet resource, which allows them to observe the position of the vocal apparatus, facial expressions, and pay attention to the pronunciation of words. Online dictionary simulators are also quite interesting tools that allow them to learn foreign words, their pronunciation, and spelling (Ou-sekou et al., 2021). For students, this is a convenient way to memorize words and learn foreign languages.

In many higher education institutions, foreign language instruction continues to emphasize grammatical accuracy, vocabulary acquisition, and the development of receptive language skills (Heiser, 2019). Although these components are essential, they do not sufficiently prepare students to use language appropriately in authentic communicative situations. As a result, students often demonstrate satisfactory linguistic knowledge while experiencing difficulties in selecting contextually appropriate expressions, interpreting communicative intentions, and adapting their speech to different sociocultural contexts.

This discrepancy represents a significant challenge for contemporary university language education. Current instructional practice lacks evidence-based pedagogical models that systematically integrate digital resources into the development of pragmatic competence. Existing digital technologies are frequently employed to support grammar, vocabulary, and general language practice rather than to facilitate authentic pragmatic interaction, sociopragmatic awareness, and pragmalinguistic development (Panero et al., 2017).

Previous studies have confirmed the educational potential of digital technologies for language learning; however, considerably less attention has been devoted to the design and experimental validation of pedagogical systems specifically aimed at developing pragmatic competence through digital resources in higher education. Consequently, the effectiveness of such approaches remains insufficiently investigated.

Addressing this gap, the present study examines whether the systematic integration of digital resources into foreign language instruction can enhance university students' pragmatic competence. The study aims to develop and experimentally evaluate a pedagogical system that combines digital educational resources, targeted instructional conditions, and a specially designed course to improve students' ability to communicate appropriately and effectively in authentic foreign-language contexts.

Literature Review

Pragmatic competence is recognized as one of the key components of communicative competence because it enables language learners to interpret communicative intentions and produce contextually appropriate utterances in authentic social interaction. Contemporary research distinguishes two complementary dimensions of pragmatic competence: pragmalinguistic competence, which concerns the linguistic realization of communicative intentions, and sociopragmatic competence, which involves selecting language that is socially appropriate in specific communicative contexts (Moghaddam et al., 2020; Mugford, 2022). Recent studies demonstrate that insufficient pragmatic competence often results in communication breakdowns even when learners possess advanced grammatical and lexical knowledge.

The rapid development of digital technologies has substantially transformed foreign language education. Research in computer-assisted language learning (CALL) and technology-enhanced language learning (TELL) indicates that digital platforms, virtual learning environments, multimedia resources, mobile applications, and artificial intelligence provide learners with authentic communicative experiences that facilitate the development of pragmatic competence. These technologies promote learner autonomy, individualized instruction, immediate feedback, and meaningful interaction in real-life communicative contexts (Belda-Medina & Calvo-Ferrer, 2022). Artificial intelligence has become an important component of contemporary foreign language instruction. Systematic reviews demonstrate that AI-powered chatbots improve speaking performance, writing, interaction quality, learner engagement, and communicative confidence through personalized learning pathways and real-time feedback (Belda-Medina & Kokošková, 2023). At the same time, researchers emphasize that AI should complement rather than replace pedagogically structured instruction, particularly in developing sociopragmatic awareness and intercultural communicative competence.

Another important research direction concerns the integration of digital technologies into intercultural communication. Virtual exchanges, online collaboration, videoconferencing, and multimedia communication provide authentic opportunities for learners to practice speech acts while interacting with speakers from different cultural backgrounds. Such learning environments contribute simultaneously to the development of pragmatic competence, intercultural communicative competence, and digital competence, thereby preparing students for communication in multilingual professional settings (Jacome Paredes et al., 2025; Jin et al., 2025).

Despite the increasing number of studies devoted to digital language learning, important research gaps remain. Most previous investigations have focused on vocabulary acquisition, grammar instruction, pronunciation, or general communicative competence, whereas considerably fewer experimental studies have examined comprehensive pedagogical systems specifically designed to develop pragmatic competence through the systematic integration of digital educational resources. Existing systematic reviews also indicate the need for

longitudinal quasi-experimental research that evaluates the effectiveness of integrated pedagogical models combining digital technologies, authentic communication, and structured instructional interventions.

Therefore, the present study addresses this research gap by developing and experimentally validating a pedagogical system that integrates digital educational resources into foreign language instruction to enhance university students' pragmatic competence. Unlike previous studies focusing on individual technologies or isolated pragmatic skills, the proposed model combines digital resources, pedagogical conditions, and a specially designed instructional course to promote sustainable development of students' sociopragmatic and pragmalinguistic competence in authentic intercultural communication.

Research objective. Developing students' pragmatic competence in learning a foreign language using digital resources.

Methodology

Research Design

The study employed a quasi-experimental research design to investigate the effectiveness of a system for developing students' pragmatic competence in foreign language learning through the use of digital resources. The research was based on the hypothesis that the formation and development of students' pragmatic competence would be more effective through the implementation of an innovative pedagogical system, a set of theoretically substantiated pedagogical conditions, and a specially designed course integrating digital resources into foreign language learning.

The experimental study was conducted between 2022 and 2025 and consisted of three stages: search, ascertaining, and formative.

Participants

A total of 478 students participated in the experimental study. The participants were divided into an experimental group (EG; n = 235) and a control group (CG; n = 243). The experimental group participated in the implementation of the proposed pedagogical system, pedagogical conditions, and special course, while the control group continued their foreign language learning within the traditional educational framework.

Research Methods

The study employed a combination of theoretical, empirical, and statistical research methods.

Theoretical methods included analysis, systematization, synthesis, generalization, and comparison of scientific and methodological literature to examine the problem of developing students' pragmatic competence in foreign language learning through digital resources, clarify the conceptual foundations of the study, and substantiate the proposed pedagogical system and conditions.

Empirical methods included pedagogical observation, testing, surveys, analysis of pedagogical activities, and analysis of students' educational activity outcomes. A

pedagogical experiment was conducted to assess the effectiveness of the proposed pedagogical conditions and the special course aimed at developing students' pragmatic competence through digital resources.

Assessment Framework

Students' pragmatic competence was assessed based on three interrelated components: motivational-value, cognitive, and activity. A diagnostic framework was developed to determine the level of pragmatic competence formation, including specific criteria and indicators corresponding to each component.

The motivational-value component reflected students' values, motivation, interest, and self-reflection regarding the development of pragmatic competence in foreign language learning. The cognitive component focused on students' knowledge and understanding of pragmatic phenomena and the appropriate use of language in different communicative contexts. The activity component assessed students' ability to apply pragmatic knowledge and skills in practical foreign language communication.

The level of students' pragmatic competence was determined according to the established criteria and indicators.

Experimental Procedure

The experimental study was conducted in three stages.

During the **search stage**, the theoretical and methodological foundations of developing students' pragmatic competence in foreign language learning through digital resources were examined. The factors influencing the formation and development of pragmatic competence were identified, and the conceptual foundations of the pedagogical system were developed.

During the **ascertaining stage**, the initial level of students' pragmatic competence was assessed using the developed diagnostic tools. The criteria, indicators, and levels of pragmatic competence formation were determined, and the initial equivalence of the experimental and control groups was examined.

During the **formative stage**, the proposed system for developing students' pragmatic competence through digital resources was implemented in the experimental group. The intervention involved the introduction of the substantiated pedagogical conditions and a specially developed course aimed at enhancing students' pragmatic competence in foreign language learning. Digital resources were integrated into the educational process to support students' pragmatic knowledge, motivation, self-reflection, and practical ability to use language appropriately in different communicative situations.

The control group continued its educational activities according to the established approach to foreign language instruction without the targeted implementation of the proposed pedagogical system and pedagogical conditions.

At the end of the formative stage, the level of students' pragmatic competence was reassessed using the same criteria and indicators applied during the ascertaining stage. The results obtained in the experimental and control groups were subsequently compared to determine the effectiveness of the implemented intervention.

Research Instruments

The diagnostic instruments used in this study were developed based on established theoretical frameworks of pragmatic competence and adapted from questionnaires and assessment tools previously validated in the literature. Prior to their administration, the instruments were reviewed to ensure that the items corresponded to the research objectives and the content of the educational intervention. The final version of the questionnaire included items assessing the motivational, cognitive, and activity components of students' pragmatic competence. Since the study employed adapted rather than newly developed instruments, no additional psychometric validation, such as expert content validation or reliability testing, was conducted within the present research. This methodological aspect should be considered when interpreting the findings.

Data Analysis

The collected data were analyzed using qualitative and quantitative approaches. Descriptive analysis was used to determine the distribution of students according to the established levels of pragmatic competence formation.

To verify the comparability of the experimental and control groups at the beginning of the experiment and to determine the statistical significance of differences between the empirical distributions after the formative intervention, Pearson's chi-square (χ^2) test was applied. The null hypothesis (H_0) assumed that there were no statistically significant differences between the compared distributions, whereas the alternative hypothesis (H_1) assumed that statistically significant differences existed.

The statistical significance of the obtained differences was assessed at significance levels of $p < .05$ and $p < .01$. The results of the statistical analysis were used to determine whether the implementation of the proposed pedagogical system, pedagogical conditions, and special course had a statistically significant effect on the formation of students' pragmatic competence in foreign language learning through digital resources.

Ethical Considerations

The study was conducted in accordance with the ethical principles applicable to educational research. Participation in the study was voluntary, and all participants were informed about the purpose and procedures of the research. Participants provided informed consent before taking part in the experimental activities. The confidentiality and anonymity of the participants were ensured throughout the research process, and the collected data were used exclusively for scientific and research purposes. Participants were informed of their right to withdraw from the study at any stage without any negative consequences.

Results and Discussion

The experiment is based on the hypothesis that the formation and development of students' pragmatic competence in learning a foreign language using digital resources, as a developmental process, will be effective if such an innovative system for forming students' pragmatic competence in learning a foreign language using digital resources and the pedagogical conditions we have identified are introduced into the process of preparing students for professional activity, and a special course is implemented.

At the ascertainment stage of the experiment, to assess students' motivation for developing pragmatic competence when learning a foreign language using digital resources, a survey of students in the control and experimental groups was conducted, in which students expressed their views on the outlined phenomenon. It should be noted that the students' answers were mostly inaccurate and incomplete. The initial survey revealed students' level of pragmatic competence, their self-motivation, and their self-reflection regarding the possession of pragmatic competence.

95% of respondents have a positive attitude towards the formation of pragmatic competence of students using digital resources when learning a foreign language. However, only 18% of respondents have a full understanding of the essence and importance of this competence for professional specificity.

Thus, students are ready to form pragmatic competence and are positively motivated by the described phenomenon.

The assessment of the level of formation of pragmatic competence was based on three components: motivational and value; cognitive; activity:

- Motivational and value – a questionnaire, which takes into account the concept of internal and external motivation.
- Cognitive – diagnostics regarding awareness of the outlined competence and the features of its implementation.
- Activity – in the process of passing pedagogical practice, an analysis of the results of students' practical activities was carried out.

To determine pragmatic competence, a diagnostic toolkit was developed and indicators of each component were determined (development of active independence; assimilation of content, a set of concepts, properties, features, relationships, patterns, as well as digital processes in modern education, stimulation of cognitive activity of respondents, a conscious attitude to future professional activity and to the educational digital process), which enabled qualitative analysis and quantitative analysis of the effectiveness of the system and pedagogical conditions, special course developed by us.

Indicators of mastering the content of the system, conditions, and special course were determined in terms of completeness of mastery using a coefficient; this is the ratio of actually mastered elements of knowledge that students need to master to the elements of knowledge that were at a certain stage of training. For this, the formula was used:

$$K_c = \frac{N_c}{N_t}$$

N_c – the number of correct answers in the test, i.e., the number of correctly identified knowledge elements;
N_t – the total number of test items, i.e., the total number of knowledge elements that students are expected to acquire at a particular stage of learning.

The results were evaluated according to the diagnostic data of the level of mastery of the system, conditions, and content of the special course using test control. If the content is fully acquired (K_c = 1); if there are no correct answers during testing, the content is not mastered (K_c = 0).

For a high level of mastery of the content, K_c > 0.9.
For an average level of mastery of the content – 0.75< K_c <0.89.
For a sufficient level of mastery of the content – 0.6< K_c <0.74.
For a low level of mastery of the content – K_c < 0.6.

The overall indicator of the effectiveness of the entire system is considered to be the integrated indicator, which was determined before the beginning of the formative stage of the study as the difference between the total formation of the levels of educational activity and after its completion.

The effectiveness of the system, conditions, and special course was determined as the weighted average value, according to three degrees of importance of the components, of all efficiency indicators that determine the value of the integrated (general) indicator:

- High weight coefficient (k_1 = 3 points).
- Medium weight coefficient (k_2 = 2 points).
- Low weight coefficient, the least important (k_3 = 1 point).

In this regard, the formula was used:

$$E_{av} = \frac{k_1 M_1 + k_1 M_2 + k_2 K_1 + k_2 P_1 + k_3 P_2}{k_1 + k_1 + k_2 + k_2 + k_3}$$

The first statistical alternative partial hypotheses for determining the effectiveness of the developed and implemented system, pedagogical conditions, and a special course for the formation of pragmatic competence of students using digital resources when learning a foreign language were defined as follows:

H_0 – a substantiated and developed system, pedagogical conditions and a special course using digital resources when learning a foreign language do not allow the formation of an appropriate level of pragmatic competence;
H_1 – a substantiated and developed system, pedagogical conditions and a special course using digital resources when learning a foreign language allow the formation of an appropriate level of pragmatic competence.

We used one of the non-parametric criteria; in particular, the Pearson χ^2 criterion was chosen.

The results of the ascertaining stage of the experiment showed an insufficient level of formation of students' pragmatic competence, which made it possible to establish factors that influence the formation and development of students' pragmatic competence, outline a range of practical and theoretical problems, develop a system, determine and substantiate pedagogical conditions, and implement a special course.

Results of the ascertaining stage of the experiment. To determine the level of formation of students' pragmatic competence and the level of their motivation according to the motivational and value criterion, we surveyed students, the results of which are presented in Table 1:

Table 1.
Levels of formation of students' pragmatic competence according to the motivational and value criterion (assertive stage of the experiment)

Level	Control group (CG), n (%)	Experimental group (EG), n (%)
High	101 (41.56%)	97 (41.28%)
Sufficient	73 (30.04%)	72 (30.64%)
Average	51 (20.99%)	46 (19.57%)
Low	18 (7.41%)	20 (8.51%)
Total	243 (100%)	235 (100%)

To determine the level of formation of students' pragmatic competence by cognitive criterion, we used student diagnostics (input, current, and output). The results of the assessment are presented in Table 2.

Table 2.
Levels of formation of students' pragmatic competence by cognitive criterion (confirmatory stage of the experiment)

Level	Control group (CG), n (%)	Experimental group (EG), n (%)
High	20 (8.23%)	24 (10.21%)
Sufficient	48 (19.75%)	42 (17.87%)
Average	74 (30.45%)	71 (30.21%)
Low	101 (41.56%)	98 (41.70%)
Total	243 (100%)	235 (100%)

To determine the level of formation of students' pragmatic competence according to the activity criterion, we used a package of complex tasks to assess the levels of formation of the outlined competence. The results of the assessment are presented in Table 3:

Table 3.
Levels of formation of students' pragmatic competence according to the activity criterion (confirmatory stage of the experiment)

Level	Control group (CG), n (%)	Experimental group (EG), n (%)
High	18 (7.41%)	18 (7.66%)
Sufficient	50 (20.58%)	44 (18.72%)
Average	72 (29.63%)	74 (31.49%)
Low	103 (42.39%)	99 (42.13%)
Total	243 (100%)	235 (100%)

As can be seen from Tables 1-3, at the ascertaining stage, low and medium levels of pragmatic competence formation prevail among students according to all criteria.

Using the Pearson χ^2 criterion, the reliability of the obtained results was checked, in particular, to test the H_0 hypothesis about the absence of differences between the two experimental (empirical) distributions: EG and CG.

$\chi^2_{emp} < \chi^2_{crit}$; therefore, we accept H_0 – the null hypothesis that the initial level of pragmatic competence formation of students in the control and experimental groups does not differ significantly.

The results of the experiment showed that at the significance levels of 0.01 and 0.05 between the groups that directly participated in the experiment, there are no statistically significant differences in the level of pragmatic competence formation of

students. This allows us to conclude about an equivalent and homogeneous contingent of students in the experimental and control groups.

The formative stage of the experiment. At the formative stage of the experiment, we outlined a range of practical and theoretical problems, developed a system for the formation of pragmatic competence, defined and justified pedagogical conditions, and implemented a special course.

A system for the formation of pragmatic competence was introduced into the educational process of the EG, which can be presented in general terms as a scheme of four consecutive milestones:

- Selection of units with pragmatic potential, formulation of the goal.
- Selection of approaches to learning and principles, theoretical justification of ways to develop students' pragmatic competence when learning a foreign language.
- Technological support using digital resources, selection of teaching aids and methods, etc.
- Assessment of the results of the formation of students' pragmatic competence when learning a foreign language.

Pragmatic meaning when studying a foreign language by EG students using digital resources was formed by various speech, language, and extra-linguistic means – by means of the language code of the phonological level (specificity of stress, special pronunciation, repetition of sounds), lexical-semantic level (professionalisms, dialectisms, non-normative words), morphological level (suffixes, pettiness, pettiness), syntactic level (special use of interjections, certain types of sentences, constructions), paralinguistic means (facial expressions, posture, facial expression, gestures), and speech means (intonation, tone, emphasis, pauses).

In the classes, we set the goal of teaching EG students to see and analyze pragmatic meanings as a manifestation of the speaker's intention. This was a primary task, carried out within the framework of the competency approach when studying a foreign language.

The development of pragmatic competence, regardless of the chosen teaching methods, was based on the principle of “input – interaction – output”, which aimed to:

- Perform exercises on the use of non-verbal means and necessary language means with a certain communicative conscious intention.
- Independent creation using the acquired pragmatic skills and knowledge of the act of communication.
- Familiarization with the text, audio, video plot – a real sample of speech, which contains an analysis of the communicative situation and pragmatic units.

Among the principles of the formation of pragmatic competence in EG, we have highlighted:

1. Step-by-step formation of pragmatic competence, where the principle of “input – interaction – output” lies. “Input” – familiarization with a speech sample, which includes an analysis of the communication situation and pragmatic units. “Interaction” – performing exercises with a specific communicative goal using the necessary linguistic/non-linguistic means. "Output" – independent creation

of EG by students using pragmatic knowledge and skills of the act of communication;
2. Development of pragmatic awareness – the ability to use in various communication situations and recognize language tools and communicative strategies, taking into account their impact on the interaction of speakers, behavior, perception;
3. Explicit learning involves the teacher explaining, using digital resources, the rules for the conscious application and use of a specific pragmatic phenomenon by students during the performance of training exercises. Knowledge is reproduced according to the requirements of a specific speech situation and, using an explicit approach, is retained in the memory of students. Therefore, the development of students' English-language pragmatic competence using digital resources will be facilitated by step-by-step explicit learning and the development of students' conscious attitude to the studied speech and language units.

Using digital resources, EG students developed quizzes, online tests, and used auxiliary services such as JeopardyLabs, WordLearner, Kahoot, BrainFlips, etc. Digital resources in foreign languages are an effective tool for forming pragmatic competence.

The use of educational digital resources strengthened and increased the interest of EG students in learning a foreign language. The desire to obtain modern professional knowledge and motivation to study helped develop their pragmatic competence in a foreign language and, as a result, created a comfortable environment for modern learning.

Digital resources in the formation of students' pragmatic competence performed the following functions:

- Educational − with the help of digital resources, EG students practiced skills and used a large number of exercises with grammatical structures of a foreign language to automate actions.
- Informational, because digital resources fully provided EG students with material that included grammar rules, examples of typical errors, and suggested ways to avoid them.
- Motivational, because digital resources are a modern source of knowledge for EG students, which increases their interest in learning foreign languages.
- Visual, because digital resources provided EG students with illustrative material.
- Developing, because digital resources developed curiosity and interest, helped EG students in independent learning, and improved their knowledge of foreign language grammar.

EG students, in order to develop pragmatic competence in the context of studying a foreign language, had the opportunity to take various online tests in a foreign language. For example, they could check their level of a foreign language on sites such as EnglishLearner, Test-MyEnglish, OxfordEnglishTesting, BBC, LanguageLinN, as well as take tests in the ExamEnglish and A4ESL systems, which gave EG students the opportunity to prepare for international exams. At the same time, when studying a foreign language, interdisciplinary connections helped EG students expand the information space for the formation of pragmatic competence skills and foreign language communication.

CG students had the opportunity to create multimedia applications, collect and search for sources of professional information, use audio and video materials,

electronic manuals (textbooks), electronic educational and methodological complexes, dictionaries, test tasks, webquests, educational blogs, individual communication projects, blogquests, which is an important component of the development of competencies of students of all specialties in foreign language classes.

In addition, digital resources provided EG students with the opportunity to contact colleagues in English-speaking countries, which ensured the participation of students in real situations, international scientific and technical conferences in English using interactive methods.

In EG, students used the following digital resources:

- Multimedia scrapbook – is a kind of collection of multimedia resources, which contains links to audio files, graphic information, text sites, photos, video clips, animated virtual tours.
- Treasure hunt – contains links to various sites on the topic being studied and directs search activities.
- Subject sampler – contains links to text and multimedia materials on the Internet, aimed at discussing debatable and socially sensitive topics, provides an opportunity to argue and express one's own opinion on a discussion issue.
- Webquest – a scenario for organizing students' project activities on any topic using Internet resources.

In order to study a foreign language in a structured way and develop pragmatic competence when studying a foreign language using digital resources, EG students used such publicly accessible educational platforms as: FutureLearn, Coursera, edX, Prometheus, Udemy, EdEra, which offered courses on English teaching methods, intercultural communication, academic writing, and also contained interactive video courses.

To study grammar and vocabulary, reading and listening skills, EG students used digital platforms such as LearningApps, Duolingo, Busuu, Blooke, Wordwall, Quizlet, Kahoot, and Memrise, which offered gamification in combination with classical study of the material.

Among the digital professional platforms for learning a foreign language, EG students were offered: Macmillan Education, Oxford University Press, Educational Testing Service, National Geographic Learning.

Students liked the use of communicative practice platforms: Italki, Speaky, Conversation Exchange, Tandem, HelloTalk, Mizou, Replika, TalkPal AI, which improve listening and intercultural communication skills.

For discussions, interactive classes, and debates, digital platforms such as Viber, Google Meet, Zoom, Microsoft Teams, and WhatsApp were also used.

For the development of critical thinking, the most effective digital platforms for learning a foreign language were: BBC Learning English, TED Talks, Cambridge English, VOA Learning English, British Council, Test English.

In the formation of academic writing skills, the development of reflection was supported by AI-based digital platforms (DeepL Write, ChatGPT, Grammarly, Gemini, QuillBot).

So, an innovative system for the formation of pragmatic competence of students was introduced into the educational process of EG, and we identified pedagogical conditions:

- Formation of positive motivation for mastering pragmatic competence of students in the process of their professional training.
- Updating the content of students' training by introducing a special course "Formation of pragmatic competence of students using digital resources in learning a foreign language".
- Creation of a digital environment of higher education in order to improve the practical training of students.

Analysis of the results of the formative stage of experimental work.

At the formative stage of the experiment, the level of formation of pragmatic competence of students was assessed similarly to the ascertaining stage of the experiment according to criteria (motivational-value, cognitive, and activity).

Assessment of motivation (motivational-value criterion) for professional training through the formation and development of students' pragmatic competence was carried out using a questionnaire, the results of which allowed determining the real professional interest of students in the specialty and their interest in studying the material.

To compare the survey results in the EG and CG regarding the level of development of students' pragmatic competence, their values, self-motivation, and self-reflection, the Pearson criterion was used – the χ^2 criterion:

The formula was used:

$$\chi^2 = \sum_{i=1}^{n} \frac{(x_i - y_i)^2}{y_i}$$

If the results of the ascertaining stage of the experiment showed that the development of the motivational and value component of the experimental and control groups is approximately the same and is mainly at a low and medium level, then as a result of the approbation of the system, justified pedagogical conditions, special course, the formative stage of the experiment showed a change in the level of formation of the motivational and value component in both the experimental and control groups. We observe a noticeable increase in motivational and value factors important for the formation of pragmatic competence of students and the general preparation of future specialists for professional activity in students of the experimental groups.

The results of the assessment at the formative stage of the experiment of the levels of formation of pragmatic competence of students by the motivational and value criterion are presented in Table 4.

Table 4.
Levels of formation of pragmatic competence of students using digital resources when learning a foreign language by the motivational and value criterion (formative stage of the experiment)

Level	Control group (CG), n (%)	Experimental group (EG), n (%)
High	32 (13.17%)	70 (29.79%)
Sufficient	70 (28.81%)	104 (44.26%)
Average	60 (24.69%)	33 (14.04%)
Low	81 (33.33%)	28 (11.91%)
Total	243 (100%)	235 (100%)

To compare the distributions of students' pragmatic competence levels between the experimental and control groups after the formative stage, Pearson's chi-square test was applied. For the motivational-value criterion, the analysis demonstrated statistically significant differences between the groups, $\chi^2(3, N = 478) = 31.57$, $p < .001$, with a small-to-moderate effect size (Cramer's $V = 0.257$). These results indicate that students in the experimental group achieved significantly higher levels of pragmatic competence than those in the control group.

The results of assessing students' pragmatic competence according to the activity criterion are presented in Table 5.

Table 5.
Levels of formation of students' pragmatic competence using digital resources when learning a foreign language by the activity criterion (formative stage of the experiment)

Level	Control group (CG), n (%)	Experimental group (EG), n (%)
High	29 (11.93%)	70 (29.79%)
Sufficient	69 (28.40%)	106 (45.11%)
Average	63 (25.93%)	32 (13.62%)
Low	82 (33.74%)	27 (11.49%)
Total	243 (100%)	235 (100%)

The results of assessing the levels of formation of students' pragmatic competence using digital resources when learning a foreign language after the formative stage of the experiment by the cognitive criterion are presented in Table 6, which were obtained similarly to the activity criterion.

For the activity criterion, Pearson's chi-square test also revealed statistically significant differences between the experimental and control groups, $\chi^2(3, N = 478) = 34.89$, $p < .001$. The effect size was Cramer's $V = 0.270$, indicating a small-to-moderate practical effect of the implemented pedagogical intervention.

Table 6.
Levels of formation of students' pragmatic competence using digital resources when learning a foreign language by the cognitive criterion (formative stage of the experiment)

Level	Control group (CG), n (%)	Experimental group (EG), n (%)
High	28 (11.52%)	74 (31.49%)
Sufficient	71 (29.22%)	105 (44.68%)
Average	59 (24.28%)	30 (12.77%)
Low	85 (34.98%)	26 (11.06%)
Total	243 (100%)	235 (100%)

As the results of Tables 4-6 show, after the formative stage of the experiment, the indicators of the high level of formation of pragmatic competence of students using digital resources when learning a foreign language significantly increased in EG students; respectively, the indicators of the low level significantly decreased. In CG, these changes are not significant.

For the cognitive criterion, the difference between the experimental and control groups was statistically significant, $\chi^2(3, N = 478) = 39.99$, $p < .001$, with Cramer's $V = 0.289$. These findings confirm that the implementation of the proposed pedagogical system significantly improved students' pragmatic competence compared with the traditional instructional approach.

We checked the probability of the obtained results to test the hypothesis H_1, using the Pearson criterion, in particular, the difference between the two experimental (empirical) distributions: CG and EG.

The obtained results ($\chi^2_{emp} > \chi^2_{crit}$) are significant at the level of 5% and 1%; therefore, the null hypothesis is rejected. The alternative hypothesis H_1 is accepted at a high level of significance, that the level of formation of pragmatic competence of respondents in the experimental and control groups differs significantly, which indicates the effectiveness of the introduction of the author's system for the formation of pragmatic competence, justified pedagogical conditions, and a special course.

The results of the formative stage of the experiment confirmed the effectiveness of the developed system for the formation of pragmatic competence using digital resources in learning a foreign language, the proposed and substantiated pedagogical conditions, and the developed and implemented special course. This gives grounds to assert that the goal of the study has been achieved.

The diagnostic instruments were adapted from previously validated questionnaires reported in the literature and selected according to the objectives of the study. The items were reviewed for their relevance to the components of pragmatic competence (motivational, cognitive, and activity). Therefore, the study relied on instruments with previously established validity rather than conducting an independent psychometric validation.

The findings of the present study confirm that the systematic integration of digital educational resources into foreign language instruction contributes to the development of students' pragmatic competence. Following the implementation of the proposed pedagogical intervention, students in the experimental group demonstrated significantly higher levels of motivational, cognitive, and activity-related components of pragmatic competence than those in the control group. These findings support previous studies that emphasize the positive impact of technology-enhanced language learning on authentic communication and pragmatic development (Belda-Medina & Calvo-Ferrer, 2022).

The obtained results are consistent with research indicating that digital technologies create authentic communicative environments in which learners can practice speech acts, receive immediate feedback, and develop sociopragmatic awareness through meaningful interaction. Similarly, Jin et al. (2025) reported that technology-supported instruction enhances learners' ability to interpret and produce contextually appropriate utterances, particularly in intercultural communication. The present findings extend these conclusions by demonstrating that the effectiveness of digital resources increases when they are integrated into a comprehensive pedagogical system rather than used as isolated instructional tools.

The results also corroborate previous evidence regarding the educational potential of artificial intelligence and conversational technologies. Belda-Medina and Calvo-Ferrer (2022) found that AI-based conversational agents increase learner engagement and provide personalized opportunities for communicative practice. Likewise, the present study suggests that digital educational resources facilitate students' active participation in foreign language learning and promote the practical application of pragmatic knowledge in authentic communicative situations.

At the same time, the findings differ from some previous studies that evaluated the effectiveness of individual digital applications or short-term instructional interventions. Whereas many earlier investigations focused primarily on vocabulary acquisition, grammar instruction, or isolated pragmatic skills, the present research examined a comprehensive instructional model combining digital resources, pedagogical conditions, and structured learning activities. This integrated approach may explain the broader improvements observed across all components of pragmatic competence.

Despite these positive findings, several methodological limitations should be acknowledged. The study employed a quasi-experimental design, and the assessment relied primarily on questionnaire-based measures. Furthermore, the diagnostic instruments were adapted from previously published studies but did not undergo independent psychometric validation within the present research. Consequently, the results should be interpreted with caution. Future studies should incorporate validated performance-based assessment instruments, longitudinal research designs, and independent measures of pragmatic competence to strengthen the evidence base and improve the generalizability of the findings.

Overall, the findings contribute to the growing body of research on technology-enhanced foreign language learning by demonstrating that the systematic integration of digital educational resources can effectively support the development of pragmatic competence among university students. At the same time, they highlight the need for further experimental studies examining the long-term effectiveness of digitally supported pedagogical models across different educational contexts.

Conclusions

The content and components of students' pragmatic competence in learning a foreign language are revealed. The content of sociopragmatic and pragmalinguistic competence is substantiated. The main principles of students' pragmatic competence in learning a foreign language are grouped, and the directions of studying pragmatic phenomena are shown. The main tasks of digital resources that ensure the development of pragmatic competence are identified in terms of content.

The task of the scientific research is the formation and development of students' pragmatic competence using digital resources in learning a foreign language. The study made it possible to determine students' pragmatic competence as the basis for successful professional adaptation and the process of their professionalization, and to identify its components, criteria, indicators, and levels of formation.

Using a specially organized experiment, an experimental study was conducted to determine the effectiveness of implementing the developed system for the formation of pragmatic competence using digital resources in learning a foreign language, the

proposed and substantiated pedagogical conditions, and the developed and implemented special course.

The experiment was based on the hypothesis that the formation and development of students' pragmatic competence when learning a foreign language using digital resources, as a developmental process, will be effective if such an innovative system for the formation of students' pragmatic competence when learning a foreign language using digital resources and the pedagogical conditions we have identified are introduced into the process of preparing students for professional activity, and a special course is implemented.

During 2022-2025, an experimental study was conducted, which covered the following stages of the experiment: search, ascertainment, and formative. 478 students were involved in the experimental work. An experimental (EG – 235 students) group and a control (CG – 243 students) group were formed.

The assessment of the level of formation of pragmatic competence was based on three components: motivational and value; cognitive; activity.

To determine pragmatic competence, a diagnostic tool was developed, and indicators of each component were determined. We used one of the non-parametric criteria; in particular, the Pearson χ^2 criterion was chosen.

The results of the ascertaining stage of the experiment showed an insufficient level of formation of pragmatic competence of students, which made it possible to establish factors that influence the formation and development of pragmatic competence of students, outline a range of practical and theoretical problems, develop a system, determine and substantiate pedagogical conditions, and implement a special course. At the ascertaining stage, low and medium levels of formation of pragmatic competence prevailed among students according to all criteria. Using the Pearson χ^2 criterion, the reliability of the obtained results was checked, in particular, to test the H_0 hypothesis about the absence of differences between the two experimental (empirical) distributions: EG and CG. $\chi^2_{emp} < \chi^2_{crit}$; therefore, we accept the H_0 − null hypothesis that the initial level of formation of pragmatic competence of students of the control and experimental groups does not differ significantly. This allows us to conclude about an equal and homogeneous contingent of students of the experimental and control groups. At the formative stage of the experiment, the level of formation of pragmatic competence of students was assessed similarly to the ascertaining stage of the experiment according to the criteria (motivational-value, cognitive, and activity).

To compare the results of the survey in the EG and CG regarding the level of formation of students' pragmatic competence, their values, self-motivation, and self-reflection, the Pearson criterion was used – the χ^2 criterion:

After the formative stage of the experiment, the indicators of the high level of formation of students' pragmatic competence using digital resources when learning a foreign language significantly increased in EG students; respectively, the indicators of the low level significantly decreased. In the CG, these changes are not significant. We checked the probability of the obtained results to test the hypothesis H_1, using the Pearson criterion, in particular, about the difference between the two experimental (empirical) distributions: CG and EG. The obtained results are significant ($\chi^2_{emp} > \chi^2_{crit}$) at the level of 5% and 1%; therefore, the null hypothesis is rejected. The alternative hypothesis H_1 is accepted at a high level of significance: the level of formation of pragmatic competence of respondents in the experimental

and control groups differs significantly, which indicates the effectiveness of the introduction of the author's system for the formation of pragmatic competence, justified pedagogical conditions, and a special course.

Thus, the results of the formative stage of the experiment confirmed the effectiveness of the developed system for the formation of pragmatic competence using digital resources in learning a foreign language, the proposed and justified pedagogical conditions, and the developed and implemented special course. This gives grounds to assert that the goal of the study has been achieved.

Further scientific explorations consist of developing pedagogical conditions for the integration of digital platforms into the educational process of higher education institutions in order to form the cognitive orientation of students in the context of blended and distance learning.

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Original Article

Herramientas digitales interactivas para el desarrollo de la competencia profesional de los estudiantes universitarios

Interactive digital tools for developing university students' professional competence

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Resumen

El artículo examina la efectividad de las herramientas digitales interactivas en el desarrollo de la competencia profesional de los estudiantes universitarios. El estudio analiza el potencial y las limitaciones de las plataformas digitales integradas en el entorno educativo digital de la universidad y fundamenta las condiciones pedagógicas para su uso sistemático en la formación profesional. Se realizó un estudio cuasiexperimental con 188 estudiantes de primer año de universidad, que incluyó un grupo experimental (GE; n = 93) y un grupo de control (GC; n = 95). En la etapa inicial, la mayoría de los estudiantes de ambos grupos demostraron un bajo nivel de competencia profesional, lo que confirmó la necesidad de una intervención pedagógica específica. Durante la etapa formativa, el grupo experimental participó en un curso especial impartido por el autor y en un sistema de condiciones pedagógicas que incluía la integración sistemática de herramientas digitales interactivas, aprendizaje colaborativo, comunicación digital, actividades independientes y evaluación interactiva, mientras que el grupo de control continuó sus estudios según el enfoque educativo tradicional. En la etapa de control, el grupo experimental demostró proporciones sustancialmente mayores de estudiantes con un alto nivel de competencia profesional en todos los criterios evaluados. Según el criterio cognitivo, el 60,22% de los estudiantes del grupo experimental (GE) alcanzó un nivel alto, en comparación con el 13,68 % del grupo de control (GC); según el criterio de actividad operativa, las proporciones correspondientes fueron del 59, 14% y del 18,95%; y según el criterio personal, del 53,76% y del 17,89%, respectivamente. La Figura 1 también muestra mayores incrementos en la proporción de estudiantes con un nivel alto en el GE en todos los criterios. Estos hallazgos indican que la integración pedagógica sistemática de herramientas digitales interactivas se asoció con mejoras sustancialmente mayores en la competencia profesional en el grupo experimental que en el grupo de control.

Palabras clave: herramientas digitales interactivas; la formación de competencias profesionales de los estudiantes; universidades; plataformas digitales; entorno educativo digital.

Abstract

The article examines the effectiveness of interactive digital tools in developing the professional competence of university students. The study analyzes the potential and limitations of digital platforms integrated into the university's educational digital environment and substantiates pedagogical conditions for their systematic use in professional training. A quasi-experimental study was conducted with 188 first-year university students, including an experimental group (EG; n = 93) and a control group (CG; n = 95). At the ascertaining stage, the majority of students in both groups demonstrated a low level of professional competence, confirming the need for targeted pedagogical intervention. During the formative stage, the experimental group participated in an author's special course and a system of pedagogical conditions involving the systematic integration of interactive digital tools, collaborative learning, digital communication, independent activities, and interactive assessment, whereas the control group continued studying according to the

traditional educational approach. At the control stage, the experimental group demonstrated substantially higher proportions of students with a high level of professional competence across all assessed criteria. According to the cognitive criterion, 60.22% of EG students achieved a high level compared with 13.68% in CG; according to the activity-operational criterion, the corresponding proportions were 59.14% and 18.95%; and according to the personal criterion, 53.76% and 17.89%, respectively. Figure 1 also demonstrated greater increases in the proportion of students with a high level in EG across all criteria. These findings indicate that the systematic pedagogical integration of interactive digital tools was associated with substantially greater improvements in professional competence in the experimental group than in the control group.

Keywords: interactive digital tools; the formation of professional competence of students; universities; digital platforms; educational digital environment.

Introduction

The digital transformation of higher education has substantially changed the requirements for university students' professional preparation. Contemporary specialists are expected not only to possess disciplinary knowledge but also to communicate effectively in digital environments, collaborate through digital platforms, evaluate and process information, and apply digital technologies to professional tasks. Consequently, professional competence increasingly incorporates the ability to use digital tools purposefully, critically, and independently rather than merely demonstrate technical proficiency. Previous studies have emphasized the relationship between digital competence, professional activity, communication, and learning outcomes, as well as the importance of creating educational environments that support meaningful digital interaction (Aagaard & Lund, 2020; Dang et al., 2024; Fernández-Batanero et al., 2022).

However, the institutional problem addressed in the present study is more specific than the general digitalization of higher education. The initial diagnostic stage conducted among 188 first-year university students revealed insufficient development of professional competence in both the experimental and control groups. In particular, a low level was identified for 61.29% of students in the experimental group and 61.05% in the control group according to the cognitive criterion, indicating insufficient professional knowledge and mastery of relevant terminology. Similarly, a low level according to the activity-operational criterion was observed in 62.37% and 62.11% of students, respectively, indicating insufficient ability to perform professional tasks and apply digital tools systematically in professional learning activities. The personal criterion also demonstrated predominantly low results, accounting for 60.22% of students in the experimental group and 60.00% in the control group. These findings indicate that the problem was not simply limited access to digital technologies; rather, students experienced difficulties in transforming available digital resources into professional knowledge, practical skills, communication abilities, and professionally important personal qualities.

This situation also points to a limitation of approaches in which digital technologies are introduced primarily as additional technical resources without a coherent pedagogical framework. The use of individual platforms, multimedia materials, online communication tools, or digital assessment services does not automatically ensure the development of professional competence (Guillén-Gámez et al., 2023). Effective integration requires pedagogical support, purposeful learning activities, opportunities for collaboration and independent work, and a safe digital educational environment (Palshkov et al., 2026). The literature similarly indicates that professional digital competence depends on contextual and pedagogical conditions

rather than on technological access alone (Carpenter et al., 2024; Ifenthaler & Egloffstein, 2020; Lindfors et al., 2021). Thus, the relevant educational problem is how to organize the systematic use of interactive digital tools so that they become an integral component of professional preparation rather than an isolated technological supplement.

Interactive digital tools provide a potentially appropriate response to this problem because they can combine several dimensions of professional learning within a single educational environment. Synchronous and asynchronous communication platforms can support professional dialogue and feedback; collaborative digital environments can facilitate teamwork and joint problem solving; interactive exercises and gamified activities can increase students' involvement; multimedia and visualization tools can support the understanding and presentation of professional content; and digital assessment tools can provide opportunities for continuous monitoring of learning outcomes. Research on digital competence and digital transformation has demonstrated the educational potential of such tools, while also emphasizing the need for their pedagogically justified integration into teaching and learning (López Simó et al., 2020; Pedersen et al., 2024; Zadorina et al., 2024). The theoretical basis of the proposed intervention is therefore grounded in the systemic, competency-based, and student-oriented approaches to professional preparation. Within this framework, professional competence is considered as an integrated construct that includes cognitive knowledge, activity-operational skills, and professionally important personal qualities, with digital competence functioning as an important component of professional readiness for contemporary professional activity. This conceptualization is consistent with the study's assessment framework, which distinguishes cognitive, activity-operational, and personal criteria and evaluates their formation at high, medium, and low levels. The intervention consequently focuses not on the introduction of particular technologies for their own sake but on the purposeful integration of interactive digital tools into professional learning activities.

A further research gap concerns the limited empirical substantiation of how a systematically organized combination of interactive digital tools, pedagogical conditions, and specially designed instructional content can influence different dimensions of university students' professional competence. Existing research has established the importance of digital competence and described individual technologies or digital learning practices, but further empirical evidence is needed regarding the effectiveness of an integrated pedagogical system that connects digital tools with professional tasks, collaborative interaction, active learning, independent work, and structured assessment. The present study addresses this gap by examining an intervention that combines an author's special course, pedagogical conditions, and systematic use of interactive digital tools within the university's digital educational environment. The intervention included different models of student–teacher interaction, collaborative and independent activities, interactive assessment, project-based learning, gamification, multimedia resources, and other digital learning technologies.

Accordingly, the **purpose of this study** was to assess the effectiveness of a pedagogically structured integration of interactive digital tools in developing the professional competence of university students.

The study specifically examined whether the implementation of the proposed pedagogical system, special course, and pedagogical conditions would result in

higher levels of professional competence among students in the experimental group compared with those following the traditional educational approach.

Literature Review

In the modern conditions of digitalization of education, to form the professional competence of students, the use of digital interactive tools is the focus of attention of scientists, both in the practical aspects of the introduction of digital technologies into the professional training of specialists and in the theoretical and methodological principles of the digital transformation of the educational process.

The work of Dang et al. (2024) substantiates the impact of digital competence of specialists on the learning outcome and on the development of their communication skills. Other scientists, Zadorina et al. (2024), analyze the role of artificial intelligence in creating a personalized educational environment, which provides new formats for educational interaction.

Ifenthaler and Egloffstein (2020) propose a model of digital maturity of students for the use of digital interactive tools, within the practical aspects of the implementation of digital technologies and outlining the importance of digital transformation for the formation of digital competence of education seekers.

López Simó et al. (2020) pay attention to the formation and development of ICT competence and digital competence when transferring education to a blended and distance format, during classroom and extracurricular work in the process of studying STEM disciplines, which is closely related to digital tools.

González-Rodríguez and Urbina-Ramírez (2020) reveal the role of ICT in the future activities of applicants and present the digitalization of studying STEM disciplines, provide innovative tasks for students to encourage them to form research digital competence, which takes into account factors such as enjoyment of technology and motivation, the quality of resources, which is not limited to knowledge, skills in the scientific process for managing digital resources.

Thus, the analysis of publications confirms the relevance of studying the use of interactive digital tools and platforms for the formation of professional competence of university students. Existing approaches in the context of modern challenges and needs of the educational industry require further generalization and improvement.

Research purpose: to assess the effectiveness of using interactive digital tools for the formation of professional competence of university students.

Methodology

Research Design

The study employed a quasi-experimental research design to investigate the effectiveness of interactive digital tools in developing the professional competence of university students. The research was based on the hypothesis that systematically integrating interactive digital tools into the university digital educational environment, supported by appropriate pedagogical conditions and a specially designed instructional system, would significantly enhance students' professional competence.

The research combined theoretical, empirical, and statistical methods and was conducted in three consecutive stages: ascertaining, formative, and control.

Participants

The experimental study involved 188 first-year university students. The participants were divided into a control group (CG; n = 95) and an experimental group (EG; n = 93). The slight difference in the number of participants between the groups did not affect the validity or representativeness of the experimental results. Both groups participated in the study throughout the entire experimental period, while the experimental group received the educational intervention based on the proposed pedagogical system.

Research Methods

The study employed theoretical, empirical, and statistical research methods.

Theoretical methods included systematic analysis, comparison, generalization, systematization, specification, and instructional design. These methods were applied to analyze psychological, pedagogical, and methodological literature, clarify the conceptual framework of the study, and substantiate the pedagogical conditions for developing students' professional competence through interactive digital tools.

Empirical methods included questionnaires, pedagogical observation, interviews, and a pedagogical experiment. These methods were used to assess students' professional competence before and after the educational intervention and to evaluate the effectiveness of the developed pedagogical system and the author's special course.

Assessment Framework

Students' professional competence was assessed using an integrated diagnostic framework comprising three criteria: cognitive, activity-operational, and personal. The cognitive criterion reflected the level of students' professional knowledge, understanding of relevant concepts and terminology, and ability to apply theoretical knowledge in professional contexts. The activity-operational criterion concerned students' ability to perform professional tasks, apply digital tools, solve practical problems, and independently organize professional activities. The personal criterion reflected professionally important qualities, including motivation, communication, responsibility, emotional stability, and readiness for professional interaction.

The assessment framework combined several sources of evidence, including pedagogical observation, interviews, and questionnaire-based assessment. The results were aggregated into three levels of professional competence: high, medium, and low. The level classification was based on predefined indicators associated with each criterion and was applied consistently at the ascertaining and control stages.

Because the available research dataset contains aggregated criterion-level results rather than individual item-level responses, internal-consistency coefficients such as Cronbach's alpha and KR-20 could not be calculated retrospectively. Therefore, the present study does not claim psychometric reliability of the questionnaire scales. Instead, the assessment framework was grounded in theoretically defined criteria and indicators and applied consistently across the experimental and control groups.

Research Instruments

The study employed a structured assessment framework consisting of pedagogical observation, interviews, and questionnaire-based procedures. These instruments were used to obtain complementary information concerning students' professional knowledge, practical performance, motivation, communication, and professionally important personal qualities. The assessment indicators were defined in accordance with the cognitive, activity-operational, and personal criteria established for the study.

The available dataset was retained in aggregated form at the criterion and competence-level categories. Consequently, item-level psychometric analysis was not possible, and coefficients of internal consistency, including Cronbach's alpha or KR-20, were not calculated. This limitation is explicitly acknowledged because reliability coefficients require access to individual responses to the respective questionnaire items. Future studies should include item-level datasets and conduct formal reliability and validity analyses, including internal-consistency assessment and, where appropriate, exploratory or confirmatory factor analysis.

Experimental Procedure

The experimental research consisted of three consecutive stages.

During the **ascertaining stage**, diagnostic instruments were selected, students were assigned to the experimental and control groups, and the initial level of professional competence was assessed.

During the **formative stage**, the proposed pedagogical system was implemented in the educational process of the experimental group. The intervention included the introduction of an author's special course and the implementation of pedagogical conditions designed to enhance students' professional competence through the systematic use of interactive digital tools within the university's digital educational environment.

The intervention emphasized three complementary models of student–teacher interaction based on the characteristics of educational communication: synchronicity versus diachronicity, communication types and channels, and individual versus collaborative learning. Interactive digital platforms, online communication tools, collaborative technologies, and other digital educational resources were integrated into learning activities to promote students' professional knowledge, practical skills, collaboration, and independent learning.

The control group continued studying according to the traditional educational approach without the targeted implementation of the proposed pedagogical system and pedagogical conditions.

During the **control stage**, students' professional competence was reassessed using the same diagnostic instruments applied during the ascertaining stage. The obtained results were compared with the initial measurements to determine changes in the level of professional competence following the educational intervention.

Data Analysis

The collected data were analyzed using qualitative, quantitative, and statistical methods. Descriptive statistics were applied to determine the distribution of students

according to the established levels of professional competence and to evaluate changes observed during the experimental study.

The statistical significance of differences between the experimental and control groups was determined using Pearson's chi-square (χ^2) test. The null hypothesis (H_0) assumed that no statistically significant differences existed between the empirical distributions, whereas the alternative hypothesis (H_1) assumed the presence of statistically significant differences. Statistical significance was determined at $p < .05$.

Ethical Considerations

The study was conducted in accordance with the ethical principles governing educational research. Participation in the experiment was voluntary, and all participants were informed about the purpose, procedures, and expected outcomes of the study before providing informed consent. Participants' anonymity and confidentiality were maintained throughout the research process, and the collected data were used exclusively for scientific purposes. Participants were informed of their right to withdraw from the study at any stage without any negative consequences.

Results and Discussion

Content and significance of interactive digital tools for the formation of professional competence of university students.

In the process of professional training of specialists, increasing the share of digital content is a positive step: familiarizing oneself with digital technologies and tools fully corresponds to modern trends in the development of professional activity and various areas of science.

The formation of professional competence in university students is an integral part of their professional training for education seekers, since the ability to argue and present one's own thoughts, interact effectively, and engage in dialogue determines the competitiveness of the future specialist in the labor market. Professional competence includes the ability to use interactive digital tools to form students' professional competence in accordance with the situations of the professional context and the requirements of the digital society (García Chamorro & Rolong Gamboa, 2025).

The digital environment and interaction tools in it open up new opportunities for the development of professional skills, team interaction, and information analysis (Aagaard & Lund, 2020).

Analysis of the capabilities and limitations of digital platforms that are actively integrated into the educational digital environment. The most popular digital educational resources that can be effectively used to form the professional competence of university students.

During classes using interactive digital tools, in particular the Zoom or Padlet platforms, education students actively participate in discussions, which contributes to the development of group work and public speaking skills. Students' technical and communication skills are formed by participation in joint projects – active listening, argumentation, mutual respect. Digital tools must allow you to create a digital,

communicative, safe environment where each person has the opportunity to express themselves, receive feedback, and gradually overcome communication barriers. The integration of chats and forums, gamification, and multimedia content increases participants' interest in the educational process and contributes to diversifying ways of interaction (Fernández-Batanero et al., 2022).

Thus, digital technologies form a new paradigm of digital culture, and not only expand the space of educational communication, but also contribute to open and adaptive changes in the digital society. In this context, for the active integration of students into the educational digital environment, the analysis of the limitations and opportunities of increasingly developed digital platforms becomes particularly relevant (Carpenter et al., 2024).

Digital platforms transform approaches to interaction between all participants in the educational process, communication, and learning. However, despite the obvious advantages for education and professional activity, digital platforms open up new horizons. However, their effective implementation requires digital culture, pedagogical support, a conscious approach to organizing the educational process, and not just technical support. For digital technologies to become a truly effective tool for the formation of university students' professional competence, it is necessary to provide a pedagogically sound, holistic digital environment for their application. The effectiveness of such activities largely depends on a set of favorable factors (Lindfors et al., 2021).

Among the most popular digital educational resources that can be effectively used to form the professional competence of university students in the training of future specialists are such tools as:

Canva – a powerful tool for creating visual content – educational materials, infographics, presentations, which contributes to the development of creativity of future specialists.

LearningApps helps create interactive exercises and games that can be adapted to professional activities or for students to consolidate theoretical material.

Kahoot! – through game elements stimulates motivation, which makes the educational process more interactive and dynamic.

Padlet – a convenient platform for ensuring student teamwork, creating joint projects, and exchanging ideas, which is important for the formation of students' professional competence.

Genially – offers a wide range of tools for creating educational resources and multimedia presentations using interactive elements and animation (Pedersen et al., 2024).

Experimental testing of the effectiveness of using digital interactive tools to form the professional competence of university students. Experimental work on the formation of professional competence in students was carried out in stages:

The ascertaining stage involved selecting diagnostic tools, allocating a control group and an experimental group, and identifying the initial level of professional competence formation in students.

The formation stage involved the substantiation of the system, the implementation of an author's special course, and the identification of pedagogical conditions for the formation of professional competence in students and their introduction into the educational process of EG students.

The control stage involved the identification of the level of professional competence formation in students after the implementation of the system, the implementation of an author's special course and pedagogical conditions, and the determination of the effectiveness of their implementation, and the comparison of the results obtained with the initial results based on the results of pedagogical diagnostics.

The study identified criteria, indicators, and levels of professional competence formation in students.

The cognitive criterion reflects the mental and intellectual side of students' professional competence – a set of structured and organized scientific information that remains in the memory of the future specialist and allows establishing interdisciplinary connections between different processes and phenomena based on the formed professional thinking of the individual. Indicators of the cognitive criterion: assimilation of the system of knowledge and terminology by students in professional disciplines:

The activity-operational criterion reflects the level of specialized and fundamental, professional and applied preparedness in students; formation as future competitive specialists, their professional skills and abilities of professional activity, which are manifested in the speed and number of completed professional tasks, in the independence of their solution and the originality of the approach to them. Indicators of the activity-operational criterion – a certain level of ability to perform professional tasks and the development of skills in educational and content blocks of professional disciplines (the ability to solve professional tasks by creating digital applications; use elements of artificial intelligence, practical tasks of computer logic and structural theory of digital automata; use original, innovative methods and traditional and forms of work with purposeful, constant, systematic use of digital tools to form professional competence; classify problems of implementing information processes; perform a comparative analysis of various professional solutions; use the principle of program control to organize computational processes in a computer, etc.)

The personal criterion characterizes the personality of the future specialist as a specialist in students, reflects the formation of professional, professionally important qualities (communicative, intellectual, digital, moral, strong-willed, the ability to interact and cooperate with a team (group), with people; the ability to solve professional and social tasks; compliance with group (social), ethical, general cultural, norms and rules). Indicators of the personal criterion are manifested in the development of professionally important qualities: moral (decency, compliance with ethical rules, openness, honesty, attentiveness); digital (working with digital technologies in the digital environment of the university); communicative (overcoming barriers to communication, interaction and communication, ability to establish contact, tolerance); cognitive (creativity, volume and efficiency of memory, perception, analytical skills, flexibility of thinking using digital technologies); emotional and volitional (perseverance, professional determination, responsibility, discipline, organized self-control).

The use of the specified set of indicators allows for quantitative and qualitative assessment of the levels of formation of professional competence of specialists in a

comprehensive manner. Accordingly, the levels characterizing the degree of formation of professional competence of students are determined: high, medium, low.

Thus, the specified criteria and indicators are the basis for experimental verification of the effectiveness of the system, the introduced author's special course, and pedagogical conditions for the formation of professional competence of students.

To determine the initial level of formation of professional competence of students, we used methods (observation, interviews) and questionnaires.

Statistical significance was assessed using Pearson's chi-square (χ^2) test. The chi-square statistic was calculated as:

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

where χ^2 is the chi-square statistic.
O_i is the observed frequency in category i.
E_i is the expected frequency in category i.
k is the number of categories.

For the statistical analysis, Pearson's chi-square (χ^2) test was used to examine whether the distributions of students across the competence levels differed significantly between the experimental and control groups. The significance level was set at $\alpha = 0.05$. The calculated χ^2 value was compared with the corresponding critical value based on the appropriate degrees of freedom. The null hypothesis (H_0) stated that there were no statistically significant differences between the distributions of competence levels in the experimental and control groups, whereas the alternative hypothesis (H_1) stated that statistically significant differences existed between the groups. The null hypothesis was rejected when the calculated χ^2 value exceeded the critical value at $\alpha = 0.05$; otherwise, there was insufficient evidence to reject H_0. Effect size was additionally evaluated using Cramér's V to assess the magnitude of the observed differences.

For conducting an ascertaining experiment, the choice of the above-mentioned methods is due to:

- Validity and content compliance with the research objectives of the method.
- Accessibility in the implementation, interpretation, and evaluation of the research results.
- The possibility of use in the university educational process.

The ascertaining stage of the experiment involved determining the initial level of formation of students' professional competence.

First-year students participated in the pedagogical experiment. 188 students were involved: 95 people made up the control group, 93 people – the experimental group.

The difference in the number of respondents between the control (n = 95) and experimental (n = 93) groups was minimal and did not affect the validity or representativeness of the study. The representativeness of the obtained data was ensured by the sample size of both groups. The following methods determined the composition of the experimental and control groups:

- Nested sampling (not only individual respondents were the units of the study, but also collectives (study groups – in our case) with further selection of respondents.
- Quota sampling (respondents were selected for the control and experimental groups in compliance with quotas: first year of study, the same direction of training).

The generalized results of the formation of professional competence of university students by the cognitive criterion at the ascertaining stage of the study are given in Table 1.

Table 1.
The generalized results of the formation of professional competence in students by the cognitive criterion (the ascertaining stage)

Levels	Experimental Group (n = 93)	Control Group (n = 95)
High	11 (11.83%)	12 (12.63%)
Medium	25 (26.88%)	25 (26.32%)
Low	57 (61.29%)	58 (61.05%)

Source: created by the authors

The generalized results of the study indicate that in CG and EG students, the formation of professional competence according to the cognitive criterion is mainly low (61.29% and 61.05%, respectively), that is, it is characterized by an insufficient amount of professional knowledge, mastery of terminology, which requires the improvement of students' educational activities through the use of interactive digital tools in the created digital environment of the university for the formation of students' professional competence.

The generalized results of the formation of professional competence of university students at the ascertaining stage of the study according to the activity-operational criterion are given in Table 2.

Table 2.
The generalized results of the formation of professional competence in students according to the activity-operational criterion (the ascertaining stage)

Levels	Experimental Group (n = 93)	Control Group (n = 95)
High	11 (11.83%)	11 (11.58%)
Medium	24 (25.81%)	25 (26.32%)
Low	58 (62.37%)	59 (62.11%)

Source: created by the authors

The generalized results of the study indicate that among students of the CG and EG, the formation of professional competence according to the activity-operational criterion is dominated by a low level (62.37% and 62.11%, respectively), that is, it is characterized by an insufficient level of skills to perform professional tasks, the development of skills in educational and content blocks of professional disciplines (the ability to solve professional tasks by creating digital applications; use elements of artificial intelligence, practical tasks of computer logic and structural theory of digital automata; use original, innovative methods and traditional and forms of work with the purposeful, constant, systematic use of digital tools for the formation of professional competence; classify problems of implementing information processes; perform a comparative analysis of various professional solutions; use the principle

of program control to organize computational processes in a computer, etc.), which requires the improvement of students' educational activities through the use of interactive digital tools in the created digital environment of the university. for the formation of students' professional competence.

The generalized results of the formation of professional competence of university students at the ascertaining stage of the study by the personal criterion are given in Table 3.

Table 3.
The generalized results of the formation of professional competence in students by the personal criterion (the ascertaining stage)

Levels	Experimental Group (n = 93)	Control Group (n = 95)
High	12 (12.90%)	12 (12.63%)
Medium	25 (26.88%)	26 (27.37%)
Low	56 (60.22%)	57 (60.00%)

Source: created by the authors

The generalized results of the study indicate that in CG and EG students, the formation of professional competence according to the personal criterion is mainly low (60.22% and 60.00%, respectively), that is, it is characterized by insufficient development of professionally important qualities: moral (decency, adherence to ethical rules, openness, honesty, attentiveness); digital (working with digital technologies in the digital environment of the university); communicative (overcoming barriers to communication, interaction and communication, ability to establish contact, tolerance); cognitive (creativity, memory volume and efficiency, perception, analytical skills, flexibility of thinking using digital technologies); emotional and volitional (perseverance, professional determination, responsibility, discipline, organized self-control), which requires improving students' educational activities through the use of interactive digital tools in the created digital environment of the university to form students' professional competence.

Thus, according to the data of the ascertaining experiment, the majority of EG and CG students have a low general level of professional competence formation, which showed the need for a formative experiment.

The formative stage of the experimental study. In the process of the experimental study, three models of student-teacher interaction using interactive digital tools were productive for EG students, which were identified taking into account several characteristic criteria for the formation of professional competence of university students (synchronicity/diachronicity; type and channels; individuality/collectivity):

- Interaction using private channels for communication (Facebook, e-mail, Viber), which could be individual, asynchronous and synchronous both with the team and with specific students, when participants in the educational process simultaneously communicate in social networks, chat, group conversation.
- Synchronous interaction in a single virtual space and in real time, which took place via video communication due to active online communication (all participants hear and see each other, have the opportunity to enter into discussions).
- Asynchronous (mediated) interaction, which becomes possible due to, as a rule, delayed, mainly written communication between students, and is also a system of tasks performed independently by students and evaluated by the teacher. CG

students studied according to the standard methodology of the university's educational process.

During the establishment of the educational activities of EG students, the first model of interaction was effective and was used mainly to clarify and stipulate organizational aspects regarding the conduct of classes, their type and nature. Private communication is necessary for detailed explanations or discussions of the material, individual consultations, and approval of creative and scientific student projects. This model also makes collective communication between students possible and involves the active use of social networks.

The second model was updated when practical or lecture classes were held in accordance with the electronic schedule, and meetings with employers were organized. To organize video conferences, Internet resources (Zoom, Google Meet) were used, thanks to which students had the opportunity to record meetings, hold discussions and debates, express their own opinions, broadcast visual materials from their PC or smartphone, and communicate in chat. This format made it impossible to falsify learning, adhered to the principle of identification, strengthened control over students' task performance, and promoted each individual's independence. It was this model of distance learning that was closest in terms of digitalization to traditional learning, interaction between students and each other, and not only between the teacher and students, because the effectiveness of organizing pedagogical digital interaction of agents is determined by several factors: the content and purpose of learning (content of the discipline), background factors (level of intellectual development of students, size of the study group, ethnicity, etc.), means of communication (form and quality of communication, language of dialogue), form of control.

The third model was implemented when students completed tasks on each topic, worked independently with professional materials, and sent their work to the teacher for verification and evaluation. In particular, students completed testing, tasks for independent work (creating mind maps, interactive posters, writing essays, creating lapbooks, book trailers, video reviews; preparing projects and recommendation posters, creating interactive electronic exercises using the Learning Apps designer, etc.). To download lecture materials for students, the main platform for passing the test was d-learn – the university's distance learning system. Testing and surveys were conducted using Google Forms. Professional tasks were assigned to students in classrooms – specially created Google classes. The tasks were accompanied by instructions for completion, additional materials, samples of work, and references to Internet resources. This model of the educational process is ideal for presenting creative and written works, their evaluation, and verification by the teacher.

To achieve the set goal during the educational process, EG students used original, innovative methods and traditional forms of work with targeted, constant, systematic use of digital tools of all groups to form professional competence.

Digital tools for use by EG students belonging to the first group were: Google Meet, Zoom, Skype, Webex platforms (services for organizing video communication and online conferences), Moodle (an information environment focused on the learning management system, organizing interaction between students and the teacher, which provides the opportunity to create, design and manage information and educational resources), Google Classroom (a service for classifying, creating and distributing tasks, accelerating interaction between students and files), YouTube

(a video service for viewing video lectures and video materials and downloading them), Ding Talk (a service for distance learning and video communication).

The second group of digital tools that we proposed for use by EG students included search engines: Yandex, Google, Bing, Yahoo, which were used very actively by students when conducting and organizing webquests, project-based and flipped learning.

The third group of digital tools that we proposed for use by EG students included computer programs and online services for creating didactic material (programs for generating QR codes, electronic interactive exercises, training laboratories, creating word clouds), multimedia support for studying professional material (multimedia presentations, video and audio programs, programs that provide visualization of professional material).

Effective for creating interactive, multimedia content for communication, visualization, collaboration, and the use of digital gaming tools were web services: for creating interactive posters – Glogster, Thinglink, Genially, for creating interactive timelines of events with the addition of audio, photos, and video materials – Timeline JS, Tiki-Toki, Time. Graphics, for creating mind maps – iMindMap, Spiderscribe, FreeMind, MindMeister, Mindomo, for creating video scribing and animation videos – Sparkol VideoScribe, Powtoon.com, for visualization, creating word clouds – Word it out, Mentimeter, Wordart.com, for creating quizzes and educational games – Plickers, Kahoot, for creating interactive tasks and exercises Learning Apps, Cosrative, for creating video scribing – PowToon, PowerPoint, Sparkol VideoScribe, GoAnimate, Animaker, etc.

The fourth group of digital tools that we proposed for assessing knowledge and skills is Google Forms, Plickers, Kahoot, Formative, and Quizizz.

For EG students, the online video communication mode made it possible to conduct lecture-conferences, lecture-visualizations, traditional lectures, and organize conversations. This format allowed EG students to implement, to a greater extent, the principle of visualization of distance learning and clarity: use available resources on the Internet.

Continues the formation of professional competence in the use of interactive digital tools. In particular, this included familiarization with the platform for blended and distance learning – the ICloud Cloud and acquiring skills in searching for and evaluating information and working with it. For this purpose, instructional and methodological materials were created. Opportunities were expanded by using collaborative services (IDroo, Padlet, Jamboard), simulators (Google 3D, Atom 3D, Simpop PheT), gamification (Kahoot, Learning Apps, Wordwall), smartphone sensors (using the Physics Suite, Phyphox, Arduino Science Journal platforms), augmented reality technologies, artificial intelligence tools, etc. During lectures and practical classes, instructional and methodological materials were offered to students.

EG students also had the opportunity to learn how to use elements of artificial intelligence in the educational process and in professional activities:

- Creating presentations (Tome, Gamma, Wepik, etc.).
- Working with text (Google Bard, chatgpt, Copilot).
- Creating videos (Myheritage, Runwayml, D-ID).
- Creating and processing images (Playground, Canva, Leonardo, etc.).

– Working with sound (Splitter, LANDR, Playbeat, etc.)

The educational process of EG students was accompanied by the use of innovative digital teaching methods, in particular, “flipped learning” technologies, interactive technologies, project-based learning, etc., which contribute to the development of critical thinking, creativity, and at the same time, they paid attention to the issues of academic integrity, copyright, and intellectual property.

Important for EG students was the issue of creating a safe, educational digital environment, which guarantees high-quality training of specialists. For this purpose, the following were held in the EG: a cycle of info-lessons "Media Literacy"; media educational challenge "Use of interactive digital tools for the formation of professional competence of the individual"; information and educational campaign "Safe Digital Space"; information cafe "Digital Applications in Professional Activities". The concept of a safe digital educational environment was considered "a systematically organized set of technical, digital, educational and methodological support for the educational process of the university".

Openness to the use of interactive digital tools and the perception of the new create all the conditions for setting students up for a constant search for digital tools and technologies that can be used in professional activities to increase their productivity and efficiency. Therefore, the process of forming professional competence from the standpoint of understanding its features of the formation of individual components and digital content requires the development of a system that will ensure the comprehensive formation of a system of professionally important qualities, skills, and knowledge, which is what the pedagogical conditions for the formation of professional competence of students proposed to EG students were aimed at.

The first pedagogical condition for the formation of professional competence of university students is the comprehensive formation of a system of professionally important qualities, knowledge, and skills for the development of digital competence, which is a component of professional competence. The outlined pedagogical condition for the formation of professional competence of students corresponds to the algorithm for the formation of digital competence of students developed by us in the process of research. It takes into account the objective need to clarify the content of professional training from the standpoint of its understanding as an integral set of special and general competencies, the list of which includes digital competence in the conditions of a higher education institution.

To ensure that students form an adaptive, flexible system of skills for using digital technologies and tools in the process of professional training, it is possible to use active learning methods.

Thus, the second pedagogical condition is the creation of a safe digital educational environment, which guarantees high-quality specialist training, because the formation of students' professional competence is possible in the process of professional training by introducing active learning methods using digital tools. The ability to use digital technologies is the result of their successful use, which indicates the expediency of introducing practical tasks into the educational process, the implementation of which will involve the use of digital technologies.

Therefore, the pedagogical conditions for the formation of professional competence of university students are the creation of a digital environment of the educational space, ensuring the comprehensive formation of a system of professionally

important qualities, knowledge, skills, and digital competence, as components of professional competence, and the use of active learning methods in the process of professional training for mastering digital tools in professional activity. The jointly developed pedagogical conditions for the formation of professional competence of university students correspond to the systemic, competency-based, personality-oriented approaches in education and ensure a comprehensive introduction of changes into the process of professional training, consistently forming students' motivation to form professional competence, creating conditions for acquiring professional knowledge about innovative technologies and digital tools and methods of their use, and using digital tools for forming a system of skills for professional activity.

EG students were offered an integrated special course "Use of interactive digital tools for the formation of professional competence of university students", developed by integrating the content of academic disciplines and allowing the formation of specialized and general professional components of professional competence.

The purpose of creating an integrated special course was to form a basic set of knowledge, skills, and abilities that cover various aspects of educational work (design, organizational, calculation, etc.); to form a holistic expanded set of professional knowledge through the integration of the content of various academic disciplines.

The results of the control experiment were obtained after the introduction of the system, special course, and pedagogical conditions aimed at the formation of students' professional competence.

We present the results of the control experiment, which were obtained after the introduction of the system, special course, and pedagogical conditions aimed at the formation of students' professional competence.

At the control stage of the experiment, changes were found in the level of formation of professional competence according to the methods that were used at the ascertaining stage of the experiment for diagnostics.

According to the data presented, there is a positive dynamics among students of the experimental group in the level of formation of knowledge according to all criteria and their indicators, which is the basis for the formation of students' professional competence.

The average general indicators of the level of knowledge of students indicate that the average and high level of knowledge have significantly increased in EG students, and in CG students we observe a slight increase.

The generalized results of the formation of professional competence in students according to all criteria are presented in Tables 4-6.

The generalized results of the formation of professional competence of university students according to the cognitive criterion at the control stage of the study are given in Table 4.

Table 4.
The generalized results of the formation of professional competence in students according to the cognitive criterion (control stage)

Levels	Experimental Group (n = 93)	Control Group (n = 95)
High	56 (60.22%)	13 (13.68%)
Medium	31 (33.33%)	37 (38.95%)
Low	6 (6.45%)	45 (47.37%)

Source: created by the authors

The generalized results of the study indicate that in EG students, the formation of professional competence according to the cognitive criterion is mainly at a high level. In CG students – we observe insignificant changes (60.22% and 13.68%, respectively), that is, EG students are characterized by a high, and CG students – by a small amount of professional knowledge and mastery of terminology, which occurred through the use of interactive digital tools in the created digital environment of the university for the formation of students' professional competence.

The generalized results of the formation of professional competence of university students at the control stage of the study according to the activity-operational criterion are given in Table 5.

Table 5.
The generalized results of the formation of professional competence in students according to the activity-operational criterion (control stage)

Levels	Experimental Group (n = 93)	Control Group (n = 95)
High	55 (59.14%)	18 (18.95%)
Medium	27 (29.03%)	26 (27.37%)
Low	11 (11.83%)	51 (53.68%)

Source: created by the authors

The generalized results of the study indicate that the formation of professional competence among EG students is significant according to the activity-operational criterion at the control stage – a high level prevails (59.14%, in contrast to the CG – 18.95%, respectively). That is, EG students, unlike CG students, are characterized by a sufficient level of skills to perform professional tasks, the development of skills in educational and content blocks of professional disciplines (the ability to solve professional tasks by creating digital applications; use elements of artificial intelligence, practical tasks of computer logic and structural theory of digital automata; use original, innovative methods and traditional and forms of work with purposeful, constant, systematic use of digital tools to form professional competence; classify problems of implementing information processes; perform a comparative analysis of various professional solutions; use the principle of program control to organize computational processes in a computer, etc.), which occurred through the use of interactive digital tools in the created digital environment of the university to form professional competence of students. The generalized results of the formation of professional competence of university students at the control stage of the study by the personal criterion are given in Table 6.

Table 6.
Generalized results of students' professional competence formation according to the personal criterion (control stage)

Levels	Experimental Group (n = 93)	Control Group (n = 95)
High	50 (53.76%)	17 (17.89%)
Medium	33 (35.48%)	27 (28.42%)
Low	10 (10.75%)	51 (53.68%)

Source: created by the authors

The generalized results of the study indicate that EG students show a high level of formation of professional competence according to the personal criterion at the control stage of the study, unlike CG (53.76% and 17.89%, respectively), that is, we can say that EG students are characterized by a high development of professionally important qualities: moral (decency, adherence to ethical rules, openness, honesty, attentiveness); digital (working with digital technologies in the digital environment of the university); communicative (overcoming barriers to communication, interaction and communication, ability to establish contact, tolerance); cognitive (creativity, memory volume and efficiency, perception, analytical skills, flexibility of thinking using digital technologies); emotional and volitional (perseverance, professional determination, responsibility, discipline, organized self-control), which occurred through the use of interactive digital tools in the created digital environment of the university to form the professional competence of students.

The differences between the experimental and control groups regarding the proportion of students who achieved a high level of professional competence after the formative experiment are presented in Figure 1.

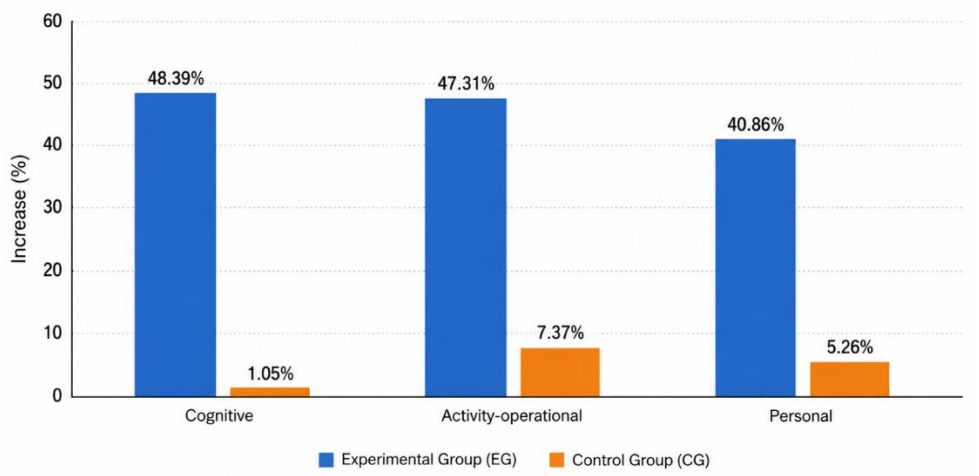


Figure 1. Increase in the proportion of students with a high level of professional competence according to the cognitive, activity-operational, and personal criteria after the formative experiment.
Source: created by the authors

As shown in Figure 1, the proportion of students with a high level of professional competence was considerably higher in the experimental group across all criteria. The greatest difference was observed for the cognitive criterion (48.39% in EG compared with 1.05% in CG), while significant improvements were also recorded for the activity-operational (47.31% vs. 7.37%) and personal (40.86% vs. 5.26%)

criteria. These results indicate the effectiveness of the implemented pedagogical conditions.

The results of the control stage demonstrate substantially greater positive dynamics in the experimental group than in the control group. According to Table 4, 60.22% of students in the experimental group achieved a high level of professional competence according to the cognitive criterion, compared with 13.68% in the control group. At the same time, the proportion of students with a low level was considerably lower in EG (6.45%) than in CG (47.37%).

A similar pattern was observed for the activity-operational criterion. A high level was demonstrated by 59.14% of EG students compared with 18.95% of CG students, while the proportion of students with a low level was 11.83% in EG and 53.68% in CG. These findings indicate that students who participated in the intervention demonstrated substantially stronger development of professional skills and abilities than students who continued their studies according to the traditional educational approach.

The same tendency was identified according to the personal criterion. The proportion of students demonstrating a high level was 53.76% in EG compared with 17.89% in CG, whereas the proportion with a low level was 10.75% and 53.68%, respectively. Thus, the experimental group demonstrated more pronounced development of professionally important moral, digital, communicative, cognitive, and emotional-volitional qualities.

The comparative results presented in Figure 1 further support this interpretation. The increase in the proportion of students achieving a high level was considerably greater in the experimental group across all three criteria: 48.39% versus 1.05% for the cognitive criterion, 47.31% versus 7.37% for the activity-operational criterion, and 40.86% versus 5.26% for the personal criterion. These differences provide empirical support for the effectiveness of the pedagogical conditions and the systematic integration of interactive digital tools implemented in the experimental group.

The control group also demonstrated some positive changes, but these were considerably smaller than those observed in the experimental group. This pattern is consistent with the study design: the experimental group received the proposed pedagogical system, author's special course, and targeted pedagogical conditions, whereas the control group continued studying according to the traditional educational approach. Therefore, the observed differences should be interpreted as evidence of the greater effectiveness of the proposed intervention for developing students' professional competence rather than as evidence of the effectiveness of the intervention in the control group.

An important limitation concerns the psychometric validation of the assessment instruments. Although questionnaires, interviews, and pedagogical observation were used to assess students' professional competence, the available dataset did not contain item-level individual responses. Therefore, internal-consistency coefficients such as Cronbach's alpha and KR-20 could not be calculated. The study consequently does not provide numerical estimates of internal consistency for the questionnaire-based measures. This limitation should be considered when interpreting the measurement results. Future research should collect and preserve item-level responses and establish the reliability and validity of the assessment instruments before conducting the main intervention study.

Conclusions

The study investigated the effectiveness of systematically integrating interactive digital tools into the process of developing university students' professional competence. The quasi-experimental study involved 188 first-year university students who were divided into an experimental group (EG; n = 93) and a control group (CG; n = 95). At the formative stage, the experimental group participated in an author's special course and was exposed to a system of pedagogical conditions based on the systematic use of interactive digital tools in the university's digital educational environment, whereas the control group continued studying according to the traditional educational approach.

The results of the ascertaining stage showed that the majority of students in both groups initially demonstrated a low level of professional competence, which confirmed the need for targeted pedagogical intervention. The assessment of professional competence was based on three criteria: cognitive, activity-operational, and personal. These criteria provided an integrated basis for evaluating students' professional knowledge, practical skills, and professionally important qualities.

The control-stage results demonstrated substantially more pronounced positive changes in the experimental group than in the control group. According to the cognitive criterion, 60.22% of EG students achieved a high level of professional competence, compared with 13.68% of CG students. According to the activity-operational criterion, the proportion of students with a high level was 59.14% in EG and 18.95% in CG. According to the personal criterion, the corresponding proportions were 53.76% and 17.89%, respectively. At the same time, the proportion of students with a low level remained considerably higher in the control group across all three criteria.

The comparative analysis presented in Figure 1 further demonstrates the greater positive dynamics observed in the experimental group. The increase in the proportion of students with a high level of professional competence was 48.39% in EG compared with 1.05% in CG for the cognitive criterion, 47.31% compared with 7.37% for the activity-operational criterion, and 40.86% compared with 5.26% for the personal criterion.

These findings indicate that the pedagogically structured integration of interactive digital tools, combined with the author's special course and the proposed pedagogical conditions, was associated with substantially greater improvements in students' professional competence in the experimental group than in the control group. The control group also demonstrated some positive changes; however, these changes were considerably smaller. Therefore, the empirical evidence supports the effectiveness of the proposed intervention for enhancing the assessed dimensions of professional competence, while the quasi-experimental design does not warrant attributing all observed changes exclusively to the intervention.

The study contributes to the empirical discussion of digital transformation in higher education by demonstrating the potential value of integrating interactive digital tools with purposeful pedagogical conditions, collaborative learning, digital communication, independent activities, and interactive assessment rather than treating digital technologies as isolated instructional resources. The findings suggest that the pedagogical organization of digital learning activities is an important factor in supporting the development of students' professional knowledge, practical skills, and professionally important qualities.

At the same time, the findings should be interpreted in light of the study's limitations. The quasi-experimental design, the absence of random individual assignment, and the use of pedagogical observation, interviews, and questionnaires limit the extent to which causal conclusions and generalizations can be made. Further research should therefore employ larger and more diverse samples, validated performance-based assessment instruments, longitudinal measurements, and, where feasible, randomized or otherwise stronger comparative designs to examine the sustainability and transferability of the observed effects.

Overall, the results indicate that systematic pedagogical integration of interactive digital tools can serve as a promising approach to supporting the development of university students' professional competence. The most pronounced improvements were observed in the experimental group across the cognitive, activity-operational, and personal criteria, providing empirical grounds for further investigation and refinement of digitally supported professional training in higher education.

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Original Article

Desarrollo de la competencia inclusiva entre estudiantes de maestría mediante una intervención pedagógica con apoyo digital

Development of Inclusive competence among master's students through a digital-supported pedagogical intervention

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Resumen

El estudio tuvo como objetivo desarrollar y evaluar experimentalmente una intervención pedagógica con apoyo digital para desarrollar la competencia inclusiva de los estudiantes durante su formación profesional. Se realizó un estudio pedagógico cuasiexperimental entre 2023 y 2025 con 174 estudiantes de maestría, incluyendo un grupo experimental (GE, n = 84) y un grupo de control (GC, n = 90). La competencia inclusiva de los estudiantes se evaluó según cuatro criterios: motivacional, cognitivo, de actividad y reflexivo, con tres niveles de formación (bajo, medio y alto). Durante la etapa formativa, el grupo experimental participó en un programa de formación inclusiva con apoyo digital que integró entornos de aprendizaje digital, herramientas digitales interactivas y adaptativas, recursos digitales especializados, tareas prácticas, casos profesionales, sesiones de capacitación, seminarios, clases magistrales, mentorías y actividades reflexivas. El grupo de control continuó su formación profesional regular sin la intervención específica. Los cambios en la distribución de los niveles de competencia se analizaron utilizando el criterio de chi-cuadrado de Pearson (χ^2). Los resultados demostraron cambios positivos en el grupo experimental en los cuatro criterios. La proporción de estudiantes con un alto nivel cognitivo aumentó del 20,24 % en la etapa inicial al 38,10 % en la etapa de control, mientras que el nivel reflexivo alto aumentó del 21,43 % al 34,52 %. El grupo experimental también mostró una reducción en la proporción de estudiantes con un nivel bajo, particularmente en el criterio cognitivo, donde disminuyó del 42,86 % al 7,14 %. Estos hallazgos indican cambios positivos en la competencia inclusiva de los estudiantes tras la implementación de la intervención pedagógica con apoyo digital.

Palabras clave: entorno educativo inclusivo; instituciones educativas; recursos web; digitalización de la educación; formación de competencias inclusivas en los estudiantes.

Abstract

The study aimed to develop and experimentally evaluate a digital-supported pedagogical intervention for developing students' inclusive competence during professional training. A quasi-experimental pedagogical study was conducted from 2023 to 2025 with 174 master's students, including an experimental group (EG, n = 84) and a control group (CG, n = 90). Students' inclusive competence was assessed according to four criteria: motivational, cognitive, activity, and reflective, with three levels of formation (low, average, and high). During the formative stage, the experimental group participated in a digital-supported inclusive training program that integrated digital learning environments, interactive and adaptive digital tools, specialized digital resources, practical tasks, professional cases, training sessions, seminars, master classes, mentoring, and reflective activities. The control group continued regular professional training without the targeted intervention. Changes in the distributions of competence levels were analyzed using Pearson's chi-square (χ^2) criterion. The results demonstrated positive changes in the experimental group across all four criteria. The proportion of students with a high cognitive level increased from 20.24% at the ascertaining stage to 38.10% at the control stage,

while the high reflective level increased from 21.43% to 34.52%. The experimental group also demonstrated a reduction in the proportion of students at the low level, particularly for the cognitive criterion, where it decreased from 42.86% to 7.14%. These findings indicate positive changes in students' inclusive competence following implementation of the digital-supported pedagogical intervention.

Keywords: inclusive educational environment; educational institutions; web resources; digitalization of education; formation of inclusive competence in students.

Introduction

Inclusive education requires higher education institutions to prepare future professionals who can respond effectively to the diverse educational needs of learners, including children with special educational needs (SEN). The quality of such preparation depends not only on students' acquisition of professional and pedagogical knowledge but also on their readiness to create accessible and supportive learning environments, interact with learners and other participants in the educational process, apply appropriate educational strategies, and critically evaluate their own professional practice. Consequently, the preparation of master's students for professional activity in inclusive educational environments has become an important component of contemporary professional education. The need for such preparation is associated with the ability of specialists to organize educational processes according to the principles of accessibility, equality, individualization, and participation.

Inclusive professional preparation is increasingly associated with tolerance, cooperation, individualized support, and innovative approaches to educational interaction. In an inclusive environment, professionals may perform multiple functions, including supporting individual educational trajectories, facilitating interaction, coordinating learning activities, and providing individualized assistance to learners. However, the acquisition of separate professional functions does not necessarily indicate that students have developed an integrated capacity to act effectively in inclusive situations. Professional readiness for inclusive practice requires the combination of appropriate attitudes and values, relevant knowledge, practical skills, and the ability to reflect on professional decisions and outcomes. Previous research has emphasized the importance of methodological, psychological, pedagogical, and professional knowledge, positive attitudes toward learners with SEN, readiness for professional interaction, and the ability to use innovative educational and digital technologies in inclusive settings (Brandon & Charlton, 2011; Čagran & Schmidt, 2011; de Boer et al., 2011; Torop et al., 2023).

At the same time, contemporary professional preparation is taking place under conditions of increasing digitalization of education. Digital technologies can provide additional opportunities to organize inclusive learning and prepare master's students for professional activity in inclusive educational environments. Digital learning environments can facilitate access to educational materials and support blended and distance learning, while interactive and adaptive tools can provide opportunities for practice, feedback, and individualized learning. Specialized digital resources, including assistive and augmentative and alternative communication technologies, screen readers, voice-recording tools, and other software, can help students become familiar with technological means that support access to learning for individuals with SEN (Shi et al., 2025). Integrating digital and traditional educational approaches can also create opportunities for case analysis, simulations of professional situations, collaborative learning, training, workshops, and reflective activities. Thus, digitalization should not be understood merely as introducing

technological tools into teaching; rather, its educational value depends on how digital resources are integrated into professional tasks and used to develop specific professional competencies.

The literature also emphasizes the importance of combining digital learning environments with active and collaborative forms of professional preparation. Online platforms can support access to instructional content and communication, whereas case-based learning, role-playing, practical training, workshops, and reflective activities can provide opportunities to apply professional knowledge and analyze complex situations in inclusive education (Balchin & Bouzaki, 2022). The development of flexibility and collaboration with colleagues, learners, and parents is also considered important for professional activity in inclusive environments (Attachoo & Imsa-Ard, 2024). Professional training in higher education, therefore, represents an important context in which students acquire knowledge, develop professional orientations, gain initial practical experience, and build readiness for inclusive interaction (Zarceño García de Soriano et al., 2024).

Nevertheless, the existing literature and professional-training approaches do not fully explain how digital technologies can be incorporated into a structured pedagogical intervention aimed specifically at the multidimensional development of inclusive competence. A particular difficulty is that inclusive competence cannot be reduced to technological proficiency or knowledge of inclusive education alone. Effective preparation requires the simultaneous development of students' motivation and professional orientations, their knowledge and understanding, their ability to apply knowledge in practical situations, and their capacity for professional reflection. Therefore, a pedagogical intervention should address these dimensions in an integrated manner rather than treating digital competence and inclusive competence as separate educational outcomes.

In the present study, inclusive competence is conceptualized through four interrelated dimensions: **motivational, cognitive, activity, and reflective**. The motivational dimension concerns students' professional orientations, willingness to work in an inclusive environment, commitment to creating barrier-free learning conditions, and motivation for professional development. The cognitive dimension concerns knowledge and understanding of inclusive education, relevant digital technologies, and specialized resources. The activity dimension concerns students' ability to apply acquired knowledge, pedagogical methods, and digital tools to practical professional situations in an inclusive educational environment. The reflective dimension concerns the ability to analyze one's own professional actions and learning experiences, identify difficulties, evaluate the results of professional activity, and determine directions for further development. This conceptualization corresponds directly to the assessment framework subsequently used in the empirical part of the study. The four criteria were operationalized through specific indicators and assessed at low, average, and high levels.

The initial diagnostic results obtained in the present study indicate that the participating master's students demonstrated considerable room for development across these dimensions. At the ascertaining stage, the experimental group included substantial proportions of students at the low level: 32.14% according to the motivational criterion, 42.86% according to the cognitive criterion, 35.71% according to the activity criterion, and 47.62% according to the reflective criterion. At the same time, the high level was demonstrated by only 28.57% of students for the motivational criterion, 20.24% for the cognitive criterion, 23.81% for the activity criterion, and 21.43% for the reflective criterion. These baseline findings indicate that

the challenge addressed in the study concerned not only the acquisition of knowledge about inclusive education but also the development of professional motivation, practical application, and reflective capacity.

A digitally supported pedagogical intervention may provide an appropriate means of addressing these interconnected dimensions when digital resources are incorporated into meaningful professional-learning activities. In particular, digital learning environments can support access to instructional materials and independent learning, interactive tools can provide opportunities for practice and feedback, and adaptive and specialized resources can expose students to technological solutions relevant to learners with SEN. Practical digital tasks and professional cases can support the activity dimension by requiring students to apply knowledge to realistic inclusive-education situations. Collaborative online activities can support communication and professional interaction, while digital assessment and reflective activities can provide opportunities for students to evaluate their own learning and professional decisions. Accordingly, the potential contribution of digitalization lies not in the number of platforms or applications used, but in their purposeful integration into pedagogical activities directed toward specific dimensions of inclusive competence.

This consideration also identifies the research gap addressed by the present study. Although previous research has examined professional readiness for inclusive education, digital learning, specialized technologies, and innovative approaches to professional preparation, there is insufficient empirical evidence on a structured digital-supported pedagogical intervention that simultaneously targets the motivational, cognitive, activity, and reflective dimensions of inclusive competence among master's students. The present study therefore focuses not simply on the use of digital technologies in professional education, but on their purposeful integration into a pedagogical intervention designed to develop a multidimensional form of inclusive competence.

Accordingly**, the study aimed** to develop and experimentally evaluate a digital-supported pedagogical intervention for developing students' inclusive competence during professional training. To achieve this aim, the study examined changes in students' inclusive competence according to the motivational, cognitive, activity, and reflective criteria and compared the distributions of competence levels between the experimental and control groups following the formative intervention.

Literature Review

Inclusive competence as a multidimensional construct

Inclusive competence is increasingly understood as a multidimensional characteristic of professional readiness to work with learners with diverse educational needs. It cannot be reduced to knowledge of inclusive education or to a general positive attitude toward learners with special educational needs (SEN). Professional preparation for inclusive practice requires the integration of professional knowledge, value orientations, practical abilities, interpersonal readiness, and the capacity to evaluate and improve professional actions. This broader understanding is reflected in research examining teachers' preparedness, attitudes, professional knowledge, and competencies for inclusive education.

Brandon and Charlton (2011) emphasize the importance of developing an inclusive learning and teaching community of practice, highlighting the need for professionals to possess knowledge and skills that support inclusive educational interaction.

De Boer et al. (2011), in their review of teachers' attitudes toward inclusive education, demonstrate the importance of attitudes as an essential component of readiness for inclusive practice. Čagran and Schmidt (2011) similarly conceptualize readiness to work with learners with SEN through personal, psychological, and professional dimensions, including knowledge of special pedagogy and psychology, information readiness, professional interaction, and consideration of learners' individual characteristics. Torop et al. (2023) further emphasize emotional acceptance, satisfaction with professional activity, and readiness to involve learners with developmental disabilities in educational activities.

Taken together, these studies suggest that inclusive professional competence encompasses several mutually related domains. Knowledge provides the cognitive basis for professional decisions; attitudes and values determine the orientation toward inclusive practice; practical abilities enable the application of knowledge in educational situations; and reflection allows professionals to evaluate their actions and identify directions for further development. On this basis, the present study operationalizes inclusive competence through four interrelated criteria: motivational, cognitive, activity, and reflective.

Motivational dimension of inclusive competence

The motivational dimension refers to the professional orientations, values, attitudes, and willingness that support inclusive educational practice. A professional may possess knowledge about inclusive education but remain insufficiently prepared for inclusive practice if this knowledge is not accompanied by acceptance of learner diversity, willingness to create accessible learning conditions, and motivation for professional development.

The literature reviewed in the manuscript provides several grounds for considering motivation and attitudes as an essential part of inclusive competence. De Boer et al. (2011) specifically address teachers' attitudes toward inclusive education, while Čagran and Schmidt (2011) relate professional readiness to personal and psychological dimensions. Torop et al. (2023) emphasize emotional acceptance of learners with different developmental characteristics and readiness to involve them in educational activities. These findings support the interpretation of the motivational dimension as more than a general interest in inclusive education: it concerns students' willingness to assume responsibility for inclusive professional activity and to develop their competence further.

In the present study, the motivational criterion therefore includes students' motivation to create a barrier-free learning environment, willingness to use digital technologies in professional activity, orientation toward inclusive professional preparation, and motivation for professional self-development. This operationalization connects the literature on attitudes and professional readiness with the motivational component measured in the experiment.

Cognitive dimension of inclusive competence

The cognitive dimension represents the knowledge base required for understanding and organizing inclusive educational processes. Inclusive practice requires knowledge of learners' individual characteristics, inclusive pedagogy, special education and psychology, appropriate educational strategies, and technologies that can support participation and access to learning.

Brandon and Charlton (2011) emphasize the importance of appropriate methodological, psychological, pedagogical, and subject knowledge for work in inclusive educational environments. Čagran and Schmidt (2011) similarly identify knowledge of special pedagogy and psychology, individual differences, and information readiness among the components of professional readiness for working with learners with SEN. Sobchenko et al. (2021) also focus on the preparation of future teachers to organize educational processes under conditions of inclusion, emphasizing the need to incorporate appropriate approaches into professional training.

The cognitive dimension is also increasingly connected with digital knowledge. Students preparing for inclusive professional activity need to understand not only inclusive pedagogical principles but also the potential and limitations of digital resources that can facilitate access to educational materials and communication. Shi et al. (2025) emphasize the role of specialized software, voice recorders, screen readers, and other technologies that support learners with special needs and facilitate access to educational materials. Thus, digital knowledge can be considered part of the contemporary cognitive basis of inclusive competence when it is directly related to professional tasks.

In the present study, the cognitive criterion consequently covers knowledge of information and communication tools, digital technologies, specialized software, and the principles of organizing professional preparation for inclusive education.

Activity dimension of inclusive competence

The activity dimension concerns the transition from knowing about inclusion to being able to implement inclusive approaches in professional situations. Knowledge and positive attitudes alone do not ensure effective practice; students must be able to select appropriate methods, organize accessible learning conditions, use relevant technologies, communicate with participants in the educational process, and solve professional problems.

Attachoo and Imsa-Ard (2024) emphasize flexibility, collaboration with colleagues, learners, and parents, and the ability to combine group and individual forms of work as important aspects of professional readiness for inclusive environments. The literature reviewed in the manuscript also identifies practical and active forms of preparation, including case-based learning, role-playing, training, workshops, projects, and pedagogical practice in inclusive educational settings. These approaches provide opportunities for students to transfer theoretical knowledge into professional action.

Digital technologies can strengthen this practical dimension when they are used as tools for solving professional tasks rather than merely as objects of technological instruction. Interactive and adaptive resources can provide opportunities for practice and feedback, while specialized technologies can allow students to model or analyze situations involving learners with SEN. Balchin and Bouzaki (2022) discuss the use of instructional technologies to respond to individual learner differences, supporting the relevance of digitally mediated activities for differentiated and inclusive learning.

Accordingly, the activity criterion in the present study focuses on students' ability to use digital technologies to solve professional tasks, create barrier-free learning conditions, apply digital resources in inclusive educational settings, and interpret information for professionally appropriate decisions.

Reflective dimension of inclusive competence

The reflective dimension represents the ability to evaluate one's own professional actions, identify difficulties, interpret learning outcomes, and determine directions for further professional development. Reflection is particularly important in inclusive education because professional decisions must respond to individual learner characteristics and may require continuous adjustment of pedagogical strategies.

The literature already included in the manuscript provides a basis for connecting reflection with inclusive professional preparation. De Boer et al. (2011), as discussed in the manuscript, emphasize the importance of value-semantic development and reflection on morally significant situations in teacher preparation. The existing literature review also identifies reflective practices, coaching, and supervision among approaches that can be incorporated into professional preparation for inclusive environments.

Digital learning environments can create additional opportunities for reflection through self-assessment, feedback, analysis of professional cases, documentation of learning progress, and collaborative discussion. However, the educational value of these technologies depends on how they are integrated into pedagogical tasks. Digitalization should therefore be considered a means of supporting reflective professional learning rather than an independent indicator of reflective competence. In the present study, the reflective criterion concerns students' ability to analyze the results of their professional activity using digital technologies, evaluate their readiness to create inclusive learning conditions, assess their use of digital technologies in inclusive practice, and identify directions for further development of inclusive competence.

Digital-supported development of inclusive competence

The four dimensions are interrelated and should not be treated as isolated outcomes. Motivation creates the orientation toward inclusive professional activity; cognitive competence provides the knowledge base; activity competence enables the application of knowledge in professional situations; and reflection allows students to evaluate and improve their practice. A pedagogical intervention aimed at developing inclusive competence should therefore provide learning experiences that address these dimensions in combination.

The literature indicates several ways in which digital technologies can support such an integrated approach. Online and blended learning environments can provide access to educational materials and facilitate flexible learning. Specialized technologies can support accessibility and familiarize students with resources relevant to learners with SEN. Interactive tools can provide opportunities for practice and feedback, while case-based activities, role-playing, training, workshops, collaborative projects, and reflective practices can connect theoretical knowledge with professional action.

Zarceño García de Soriano et al. (2024) specifically address digital teaching competence and educational inclusion in higher education, while Shi et al. (2025) examine digital pedagogy for inclusive education and its relationship with teacher competence and self-efficacy. These studies support the relevance of digital pedagogy to inclusive professional preparation, but they do not by themselves establish the four-component model used in the present study. The present research therefore combines the established literature on attitudes, knowledge, professional

readiness, practical competence, reflection, and digital pedagogy into an empirical framework for examining changes in students' inclusive competence.

Research gap

The reviewed literature demonstrates that inclusive professional preparation involves attitudes and values, knowledge, practical readiness, and reflective development, while recent research also highlights the growing role of digital technologies in inclusive education and professional learning. However, these strands of research are rarely integrated into a single empirical framework in which inclusive competence is operationalized simultaneously through motivational, cognitive, activity, and reflective criteria and evaluated before and after a structured digital-supported pedagogical intervention.

This gap provides the rationale for the present study. Rather than examining the use of individual digital platforms or digital competence as an independent outcome, the study investigates whether a structured digital-supported pedagogical intervention can contribute to positive changes in the four dimensions of students' inclusive competence during professional training.

Methodology

Research Design

The study employed a quasi-experimental research design to investigate the effectiveness of a system of professional training, innovative digital approaches, and pedagogical conditions aimed at developing students' inclusive competence and preparing master's students for professional activity in inclusive educational environments.

The study was based on the assumption that the purposeful implementation of a developed training system, innovative digital approaches, and substantiated pedagogical conditions into the professional training process would contribute to the development of students' inclusive competence.

The pedagogical experiment was conducted from 2023 to 2025 and consisted of three consecutive stages: ascertaining, formative, and control.

Participants

The study employed a quasi-experimental design and was conducted from 2023 to 2025 with 174 students enrolled at the second (master's) level of higher education. The participants were divided into an experimental group (EG; n = 84) and a control group (CG; n = 90). The groups corresponded to intact academic groups within the existing organization of the educational process rather than being formed through individual randomization.

At the beginning of the study, the experimental and control groups were considered comparable with respect to the characteristics available within the existing educational organization. In forming the groups, the researchers took into account the quantitative composition of academic groups, students' educational achievement, level of digital skills, characteristics of professional training, and similarity of the educational conditions. These characteristics were considered at the group-formation stage to avoid substantial initial differences between the groups. The groups were not individually randomized because their formation was based on

existing academic-group structures. Therefore, the study is interpreted as quasi-experimental rather than randomized controlled research.

The term “maximum homogeneity” used in the earlier version of the manuscript should not be interpreted as evidence of statistical matching or random allocation. It refers to the effort to maintain comparable educational and organizational conditions between the experimental and control groups. Because the manuscript does not contain separate baseline numerical measures for each of the characteristics used during group formation, no claim is made that the groups were statistically matched on these variables.

The participants were 174 master’s students enrolled in education-, psychology-, and social-work-related programmes at three Ukrainian higher education institutions: Bohdan Khmelnytskyi National University at Cherkasy, Oleksandr Dovzhenko Hlukhiv National Pedagogical University, and Lesya Ukrainka Volyn National University.

Assessment Criteria

The level of students’ inclusive competence was assessed according to four theoretically differentiated and empirically non-overlapping criteria: motivational, cognitive, activity, and reflective. The criteria were distinguished according to the primary function represented by each construct: motivational – dispositions and professional orientations; cognitive – knowledge and understanding; activity – practical application; and reflective – analysis, self-evaluation, and self-regulation. Digital technologies were treated as contextual and instrumental resources rather than as independent indicators of all four criteria. Thus, the same technological skill was not counted simultaneously as evidence of different dimensions.

The motivational criterion reflected students’ dispositions, values, attitudes, and professional orientations toward inclusive education and future professional activity in an inclusive environment. Its indicators included: (1) willingness to create a barrier-free and supportive learning environment; (2) positive value-based attitudes toward the inclusion of learners with special educational needs; (3) willingness to engage in professional activity in inclusive settings; and (4) orientation toward professional responsibility for supporting learners with diverse educational needs. These indicators characterize why students are willing to engage in inclusive professional activity rather than what they know or how they perform particular professional tasks.

The cognitive criterion reflected students’ knowledge and understanding of inclusive education and the principles underlying professional activity in an inclusive environment. Its indicators included: (1) knowledge of the principles and concepts of inclusive education; (2) understanding of the psychological and pedagogical characteristics of learners with special educational needs; (3) knowledge of appropriate pedagogical approaches and methods for organizing inclusive learning; and (4) knowledge of digital and specialized technologies relevant to inclusive education. The cognitive criterion therefore measured what students knew and understood, rather than their motivation to use this knowledge or their ability to apply it in practice.

The activity criterion reflected students’ ability to translate knowledge into practical professional action. Its indicators included: (1) ability to apply inclusive pedagogical methods in practical situations; (2) ability to organize barrier-free and supportive

learning conditions; (3) ability to select and appropriately use digital and specialized resources to solve specific professional tasks; and (4) ability to make professionally appropriate decisions when responding to practical situations involving learners with special educational needs. Digital technologies were therefore included in this criterion only insofar as students demonstrated their **practical application** in professional tasks.

The reflective criterion reflected students' ability to analyze, evaluate, and regulate their own professional activity and learning. Its indicators included: (1) ability to analyze the results of one's own professional actions; (2) ability to identify difficulties and limitations in one's own practice; (3) ability to evaluate the appropriateness and effectiveness of selected professional approaches; and (4) ability to determine specific directions for further professional development and self-regulation. Digital tools could be used as means of supporting reflection, such as through self-assessment, feedback, or analysis of professional cases, but the criterion measured the **reflective process itself**, rather than the use of technology.

The four criteria were interpreted as complementary but conceptually distinct dimensions of inclusive competence. The motivational criterion addressed students' professional dispositions and orientations; the cognitive criterion addressed knowledge and understanding; the activity criterion addressed the practical application of knowledge and methods; and the reflective criterion addressed analysis, self-evaluation, and self-regulation. This distinction provided the basis for assessing changes in the four dimensions at the ascertaining and control stages of the pedagogical experiment.

Based on these criteria and their indicators, three levels of inclusive competence formation were distinguished: low, average, and high. The levels reflected the degree to which the respective motivational orientations, cognitive knowledge, practical abilities, and reflective processes had been developed.

The digital-supported intervention was designed to address the four dimensions through differentiated learning activities. Knowledge-oriented activities targeted the cognitive dimension; practical professional tasks supported the activity dimension; value-oriented and professionally contextualized activities addressed the motivational dimension; and self-assessment, feedback, case analysis, and professional reflection addressed the reflective dimension. Digital technologies functioned as instructional and professional resources whose role differed according to the learning task rather than constituting a separate indicator across all four criteria.

Experimental Procedure

The pedagogical experiment was conducted from 2023 to 2025 and comprised three consecutive stages: ascertaining, formative, and control. The experimental procedure was designed to examine changes in students' inclusive competence following the implementation of a structured digital-supported inclusive professional training programme. Inclusive competence was assessed according to four conceptually differentiated criteria: motivational, cognitive, activity, and reflective.

At the ascertaining stage, the initial level of students' inclusive competence was established using the diagnostic procedures described in the Assessment Framework. The same diagnostic framework was subsequently used at the control stage to enable comparison of the distributions of competence levels before and after the formative intervention. At this stage, the experimental group (EG; n = 84)

and control group (CG; n = 90) were identified within the existing organization of the educational process. Individual randomization was not used; therefore, the study was treated as quasi-experimental.

The formative stage constituted the intervention phase. It was implemented only in the experimental group and was integrated into students' regular professional training. The intervention was designed as a digital-supported inclusive professional training programme rather than as separate instruction in the use of digital platforms. Its central principle was the purposeful integration of selected digital resources into professional learning tasks related to inclusive education. The control group continued its regular professional training without the targeted implementation of this programme.

The formative intervention combined theoretical preparation, practical professional tasks, interactive learning, case analysis, master classes, training sessions, seminars, blended and distance-learning activities, mentoring, and reflective tasks. These activities were organized around authentic or professionally oriented problems of inclusive education. Students were expected not only to acquire information about inclusive education but also to analyse professional situations, select appropriate pedagogical approaches and digital resources, complete practical assignments, discuss possible solutions, and reflect on their own learning and professional decisions.

The digital component was deliberately limited to resources that served identifiable pedagogical functions within these activities. Moodle and Google Classroom were used as learning environments for access to instructional materials, methodological resources, assignments, and feedback. LearningApps was used for interactive exercises and practice. Quizizz and Kahoot were used for formative assessment and consolidation of learning content, while Mentimeter supported interactive responses and discussion during learning activities. Canva, Prezi, and ThingLink were used for the development and presentation of digital educational materials. Notion and Trello were used to organize and monitor individual and collaborative professional tasks. In addition, students were introduced to augmentative and alternative communication (AAC) programmes, adaptive learning resources, sensory games, and specialized software relevant to supporting learners with special educational needs.

The pedagogical function of the digital resources differed according to the learning task. Learning environments primarily supported access to knowledge and independent learning; interactive tools supported practice and formative feedback; digital authoring tools supported the development of professional educational materials; organizational tools supported planning and self-regulation; and specialized resources provided opportunities to examine technological solutions relevant to learners with special educational needs. Thus, digital technologies were treated as instructional and professional resources rather than as independent outcomes of the intervention.

The intervention was aligned with the four assessed dimensions of inclusive competence. Cognitive-oriented activities focused on the acquisition and consolidation of knowledge about inclusive education, learners with special educational needs, inclusive pedagogical approaches, and relevant digital and specialized technologies. Activity-oriented tasks required students to apply this knowledge to professional cases, develop inclusive educational materials, select appropriate digital resources, and solve practical problems. Motivational activities

addressed students' professional orientations, attitudes toward inclusion, willingness to work in inclusive environments, and understanding of professional responsibility. Reflective activities involved self-assessment, analysis of completed professional tasks, discussion of difficulties, feedback, and identification of directions for further professional development.

The correspondence between the digital resources, learning activities, and assessed dimensions is presented in Table 1.

Table 1.
Digital resources, pedagogical functions, learning activities, and targeted dimensions of inclusive competence

Digital resource / resource group	Pedagogical function in the intervention	Learning activities completed by students	Primary dimension targeted
Moodle	Asynchronous access to instructional content and assignments	Study materials on inclusive education; complete individual assignments; submit professional tasks	Cognitive
Google Classroom	Blended learning, distribution of materials and feedback	Access learning materials; complete and revise professional assignments; receive feedback	Cognitive/ Activity
LearningApps	Interactive practice and consolidation	Complete interactive exercises on inclusive concepts and professional situations	Cognitive/ Activity
Quizizz, Kahoot	Formative assessment and immediate feedback	Complete quizzes following instructional units and practical activities; identify knowledge gaps	Cognitive
Mentimeter	Interactive response, discussion and feedback	Respond to questions; discuss professional situations; express and compare viewpoints	Motivational/ Reflective
Canva, Prezi, ThingLink	Development and presentation of digital educational materials	Create presentations, visual materials and interactive resources addressing inclusive-education tasks	Activity
Notion, Trello	Organization and monitoring of learning/professional tasks	Plan individual or collaborative tasks; monitor progress; organize project activities	Activity/ Reflective
AAC programmes and specialized software	Familiarization with assistive and specialized technologies	Examine functions and educational applications; analyse their suitability for specified professional situations	Cognitive/ Activity
Adaptive learning resources and sensory games	Demonstration of individualized and accessible learning possibilities	Analyse possible applications for learners with different educational needs; discuss appropriate adaptations	Cognitive/ Activity
Digital learning resources integrated into professional cases	Connecting digital tools with inclusive professional decision-making	Analyse cases, select appropriate resources, justify pedagogical choices, discuss possible solutions	Activity/ Reflective

The intervention therefore followed a task-oriented rather than platform-oriented approach. Students did not receive training simply in how to operate a particular application. Instead, they encountered an inclusive-education problem or professional task and used an appropriate digital resource as part of its solution. For example, learning-environment resources were used to study theoretical and methodological content; interactive applications were used to practise and consolidate concepts; digital authoring tools were used to create materials for

inclusive learning; and specialized resources were examined in relation to the educational needs of learners requiring additional or alternative forms of support.

The intervention also incorporated mentoring and participation in professional communities, during which students analysed complex professional cases, exchanged experiences, discussed possible solutions, and considered contemporary digital approaches to inclusive education. The existing manuscript identifies master classes, training sessions, seminars, blended and distance-learning activities, mentoring, and professional case analysis as components of the experimental training. These activities were retained as intervention components because they are described as part of the training actually provided to the experimental group, whereas broader recommendations concerning international internships, additional qualifications, orthopsychopedagogy, autology, and rehabilitation were not treated as components of the evaluated intervention.

The distinction between intervention activities and general recommendations was maintained to ensure that the treatment evaluated in the experiment could be clearly identified. In particular, international internships and additional qualifications were not considered intervention components because the available study description does not document their implementation, duration, or completion by the participants. The control group continued its regular professional preparation under the educational conditions established by the participating institutions. Students in the control group did not receive the targeted combination of inclusive professional training activities and digital-supported tasks implemented in the experimental group.

At the control stage, participants were reassessed using the same criteria, indicators, and diagnostic procedures applied at the ascertaining stage. The resulting distributions of low, average, and high levels were compared between the experimental and control groups. This procedure enabled examination of changes in the motivational, cognitive, activity, and reflective dimensions of inclusive competence following the formative intervention.

Data Analysis

The collected data were analyzed using descriptive and inferential statistical procedures. Descriptive analysis was used to summarize the distribution of students across the low, average, and high levels of inclusive competence for the motivational, cognitive, activity, and reflective criteria at the ascertaining and control stages.

At the ascertaining stage, Pearson’s chi-square test of independence was used to examine whether the experimental and control groups differed in the distribution of competence levels before the intervention. At the control stage, the same test was used to compare the distributions of competence levels between the experimental and control groups after completion of the formative intervention. For these between-group comparisons, the observations were independent because the experimental and control groups consisted of different students.

Because the same participants were assessed at the ascertaining and control stages, the pretest–posttest observations within each group were treated as dependent. Accordingly, the observed changes in the experimental group between the two stages were interpreted descriptively and were not tested using a Pearson

chi-square test of independence. The statistical significance of intervention-related between-group differences was evaluated at α = .05.

For each statistically significant between-group comparison, Cramer's V was calculated to quantify the magnitude of the association between group membership and competence level. The null hypothesis (H_0) stated that the distribution of competence levels did not differ between the experimental and control groups at the corresponding assessment stage. The alternative hypothesis (H_1) stated that the distributions differed significantly between the groups.

The results were interpreted in conjunction with the baseline comparisons and the descriptive changes observed between the ascertaining and control stages. Given the quasi-experimental design and the absence of individual randomization, statistically significant between-group differences were interpreted as evidence consistent with an intervention-related effect rather than as definitive causal proof.

Ethical Considerations

The study was conducted in accordance with the ethical principles applicable to educational research. Participation in the study was voluntary, and all participants were informed about the purpose, procedures, and stages of the research before taking part in the experiment. Informed consent was obtained from the participants. The anonymity and confidentiality of the participants were maintained throughout the research process, and the collected data were used exclusively for scientific purposes. Participants were informed of their right to withdraw from the study at any stage without any negative consequences.

Results and Discussion

Substantiation of the content of the concepts of "Inclusion" and "Inclusive educational environment of an educational institution". The purpose of an inclusive educational environment. The essence of preparation for work in an inclusive educational environment and the formation of professional qualities in master's students preparing for professional activity in inclusive educational environments.

Inclusion is a contemporary educational challenge associated with the need to provide children with special educational needs with equal access to quality education in a supportive environment. This requires highly qualified specialists with strong professional competencies, positive motivational orientations, and a humane, individualized approach (Ahsan et al., 2013).

We define an inclusive educational environment as a system of conditions, resources, methods, and approaches that ensures equal access to quality education regardless of students' abilities or individual characteristics. It includes adaptation of the educational process through differentiated and digital technologies, barrier-free physical, social, and communication access, pedagogical support, development of tolerance, and cooperation with parents (Vantieghem et al., 2023).

Preparing master's students for professional activity in inclusive educational environments requires digital and innovative approaches that develop professional competencies, emotional intelligence, creative thinking, and the ability to adapt instruction to individual needs (Altınpulluk & Kesım, 2021). It also involves developing respect for each child, professional responsibility, awareness of

individual developmental needs, the ability to implement corrective measures, and comprehensive knowledge of inclusive education (Tzafilkou et al., 2023).

The main models of organizing education for children in an inclusive environment. Cooperation in this area with state institutions and public organizations. Involvement in the informal education of master's students preparing for professional activity in inclusive educational environments, including online courses and digital learning opportunities.

Three main approaches have been identified in the organization of education for learners with special educational needs: one-track, two-track, and multi-track. In the one-track approach, most learners with special educational needs are educated within mainstream educational settings. The two-track approach is characterized by two separate systems, with mainstream education operating alongside specialized educational provision. The multi-track approach combines elements of mainstream and specialized provision, allowing different educational arrangements according to learners' needs and the organization of the national education system (Brussino, 2020).

Effective inclusive education also requires multidisciplinary psychological and pedagogical support involving teachers, teacher assistants, psychologists, speech therapists, social educators, and other specialists. Therefore, master's students should develop teamwork skills, including joint planning, coordination of decisions, and distribution of responsibilities, which contribute to comprehensive support for children with special educational needs (Altemueller & Lindquist, 2017).

Professional preparation should also incorporate informal and digital learning. Students need experience with online learning platforms, synchronous and asynchronous communication, and digital tools for interaction with students and parents (Montenegro-Rueda & Fernández-Batanero, 2022). Assistive technologies, including screen readers, voice recorders, and specialized software, are particularly important for ensuring accessibility to educational materials (Shi et al., 2025).

A combination of digital and traditional approaches–including Moodle and Google Classroom, VR/AR, online courses, case studies, role-playing, practical training, workshops, collaborative projects, reflective practices, and volunteer activities–can support the development of practical skills for inclusive education (Balchin & Bouzaki, 2022). At the same time, effective work in an inclusive environment requires flexibility, collaboration, and the ability to combine individual and group forms of learning (Attachoo & Imsa-Ard, 2024).

Thus, professional training in higher education is a key factor in developing inclusive competence by integrating professional knowledge, motivational orientations, and practical experience. Its systematic and coherent organization creates conditions for the professional development of master's students and their readiness for professional activity in inclusive educational environments (Zarceño García de Soriano et al., 2024).

Experimental verification of the developed system, innovative digital approaches, developed pedagogical conditions for the formation of inclusive competence in students, their professional skills, and effective work in a modern inclusive environment.

To ensure the reliability of the results and the objectivity of the pedagogical experiment, an experimental group (EG) and a control group (CG) were formed at the ascertaining stage of the experiment, taking into account the quantitative composition of academic groups among applicants for the second (master's) level of higher education. EG – 84 people and CG – 90 people.

The experimental and control groups were formed from existing academic groups with the aim of maintaining comparable educational and organizational conditions. The researchers considered students' educational achievement, digital skills, characteristics of professional training, and the organization of the educational process when establishing the groups.

The features of the actual filling of academic groups explain the slight difference in the quantitative composition of the research groups in different years, as well as the need to maintain integrity in the formed educational teams. This approach allowed us to ensure the conditions for experimenting and avoid disruption of the organization of the educational process in higher education.

The groups were formed from existing academic groups under comparable organizational and pedagogical conditions. Because individual randomization was not used, the study was treated as quasi-experimental, and the findings are interpreted with consideration of this design limitation.

Each level of inclusive competence was characterized by the degree of development of the motivational, cognitive, activity, and reflective dimensions.

During the formative stage, the experimental group participated in the digital-supported inclusive training program developed for the study. The intervention was integrated into students' professional training and was implemented through blended and distance-learning activities, interactive digital tasks, practical cases, training sessions, seminars, master classes, mentoring, and professional case discussions. The intervention incorporated digital learning environments, interactive and adaptive digital resources, augmentative and alternative communication software, sensory games, and specialized software relevant to inclusive education. These resources were not used as independent technological activities; rather, they were embedded in professional learning tasks designed to develop students' knowledge, motivation, practical skills, and reflective abilities related to inclusive education.

The intervention was explicitly aligned with the four assessment dimensions. Activities targeting the motivational dimension focused on students' attitudes, values, and willingness to work in inclusive environments. Activities targeting the cognitive dimension developed knowledge of inclusive education, digital technologies, and specialized resources. Practical assignments addressed the activity dimension by requiring students to apply inclusive methods and digital tools to professional situations. Reflective activities required students to analyze their decisions, evaluate their learning experience, and identify areas for professional improvement.

The control group continued its regular professional training and did not receive the targeted digital-supported intervention. At the control stage, both groups were

assessed using the same criteria and diagnostic procedures as at the ascertaining stage.

Repeated diagnostics of the levels of formation of inclusive competence of students was carried out at the control stage of the experiment, the analysis of the obtained empirical data was carried out, their processing was carried out in accordance with the identified criteria and specified indicators; the results of the experimental group and the control group were compared, the dynamics of changes in the indicators of inclusive competence of students were analyzed, and the effectiveness of the system and pedagogical conditions implemented in the process of experimental work was assessed.

Results of the ascertaining stage of the experiment.

Master's students completed the questionnaires in their respective academic groups. This process allowed for a more detailed analysis of the level of formation of inclusive competence in students, their professional skills, and effective work in a modern inclusive environment during professional training.

We summarized the data at the ascertaining stage of the study on the distribution of students by different levels and criteria of formation of inclusive competence by motivational, cognitive, activity, and reflective criteria, which are presented in Table 2.

Table 2.
Distribution of participants by levels of inclusive competence at the ascertaining stage and baseline comparison between the experimental and control groups

Criterion	Level	EG (n = 84)	CG (n = 90)
Motivational	Low	27 (32.14%)	28 (31.11%)
	Average	33 (39.29%)	34 (37.78%)
	High	24 (28.57%)	28 (31.11%)
	Pearson's χ^2 (df = 2), p	0.134, .935	
Cognitive	Low	36 (42.86%)	38 (42.22%)
	Average	31 (36.90%)	31 (34.44%)
	High	17 (20.24%)	21 (23.33%)
	Pearson's χ^2 (df = 2), p	0.269, .874	
Activity	Low	30 (35.71%)	29 (32.22%)
	Average	34 (40.48%)	39 (43.33%)
	High	20 (23.81%)	22 (24.44%)
	Pearson's χ^2 (df = 2), p	0.248, .883	
Reflective	Low	40 (47.62%)	44 (48.89%)
	Average	26 (30.95%)	25 (27.78%)
	High	18 (21.43%)	21 (23.33%)
	Pearson's χ^2 (df = 2), p	0.234, .889	

Baseline comparability of the experimental and control groups. Table 1 presents the distribution of students across the low, average, and high levels of inclusive competence at the ascertaining stage. The distributions were relatively similar across the four criteria. For example, the proportion of students with a low cognitive level was 42.86% in the experimental group and 42.22% in the control group, while the corresponding proportions for the reflective criterion were 47.62% and 48.89%, respectively.

Pearson's chi-square tests confirmed that there were no statistically significant baseline differences between the experimental and control groups. For the motivational criterion, $\chi^2(2) = 0.134$, $p = .935$; for the cognitive criterion, $\chi^2(2) = 0.269$,

p = .874; for the activity criterion, $\chi^2(2) = 0.248$, p = .883; and for the reflective criterion, $\chi^2(2) = 0.234$, p = .889. Thus, the distributions of students across the three competence levels did not differ significantly between the groups before the formative intervention. These findings provide empirical support for the baseline comparability of the groups and establish an appropriate basis for subsequent analysis of changes following the intervention.

The results of the ascertaining stage revealed a predominance of low and average levels of inclusive competence across the motivational, cognitive, activity, and reflective criteria, indicating the need for a comprehensive approach to improving students' professional preparation. Accordingly, the developed training system incorporated innovative digital approaches and pedagogical conditions aimed at strengthening inclusive competence and professional skills.

The preparation of students in the experimental group (EG) included theoretical and practice-oriented training, additional qualifications, master classes, seminars, blended and distance learning, mentoring, and participation in professional communities. Particular attention was given to digital technologies, including augmentative and alternative communication tools, adaptive learning platforms, sensory games, and specialized software. These resources were combined with emotional-intelligence development, Universal Design for Learning, art therapy, project-based and differentiated learning to support the individualization of professional training.

The training system also emphasized practical experience, analysis of professional cases, exchange of experience, and discussion of contemporary digital methods. Thus, preparation for inclusive education was organized as a multidimensional process integrating theoretical knowledge, practical skills, digital competence, and inclusive professional values.

The organization of an inclusive educational environment was guided by the principles of educational accessibility, individual planning and reasonable accommodation, adaptation of curricula and teaching methods, and additional support according to children's educational needs. It also emphasized equality, justice, respect for individual differences, continuous improvement of educational practices, humanization, safety, empathy, and acceptance of each child as an individual.

Overall, the findings of the ascertaining stage demonstrated the need to strengthen the professional preparation of master's students for professional activity in inclusive educational environments through an integrated combination of theoretical, practical, digital, and reflective approaches.

During the pedagogical interaction, EG students developed an understanding of the educational difficulties faced by children with special educational needs and learned to design appropriate psycho-pedagogical support strategies. Their training focused on understanding the psychological and pedagogical characteristics of such children, preventing conflicts, creating a supportive inclusive environment, developing positive attitudes toward inclusion, and ensuring the active participation of children with special educational needs in the educational process.

The formation of inclusive competence was supported by specific pedagogical conditions, including the creation of a barrier-free educational environment, adaptation of curricula and teaching methods, special courses and professional modules, international internships, master classes, training sessions, seminars, and

blended and distance learning. Particular attention was given to digital tools, including augmentative and alternative communication programs, adaptive learning platforms, sensory games, and specialized software for correctional and speech therapy activities.

Thus, the developed training system combined theoretical preparation, practical activities, digital tools, and pedagogical support to strengthen students' inclusive competence and professional readiness. The content of the experimental intervention was determined based on the results of the ascertaining stage.

Analysis of the research results.

At the final stage of the experiment, the effectiveness of the system and the pedagogical conditions developed by us and implemented for the formation of the respondents' inclusive competence were assessed, as well as the levels of its formation after the completion of the formative stage of the study. A repeated diagnosis was carried out within this stage using the developed toolkit, which consisted of levels, criteria, and indicators that were used at the ascertaining stage of the study. This research scheme provided the opportunity to track changes over time, conduct a comparative analysis, and objectively assess the effectiveness of the system and the developed pedagogical conditions implemented in the research process.

According to the previously defined four criteria, the assessment was carried out at three levels (high, average, low).

In Table 3, we present generalized data on the distribution of respondents by motivational criterion.

Table 3.
Distribution of experiment participants by motivational criterion (control stage of the experiment)

Level	EG, ascertaining stage	EG, control stage	Increase	CG, ascertaining stage	CG, control stage	Increase
Low	27 (32.14%)	11 (13.10%)	**−19.04%**	28 (31.11%)	26 (28.89%)	**−2.22%**
Average	33 (39.29%)	39 (46.43%)	**+7.14%**	34 (37.78%)	35 (38.89%)	**+1.11%**
High	24 (28.57%)	34 (40.48%)	**+11.91%**	28 (31.11%)	29 (32.22%)	**+1.11%**

In Table 4, we present generalized data on the distribution of respondents by cognitive criterion.

Table 4.
Distribution of experiment participants by cognitive criterion (control stage of the experiment)

Level	EG, ascertaining stage	EG, control stage	Increase	CG, ascertaining stage	CG, control stage	Increase
Low	36 (42.86%)	6 (7.14%)	**−35.72%**	38 (42.22%)	36 (40.00%)	**−2.22%**
Average	31 (36.90%)	46 (54.76%)	**+17.86%**	31 (34.44%)	32 (35.56%)	**+1.11%**
High	17 (20.24%)	32 (38.10%)	**+17.86%**	21 (23.33%)	22 (24.44%)	**+1.11%**

Table 5 presents summarized data on the distribution of respondents by activity criterion.

Table 5.
Distribution of experiment participants by activity criterion (control stage of the experiment)

Level	EG, ascertaining stage	EG, control stage	Increase	CG, ascertaining stage	CG, control stage	Increase
Low	30 (35.71%)	12 (14.29%)	**−21.42%**	29 (32.22%)	27 (30.00%)	**−2.22%**
Average	34 (40.48%)	46 (54.76%)	**+14.28%**	39 (43.33%)	41 (45.56%)	**+2.23%**
High	20 (23.81%)	26 (30.95%)	**+7.14%**	22 (24.44%)	22 (24.44%)	**0.00%**

Table 6 presents summarized data on the distribution of respondents by the reflective criterion.

Table 6.
Distribution of experiment participants by the reflective criterion (control stage of the experiment)

Level	EG, ascertaining stage	EG, control stage	Increase	CG, ascertaining stage	CG, control stage	Increase
Low	40 (47.62%)	24 (28.57%)	**−19.05%**	44 (48.89%)	43 (47.78%)	**−1.11%**
Average	26 (30.95%)	31 (36.90%)	**+5.95%**	25 (27.78%)	25 (27.78%)	**0.00%**
High	18 (21.43%)	29 (34.52%)	**+13.09%**	21 (23.33%)	22 (24.44%)	**+1.11%**

The control stage of the experiment demonstrated a substantial increase in the proportion of students with a high level of inclusive competence in the experimental group across all four criteria, whereas only minor changes were observed in the control group. The comparative dynamics of the high-level indicators according to the motivational, cognitive, activity, and reflective criteria are presented in Figure 1.

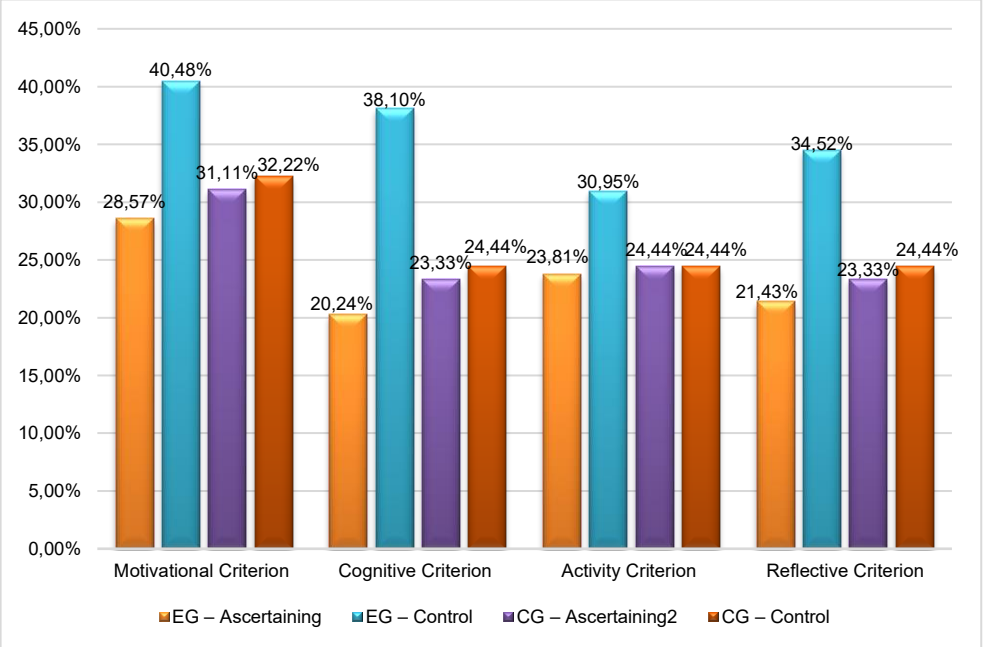


Figure 1. Changes in the proportion of students demonstrating a high level of inclusive competence across the four criteria in the experimental group

Figure 1 illustrates the changes in the proportion of students demonstrating a high level of inclusive competence across the four assessed criteria in the experimental group. The figure shows an increase in the high-level category for all four dimensions: from 28.57% to 40.48% for the motivational criterion, from 20.24% to 38.10% for the cognitive criterion, from 23.81% to 30.95% for the activity criterion, and from 21.43% to 34.52% for the reflective criterion.

The results presented in Tables 3–6 demonstrate a differentiated pattern of changes in the four dimensions of students' inclusive competence rather than a uniform improvement across all criteria. Although a general reduction in the proportion of students at the low level and an increase in the average and high levels were observed in the experimental group, the magnitude and distribution of these changes varied considerably across the four criteria.

The most pronounced changes were observed for the cognitive criterion (Table 4). The proportion of students at the low level decreased from 42.86% at the ascertaining stage to 7.14% at the control stage, representing a reduction of 35.72 percentage points. At the same time, the proportion of students at the high level increased from 20.24% to 38.10%, while the average level increased from 36.90% to 54.76%. Thus, the cognitive dimension demonstrated the strongest overall redistribution away from the low level. This pattern is consistent with the intervention components that provided students with structured access to instructional materials, interactive learning activities, formative assessment, and professional content concerning inclusive education and relevant digital and specialized technologies.

The activity criterion showed a different pattern (Table 5). The proportion of students at the low level decreased from 35.71% to 14.29%, while the average level increased from 40.48% to 54.76%. The increase in the high-level category was comparatively smaller, from 23.81% to 30.95%. Therefore, the principal shift for the activity criterion occurred from the low to the average level rather than from the low to the high level. This pattern may be associated with the practical orientation of the intervention, including professional cases, interactive tasks, development of digital educational materials, and activities requiring students to apply inclusive methods and select appropriate digital resources. The results suggest that practical application developed substantially, but a larger proportion of students remained at the average level than at the high level.

The motivational criterion demonstrated another pattern of change (Table 3). The proportion of students at the low level decreased from 32.14% to 13.10%, whereas the proportion at the high level increased from 28.57% to 40.48%. The average level also increased, from 39.29% to 46.43%. These changes indicate a substantial positive shift in students' professional orientations toward inclusive education, although the magnitude of the change was smaller than that observed for the cognitive criterion. This pattern is consistent with intervention activities that emphasized the value and professional importance of inclusive education, discussion of professional situations, mentoring, and students' involvement in tasks concerning responsibility for creating supportive educational environments.

The reflective criterion also demonstrated positive but distinct changes (Table 6). The proportion of students at the low level decreased from 47.62% to 30.95%, while the high-level category increased from 21.43% to 34.52%. The average level increased from 30.95% to 34.52%. Compared with the cognitive criterion, the reduction in the low-level category was less pronounced, indicating that reflective development was more gradual. This pattern can be related to the intervention's

reflective activities, including self-assessment, feedback, analysis of professional cases and completed tasks, identification of difficulties, and consideration of further professional development. Such activities require students not merely to acquire knowledge but to analyse and regulate their own professional actions, which may explain the comparatively more moderate shift in the distribution.

Taken together, the findings indicate that the intervention was associated with different patterns of development across the four dimensions of inclusive competence. Cognitive development showed the most pronounced redistribution toward higher levels; activity development was characterized primarily by movement toward the average level; motivational development demonstrated a notable increase in the high-level category; and reflective development showed a positive but comparatively more gradual shift. Therefore, the results should not be interpreted as evidence that all dimensions developed to the same extent. Rather, the differentiated patterns correspond to the different functions of the intervention activities and to the distinct nature of the four dimensions assessed.

These descriptive changes provide an indication of different patterns of development but do not, by themselves, establish the statistical significance of the observed differences. Therefore, the subsequent analysis examined the distributions of competence levels statistically using Pearson's chi-square test and reported the corresponding χ^2 values, degrees of freedom, p-values, and effect sizes.

Table 7.
Statistical comparison of inclusive competence levels between the experimental and control groups at the control stage

Criterion	$\chi^2(2)$	p	Cramer's V	Interpretation
Motivational	6.49	.039	.193	Small
Cognitive	25.62	< .001	.384	Moderate
Activity	6.19	.045	.189	Small
Reflective	6.79	.033	.198	Small

Table 7 presents the results of the Pearson chi-square tests comparing the distributions of inclusive competence levels between the experimental and control groups at the control stage. Statistically significant differences were observed for all four criteria. For the motivational criterion, the difference was statistically significant, $\chi^2(2) = 6.49$, $p = .039$, with a small effect size (Cramer's $V = .193$). The cognitive criterion demonstrated the largest between-group difference, $\chi^2(2) = 25.62$, $p < .001$, with a moderate effect size (Cramer's $V = .384$). Significant differences were also observed for the activity criterion, $\chi^2(2) = 6.19$, $p = .045$, Cramer's $V = .189$, and the reflective criterion, $\chi^2(2) = 6.79$, $p = .033$, Cramer's $V = .198$.

These findings indicate that, at the control stage, the distribution of inclusive competence levels differed significantly between the experimental and control groups across all four criteria. The largest difference was observed for the cognitive criterion, whereas the motivational, activity, and reflective criteria demonstrated small effect sizes.

Before and after the formative stage of the experiment, in order to compare the results obtained, statistical data processing was carried out using the Pearson criterion (χ^2), which made it possible to compare the empirical distributions of indicators in the control and experimental groups.

Pearson's chi-square test (χ^2) was used for categorical comparisons of the distributions of students across the low, average, and high levels of inclusive competence. At the ascertaining stage, the test was used to examine baseline comparability between the experimental and control groups separately for the motivational, cognitive, activity, and reflective criteria. At the control stage, the distributions of competence levels were compared between the groups to determine whether statistically significant differences were present after the formative intervention. Statistical significance was evaluated at $\alpha = .05$.

H_0: There is no statistically significant difference in the distribution of inclusive competence levels between the experimental and control groups at the control stage.
H_1: There is a statistically significant difference in the distribution of inclusive competence levels between the experimental and control groups at the control stage.

– $p < .05 \rightarrow$ reject H_0;
– $p \geq .05 \rightarrow$ fail to reject H_0.

The descriptive changes observed between the ascertaining and control stages indicate a positive shift in the distribution of inclusive competence levels in the experimental group. However, because the same students were assessed at both stages, these repeated observations are dependent and the pretest–posttest distributions were not treated as independent samples. Therefore, the primary inferential analysis of intervention effectiveness was based on comparisons between the experimental and control groups at the control stage.

Pearson's chi-square test was applied to compare the distributions of students across the low, average, and high levels of inclusive competence between the experimental and control groups after completion of the formative intervention. The analysis demonstrated statistically significant differences for all four criteria. For the motivational criterion, the distributions differed significantly between the groups, $\chi^2(2) = 6.49$, $p = .039$, with a small effect size (Cramer's $V = .193$). For the cognitive criterion, the difference was statistically significant and accompanied by a moderate effect size, $\chi^2(2) = 25.62$, $p < .001$, Cramer's $V = .384$. For the activity criterion, a statistically significant difference was also observed, $\chi^2(2) = 6.19$, $p = .045$, Cramer's $V = .189$. Finally, the reflective criterion demonstrated a statistically significant difference between the groups, $\chi^2(2) = 6.79$, $p = .033$, Cramer's $V = .198$.

These results indicate that, at the control stage, the distribution of inclusive competence levels differed significantly between students who participated in the digital-supported intervention and those who continued regular professional training. The largest between-group difference was observed for the cognitive criterion, which was also characterized by the largest effect size. The statistically significant differences observed for the motivational, activity, and reflective criteria were accompanied by small effect sizes.

The baseline comparisons showed no statistically significant differences between the experimental and control groups for any of the four criteria: motivational, $\chi^2(2) = 0.134$, $p = .935$; cognitive, $\chi^2(2) = 0.269$, $p = .874$; activity, $\chi^2(2) = 0.248$, $p = .883$; and reflective, $\chi^2(2) = 0.234$, $p = .889$. Thus, the groups were comparable in the distribution of competence levels before the intervention.

Taken together, the descriptive changes over time and the statistically significant differences between the groups at the control stage provide evidence consistent with a positive association between participation in the digital-supported pedagogical intervention and higher levels of inclusive competence. Given the quasi-experimental design and the absence of individual randomization, these findings should be interpreted as evidence of an intervention-related difference rather than definitive proof of causality.

Limitations of the Study

Several limitations should be considered. First, the quasi-experimental design and absence of individual randomization may allow selection effects or pre-existing differences between groups. Second, the study did not include long-term follow-up, so the sustainability and transfer of the observed improvements to professional practice remain uncertain. Third, inclusive competence was assessed using four criteria and three competence levels; future research could incorporate additional validated instruments and direct measures of professional performance. Fourth, because the same students were assessed before and after the intervention, pre–post observations were dependent and were therefore interpreted descriptively; future studies with individual-level longitudinal data should use appropriate repeated-measures methods. Finally, the study was conducted in a specific higher education context, limiting the generalizability of the findings. Multi-institutional studies with larger and more diverse samples are needed to confirm the robustness and transferability of the results.

Conclusions

The study substantiated the theoretical and methodological foundations for preparing master's students for professional activity in an inclusive educational environment and developed a system of professional training aimed at enhancing their inclusive competence. The proposed system integrated digital-supported learning activities, practical professional tasks, interactive learning formats, and reflective practices into the students' professional training.

The pedagogical experiment was conducted in three interconnected stages: ascertaining, formative, and control. The assessment of inclusive competence was based on four criteria–motivational, cognitive, activity, and reflective–and three levels of formation: low, average, and high. At the ascertaining stage, no statistically significant differences were identified between the experimental and control groups for any of the four criteria: motivational, $\chi^2(2) = 0.134$, $p = .935$; cognitive, $\chi^2(2) = 0.269$, $p = .874$; activity, $\chi^2(2) = 0.248$, $p = .883$; and reflective, $\chi^2(2) = 0.234$, $p = .889$. These results indicated comparable distributions of competence levels between the groups before the formative intervention.

The descriptive analysis demonstrated positive changes in the experimental group between the ascertaining and control stages. The proportion of students with a high level increased from 28.57% to 40.48% for the motivational criterion and from 20.24% to 38.10% for the cognitive criterion. For the activity criterion, the proportion of students at the high level increased from 23.81% to 30.95%, while for the reflective criterion it increased from 21.43% to 34.52%. At the same time, the proportion of students at the low level decreased across all four criteria. These changes indicate a positive redistribution of competence levels in the experimental group, although the magnitude and pattern of change differed across the four dimensions.

The comparison ofthe experimental and control groups at the control stage demonstrated statistically significant differences for all four criteria. For the motivational criterion, $\chi^2(2) = 6.49$, $p = .039$, with a small effect size (Cramer's $V = .193$). For the cognitive criterion, $\chi^2(2) = 25.62$, $p < .001$, with a moderate effect size (Cramer's $V = .384$). For the activity criterion, $\chi^2(2) = 6.19$, $p = .045$, with a small effect size (Cramer's $V = .189$). For the reflective criterion, $\chi^2(2) = 6.79$, $p = .033$, with a small effect size (Cramer's $V = .198$). The largest between-group difference was therefore observed for the cognitive criterion.

Taken together, the results provide evidence of a statistically significant association between participation in the developed digital-supported pedagogical intervention and the distribution of students' inclusive competence levels at the control stage. The findings are particularly pronounced for the cognitive dimension, while the motivational, activity, and reflective dimensions demonstrated smaller between-group effects. Thus, the results support the practical value of the proposed training system for the development of inclusive competence in master's students preparing for professional activity in inclusive educational environments.

At the same time, the findings should be interpreted in light of the quasi-experimental design. The experimental and control groups were formed from existing academic groups, and individual randomization was not used. Therefore, the statistically significant differences observed at the control stage should not be interpreted as definitive proof of a causal effect of the intervention. Rather, they provide empirical evidence consistent with the effectiveness of the developed pedagogical system under the conditions of the present study.

Future research should strengthen the evidence through randomized or longitudinal designs, repeated follow-up assessments, and additional measures of students' transfer of inclusive competence to authentic professional practice. Such research would make it possible to determine whether the observed improvements are sustained over time and to further clarify the contribution of digital-supported pedagogical interventions to the preparation of specialists for inclusive educational environments.

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Original Article

Tecnologías innovadoras para el desarrollo de las habilidades blandas de los estudiantes universitarios

Innovative technologies for developing university students' soft skills

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Resumen

El estudio aborda el problema del desarrollo de las habilidades blandas de los estudiantes universitarios mediante un sistema integrado de tecnologías educativas innovadoras. El objetivo fue desarrollar y evaluar experimentalmente un sistema metodológico y condiciones pedagógicas para potenciar las habilidades blandas de los estudiantes en la educación superior. Se llevó a cabo un experimento pedagógico de cuatro etapas entre 2021 y 2025, en el que participaron 387 estudiantes universitarios: 194 en el grupo experimental y 193 en el grupo de control. Las habilidades blandas de los estudiantes se evaluaron según criterios motivacionales, cognitivos, de actividad y reflexivos, y se clasificaron en cuatro niveles: bajo, reproductivo, de búsqueda y creativo. Durante la etapa formativa, el grupo experimental participó en una intervención integrada que combinó hackatones educativos, actividades basadas en proyectos, simulaciones, juegos de negocios y de rol, debates profesionales, herramientas de colaboración digital, inteligencia artificial, realidad virtual y gamificación. Los resultados demostraron cambios positivos sustancialmente mayores en el grupo experimental que en el grupo de control. Las puntuaciones medias en el grupo experimental aumentaron en 0,62 puntos para el criterio motivacional, 0,56 para el criterio cognitivo, 0,76 para el criterio de actividad y 0,68 para el criterio reflexivo. La diferencia general pre-post en el grupo experimental fue estadísticamente significativa ($t = 12,192$, $p < 0,05$). En la etapa final, el 57,73 % de los estudiantes del grupo experimental demostró niveles de búsqueda o creatividad en el desarrollo de habilidades blandas, en comparación con el 42,49 % del grupo de control. Los resultados indican que la participación en el sistema integrado se asoció con una mayor mejora en las habilidades interpersonales de los estudiantes universitarios que la participación en las actividades educativas regulares.

Palabras clave: habilidades blandas; tecnologías educativas innovadoras; educación superior; estudiantes universitarios; experimento pedagógico.

Abstract

The study addresses the problem of developing university students' soft skills through an integrated system of innovative educational technologies. The aim was to develop and experimentally evaluate a methodological system and pedagogical conditions for enhancing students' soft skills in higher education. A four-stage pedagogical experiment was conducted from 2021 to 2025 and involved 387 university students, including 194 students in the experimental group and 193 in the control group. Students' soft skills were assessed according to motivational, cognitive, activity, and reflective criteria and classified into four levels: low, reproductive, search, and creative. During the formative stage, the experimental group participated in an integrated intervention combining educational hackathons, project-based activities, simulations, business and role-playing games, professional discussions, digital collaboration tools, artificial intelligence, virtual reality, and gamification. The results demonstrated substantially greater positive changes in the experimental group than in the control group. Mean scores in the experimental group increased by 0.62 points for the motivational criterion, 0.56 for the cognitive criterion, 0.76 for the activity criterion, and 0.68 for the reflective criterion. The overall

pre–post difference in the experimental group was statistically significant ($t = 12.192$, $p < .05$). At the final stage, 57.73% of students in the experimental group demonstrated search or creative levels of soft skills development, compared with 42.49% in the control group. The findings indicate that participation in the integrated system was associated with greater improvement in university students' soft skills than participation in regular educational activities.

Keywords: soft skills; innovative educational technologies; higher education; university students; pedagogical experiment.

Introduction

Over the past decades, the development of university students' soft skills has become an increasingly important component of higher education. Soft skills complement professional and technical knowledge by supporting students' effective communication, teamwork, critical thinking, creativity, adaptability, emotional intelligence, and problem-solving. These competencies are particularly important in educational and professional contexts characterized by rapid technological change, interdisciplinary collaboration, and increasing demands for graduates to adapt to changing work environments. Research has shown that soft skills are associated with students' career development and employability and that higher education plays an important role in their systematic development (Munir, 2022; Ragusa et al., 2022; Shah et al., 2023).

The digital transformation of higher education has created additional opportunities for developing these competencies. Digital platforms, collaborative environments, simulations, project-based learning, and other technology-supported learning activities can increase students' engagement in authentic and collaborative tasks and create conditions for practicing communication, teamwork, decision-making, and problem-solving. Previous studies have demonstrated the potential of active learning and digitally supported educational practices for the development of students' soft skills (Almeida & Buzady, 2022; Almeida & Morais, 2023; Betti et al., 2022). Hackathon-based learning has also been associated with experiential learning, interdisciplinary collaboration, creativity, and problem-solving, although existing research has often examined specific formats or contexts rather than an integrated pedagogical system for higher educatio (Heller et al., 2023; Sajja et al., 2024).

Despite this growing body of research, an important empirical gap remains. First, existing studies frequently examine individual approaches, such as project-based learning, simulation, active learning, or hackathons, rather than evaluating an integrated system that combines several innovative educational technologies within a coherent pedagogical framework. Second, although the literature provides evidence of the potential of particular technologies and active learning strategies, fewer studies have empirically compared changes in students' soft skills between experimental and control groups using multiple dimensions of soft skills development. Third, the effectiveness of an integrated system combining experiential activities with digital technologies, artificial intelligence, virtual reality, and collaborative learning tools remains insufficiently established in university education. Therefore, there is a need for empirical research that not only describes innovative technologies but also determines whether their systematic pedagogical integration produces measurable improvements in students' soft skills.

Accordingly, the research objective was to determine the effectiveness of an integrated pedagogical system based on innovative educational technologies for

developing university students' soft skills by comparing changes in the experimental and control groups.

The study was guided by the following hypothesis:

H_1: University students who participate in the integrated pedagogical system based on innovative educational technologies will demonstrate significantly greater improvements in soft skills than students who participate in conventional educational activities.

To test this hypothesis, the study compared the experimental and control groups according to four dimensions of soft skills development: motivational, cognitive, activity, and reflective criteria. The study examined changes in students' indicators before and after the intervention and compared the final distribution of students across the identified levels of soft skills development.

Literature Review

Research on soft skills in higher education has developed along several interconnected directions, including the conceptualization and measurement of soft skills, active and experiential learning, simulation and project-based approaches, and the use of digital technologies to support their development. Rather than treating these directions as separate strands, recent studies increasingly indicate that soft skills develop most effectively when students are engaged in active, authentic, and socially interactive learning activities.

One important research direction concerns the conceptualization and measurement of soft skills. Jardim et al. (2022) developed and psychometrically examined the Soft Skills Inventory, providing empirical support for the multidimensional nature of the construct and offering a basis for its systematic assessment. This contribution is important because it demonstrates that soft skills should not be treated as a single undifferentiated competence. At the same time, measurement-oriented research does not by itself explain which pedagogical conditions are most effective for developing these competencies in specific higher education contexts. Thus, a distinction is needed between establishing valid ways of assessing soft skills and determining how educational interventions can produce measurable changes in them.

A second strand of research emphasizes active, experiential, and collaborative learning. Betti et al. (2022) demonstrated that active learning can contribute simultaneously to the development of hard and soft skills, suggesting that soft skills can be embedded in discipline-specific learning rather than taught exclusively as separate competencies. Almeida and Buzady (2022), using simulation-based learning, reported the potential of experiential activities for developing teamwork, decision-making, and leadership. Almeida and Morais (2023) similarly emphasized interactive teaching, digitalization, and interdisciplinary approaches as strategies for developing soft skills in technical education. Taken together, these studies indicate a relatively consistent pattern: students' soft skills are supported when learning requires participation, collaboration, decision-making, and the application of knowledge to meaningful tasks.

Project-based and hackathon-based learning provide a more intensive form of such experiential engagement. Research on hackathons emphasizes their capacity to combine teamwork, creativity, problem-solving, interdisciplinary interaction, and

practical project development (Heller et al., 2023; Sajja et al., 2024). However, the evidence in this area is largely focused on particular educational formats or contexts. Hackathons, simulations, and project activities therefore provide evidence for the value of individual experiential approaches, but this does not establish whether their systematic combination with other innovative technologies produces additional benefits for the broader development of soft skills.

Another strand of the literature concerns the relationship between soft skills and students' professional development. Munir (2022) shows that engineering professionals require social and communicative competencies alongside technical expertise, while Shah et al. (2023) demonstrate an association between multidimensional soft skills and students' career development and career intentions. Ragusa et al. (2022) further emphasize the importance of soft skills within university teaching and learning processes. These studies strengthen the argument that soft skills are an important outcome of higher education; however, their primary contribution concerns the relevance and professional value of these competencies rather than the comparative effectiveness of integrated pedagogical interventions for developing them.

Recent literature also points to the growing role of digital technologies in higher education. Digital platforms, online collaboration environments, simulations, and other technology-supported activities can provide additional opportunities for communication, cooperation, problem-solving, and self-directed learning. Almeida and Morais (2023) highlight digitalization as one element of broader strategies for developing soft skills. At the same time, the presence of digital technologies alone does not demonstrate pedagogical effectiveness. The educational value of a technology depends on how it is integrated into learning activities, interaction, assessment, and students' practical engagement.

The literature therefore provides relatively consistent evidence for three propositions. First, soft skills are multidimensional and can be systematically assessed (Jardim et al., 2022). Second, active, experiential, collaborative, and project-based learning can create favorable conditions for their development (Almeida & Buzady, 2022; Almeida & Morais, 2023; Betti et al., 2022). Third, soft skills have substantial relevance for students' professional and career development (Munir, 2022; Ragusa et al., 2022; Shah et al., 2023). However, these strands have generally been investigated separately, and the literature provides less evidence concerning the effectiveness of an integrated pedagogical system that combines experiential learning activities with multiple innovative technologies and explicit pedagogical conditions.

Accordingly, the research gap addressed in the present study is not a general lack of empirical research on soft skills. Rather, it concerns the limited empirical evidence on the effectiveness of an integrated system that combines educational hackathons, project activities, simulations, collaborative digital tools, artificial intelligence, virtual reality, and gamification within defined pedagogical conditions for developing university students' soft skills. The present study addresses this gap by implementing such a system in an experimental group and comparing changes in students' motivational, cognitive, activity, and reflective dimensions of soft skills with those observed in a control group.

Methodology

Research Design

The study employed a quasi-experimental pedagogical design to examine the effectiveness of an integrated system of innovative educational technologies for developing university students' soft skills. The study was conducted from 2021 to 2025 and comprised four interconnected stages: search, ascertaining, formative, and final. The search stage involved the analysis and systematization of relevant psychological, philosophical, pedagogical, and methodological literature and the identification of theoretical foundations for developing students' soft skills. The ascertaining stage was used to determine students' initial level of soft skills, their readiness to participate in innovative learning activities, and their perceptions of the role of such activities in soft skills development. During the formative stage, the developed methodological system and pedagogical conditions were implemented in the experimental group. The final stage involved assessment of changes in students' soft skills and comparison of the experimental and control groups.

The quasi-experimental design was selected because the study was conducted within existing academic groups and did not involve individual random assignment of students to experimental conditions. The design therefore enabled comparison of changes between the experimental and control groups while recognizing the contextual limitations associated with non-random group allocation.

Participants and Setting

The study involved 387 university students from three Ukrainian higher education institutions: Rivne State University of the Humanities, Ternopil Volodymyr Hnatiuk National Pedagogical University, and Central Ukrainian State University named after Volodymyr Vynnychenko. The participants were enrolled in master's-level programmes in education, psychology, social work, and related fields. The sample comprised 194 students in the experimental group and 193 students in the control group.

Sampling and Recruitment Procedure

Participants were selected using a non-probability sampling approach. At the ascertaining stage, the sample size for the student survey was determined with consideration of the required confidence level and sampling error. The study also applied a variational maximum sampling approach for selecting students for the relevant research activities.

The participating academic groups were identified in cooperation with the academic units of Rivne State University of the Humanities, Ternopil Volodymyr Hnatiuk National Pedagogical University, and Central Ukrainian State University named after Volodymyr Vynnychenko. Students received information about the purpose, procedures, expected activities, and voluntary nature of participation before enrolment in the study. Participation was voluntary, and students could decline participation without academic consequences.

Because the study was conducted within existing academic groups, students were not individually randomized to the experimental or control condition. The experimental and control groups were formed from participating academic groups in cooperation with the relevant academic units of the participating higher education

institutions. The initial assessment was conducted before the intervention to examine the comparability of the groups across the selected soft-skills criteria. Although the experimental group showed slightly lower baseline mean scores on some indicators, these baseline values were not used as a criterion for selecting students or academic groups for the experimental condition. Rather, the baseline assessment was used to identify the initial level of soft-skills development and to assess the comparability of the two groups. The baseline comparison did not indicate a statistically significant difference between the groups ($t = 1.623$). Accordingly, the study should be regarded as a quasi-experimental design with non-random group allocation, and the possibility of residual selection bias cannot be completely excluded. The observed differences in outcomes should therefore be interpreted as evidence of an association between participation in the integrated intervention and changes in students' soft skills, rather than as definitive causal evidence.

The study evaluated an integrated pedagogical intervention in which educational hackathons, project activities, simulations, business and role-playing games, professional discussions, digital collaboration tools, artificial intelligence, virtual reality, and gamification were implemented as interconnected elements. Because the research design did not include separate intervention groups for individual technologies, the study does not permit the independent effectiveness of any particular technology to be determined or ranked. Accordingly, expressions such as "the most effective" are not used to characterize virtual reality, gamification, artificial intelligence, or other individual tools. References to the contribution of specific technologies are therefore understood as descriptions of their role within the integrated intervention rather than as evidence of their independent causal effectiveness.

Assessment Framework

Students' soft skills were assessed according to four criteria: motivational, cognitive, activity, and reflective. The motivational criterion reflected students' motives and readiness for educational activities and for the development of soft skills and personal qualities. The cognitive criterion reflected students' knowledge and understanding of soft skills and their development. The activity criterion concerned students' ability to apply soft skills in educational and professional situations, including communication, teamwork, problem-solving, leadership, and decision-making. The reflective criterion concerned students' ability to evaluate their own activities and achievements and to use self-assessment for further development.

Four levels of soft skills development were distinguished: low, reproductive, search, and creative.

Measurement Instrument

The assessment of students' soft skills was conducted using a structured assessment instrument based on four dimensions of soft-skills development: motivational, cognitive, activity, and reflective. The instrument was developed for the purposes of the present pedagogical experiment and was administered to students at both the ascertaining and final stages.

The motivational dimension assessed students' motivation and readiness to develop soft skills and personal qualities. The cognitive dimension assessed students' knowledge and understanding of the nature, importance, and components of soft skills. The activity dimension assessed students' ability to apply communication,

teamwork, leadership, decision-making, and problem-solving skills in educational and professionally oriented situations. The reflective dimension assessed students' ability to evaluate their own performance, identify strengths and areas for improvement, and use reflection and self-assessment for further development.

Each dimension was assessed using a set of questionnaire items and complementary pedagogical observation indicators. The instrument consisted of 20 items, with 5 items assigned to each of the four dimensions: motivational, cognitive, activity, and reflective. Responses to the questionnaire items were recorded using a 5-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"), where higher scores indicated a higher level of soft-skills development.

For each participant, scores were calculated separately for the four dimensions. The dimension scores were obtained by averaging the scores of all items belonging to the respective dimension. An overall soft-skills score was subsequently calculated as the arithmetic mean of the four dimension scores. The same instrument and scoring procedure were applied to the experimental and control groups before and after the intervention.

Research Methods and Data Collection

The study employed theoretical, empirical, and statistical methods. The theoretical methods included analysis, synthesis, induction, deduction, systematization, and generalization of psychological, philosophical, pedagogical, and scientific-methodological literature. Empirical methods included questionnaires, surveys, interviews, pedagogical observation, analysis of students' educational activities, and pedagogical experimentation.

The assessment procedures were conducted at the ascertaining and final stages to identify changes in students' soft skills following the formative intervention. The same assessment framework was applied to the experimental and control groups to enable comparison of changes over time.

Experimental Intervention

During the formative stage, the experimental group participated in an integrated methodological system designed to develop soft skills through innovative educational technologies. The intervention combined educational hackathons, project activities, simulations, business and role-playing games, professional discussions, debates, presentations, digital collaboration tools, artificial intelligence, virtual reality, and gamification.

The intervention was implemented through three pedagogical conditions: (1) creation of a modern innovative educational environment; (2) involvement of students in communicative activities, development of creative abilities, and formation of skills for rational use of time; and (3) systematic application of innovative learning technologies for developing students' soft skills.

The methodological system consisted of four interconnected components: technological, content, personal, and activity. The technological component focused on creating an innovative educational environment; the content component addressed the content of soft skills and related communicative and creative abilities; the personal component involved the purposeful use of innovative learning

technologies for students' development; and the activity component focused on students' practical engagement in activities aimed at developing and assessing soft skills.

In the experimental group, students participated in hackathons and project activities and completed simulations, business games, role-playing activities, professional discussions, debates, and presentations. Digital technologies included virtual reality, gamification, online collaboration tools, artificial intelligence, online forums, and social networks.

The control group continued its regular educational activities without systematic implementation of the developed integrated intervention.

Data Analysis

The empirical data were analysed quantitatively and qualitatively. Quantitative analysis was used to compare students' indicators according to the four assessment criteria before and after the intervention and to examine differences between the experimental and control groups.

The coefficient of significance of differences was calculated to determine whether the observed differences between the groups could be considered statistically significant.

Before the intervention, baseline equivalence between the experimental and control groups was examined. Within-group pre–post changes were also assessed separately. However, because the research hypothesis predicted significantly greater improvement in the experimental group than in the control group, the primary analysis focused on a direct between-group comparison of change scores. For each criterion, change scores were calculated as the difference between the post-intervention and pre-intervention scores (Δ = post-test − pre-test), and the mean changes in the experimental and control groups were compared using an independent-samples t-test. Statistical significance was evaluated at the .05 level.

Changes in the distribution of students across the four levels of soft skills development were also examined. At the final stage, the distributions of 193 control-group students and 194 experimental-group students were compared across the low, reproductive, search, and creative levels.

Ethical Considerations

Participation in the study was voluntary. Before participating, students were informed about the purpose, procedures, and conditions of the research, and informed consent was obtained from all participants. Students were informed that they could withdraw from the study at any time without any negative consequences. Confidentiality and anonymity of participants' responses were maintained throughout the study, and the collected data were used exclusively for scientific purposes. The study was conducted in accordance with the ethical principles and institutional requirements applicable to educational research.

Results and Discussion

Soft skills encompass non-cognitive competencies that support effective social and professional interaction and personal effectiveness, including leadership, teamwork, emotional intelligence, time management, critical and creative thinking, adaptability,

persuasion, and public speaking. Their development is increasingly important in higher education because these competencies contribute to students' professional readiness and ability to respond to changing professional demands.

Innovative and active learning technologies provide opportunities to develop these competencies through practical and collaborative activities. Educational hackathons engage students in intensive teamwork on authentic problems, promoting critical thinking, creativity, time management, and collaboration (Sajja et al., 2024). Their practical and problem-oriented nature distinguishes them from traditional instructional formats and supports students' engagement in solving real-world tasks (Kitsios & Kamariotou, 2023). Their interdisciplinary character can additionally stimulate reflection, innovation, and social interaction (Araújo et al., 2025; Heller et al., 2023).

Project-based activities similarly provide opportunities to develop soft skills through practical experience, collaboration, communication, leadership, critical thinking, and problem-solving. Tasks that simulate professional situations can also support students' adaptability and creativity (Chagovets et al., 2020).

Thus, hackathons, project-based learning, case studies, training sessions, virtual laboratories, digital platforms, AI, and augmented and mixed reality can be considered complementary elements of an integrated pedagogical approach to soft skills development, rather than isolated technologies. Their educational value lies in creating opportunities for active participation, collaboration, problem-solving, reflection, communication, and practical application of knowledge.

Organization of a pedagogical experiment on the development of soft skills in university students.

In the process of experimental research, we, together with students, identified the stages of soft skills development:

1. Cognitive stage, to identify and form students' motives for educational activities, for the development of soft skills and their personal qualities.
2. Applied stage, to form students' soft skills and communication, teamwork, solving practical problems, practical skills, and skills of educational activities, etc.
3. Evaluation stage, to form adequate self-esteem in students for their self-improvement of soft skills.

All the stages we have described form a holistic system for the development of soft skills in university students using innovative technologies.

Analyzing the proposed questions and tasks at the ascertaining stage of the experiment according to the specified criteria, we found that 28.68% of students are at a low level of soft skills development, 63.05% are at an average level, and only 8.27% are at a high level.

Such results of the ascertaining section showed a low level of soft skills development in university students. They prompted us to study in more detail the ways of developing soft skills in university students and to develop an innovative system and pedagogical conditions for the development of soft skills in students using innovative technologies.

The theoretical and methodological basis of the study, which we determined, made it possible to plan a pedagogical experiment, which was carried out from 2021 to 2025 in four stages.

At the search (first) stage, we studied, systematized, and generalized information on the research problem in practice and in psychological, philosophical, and pedagogical literature, and analyzed and accumulated personal work experience.

At the ascertaining (second) stage, we determined students' views on the need to develop soft skills using innovative technologies and their readiness for this type of activity. The study used a phenomenological method, and students were selected using the variational maximum sampling method.

At the formative stage, the developed innovative system and pedagogical conditions for developing students' soft skills using innovative technologies were implemented; the effectiveness of the integrated innovative pedagogical system was evaluated by comparing changes in the experimental and control groups and students' skills and knowledge were measured.

At the final stage, the results of experimental work were processed and analyzed using generalization and mathematical statistics methods.

At the ascertaining stage of the study, the sample size was determined in order to ensure the reliability of the results of the student survey. To determine the number of respondents who needed to be interviewed, we used the formula so that we could state the results with a probability of 0.95 regarding the development of soft skills in university students and at the same time, the sample should have a difference from the general population of no more than 0.05:

$$n = \frac{Nt^2pq}{N\Delta^2 + t^2pq}$$

Where N is the number of respondents in the general population;
p and q are the shares of respondents who are not ready or ready to develop soft skills while studying at the university;
$\Delta = 0{,}05, t = 1{,}96$ – determined from tables for $F(t) = 0{,}95$.

Since we do not know the proportions p and q, we need to take their values such that their product is maximal, i.e., $pq = 0{,}25$. Received $n \approx 396$ − by substituting the corresponding values into the formula.

The results of the study showed that students, their motivation, and self-training play a significant role in developing soft skills. In addition, students expressed the opinion that extracurricular activities, as well as classes, are an important innovative environment for developing soft skills. Students also emphasized that they experienced difficulties in developing soft skills during the implementation of educational activities: educational hackathons, project activities, training sessions, case methods, virtual laboratories, digital platforms and technologies, artificial intelligence, augmented and mixed reality technologies.

We also set the goal at the ascertaining stage of the study to assess the general level of development of soft skills among university students, students' awareness of types of life skills, and the need to use innovative learning technologies in the educational process of higher education to develop flexible or soft skills of future

specialists, to identify the main shortcomings of the educational process of higher education and the reasons for their occurrence.

During the ascertaining stage of the study, it was found that not all students possess the necessary system of life skills, and the real level of development of flexible or soft skills of future specialists was identified.

At the formative stage of the study, the developed innovative system and pedagogical conditions for the development of soft skills in EG students through innovative technologies were implemented; the effectiveness of the implemented digital innovative educational technologies was compared.

In the process of professional training of EG students and the hackathon, the participants went through the main proposed stages of project work: from the presentation and assessment of the effectiveness of the work done and ready-made solutions, starting from the development of ideas and the formulation of a production problem. This educational format stimulated the development of flexible or soft skills of future EG specialists, such as analysis of production cases, the implementation and development of leadership qualities, independent search for information, and making reasoned decisions.

The introduction of hackathons into the educational process of EG in higher education institutions contributed to:

- The development of soft skills (teamwork, communication, critical and creative thinking), which are crucial in the modern educational sector for effective professional activity.
- The organization of joint work in teams, the formation of experience in interdisciplinary interaction, the exchange of achievements and ideas.
- The motivation of students to develop flexible skills (soft skills) through innovative technologies, research, and an independent approach of higher education applicants through participation in project activities and solving practical production tasks.
- The involvement of stakeholders in the educational process to increase the practical significance of the results obtained.

The educational hackathons conducted in EG showed students' readiness to create relevant projects, greater student activity, responsibility, and cohesion, which can be implemented in real conditions of professional activity. Thus, introducing hackathons in universities was an effective means of modernizing education and developing the soft skills and professional activities of EG students.

In the EG educational process, we focused on the connection between emotional intelligence, project-based learning, and the development of soft skills in university students. EG students demonstrated higher levels of soft skills than those who participated in project activities compared to students who did not participate in such activities (CG). This proves that project-based learning improves professional knowledge and helps develop soft skills in university students, which is very important for strengthening interpersonal relationships and developing leadership.

EG students performed exercises aimed at developing soft skills in a professional context. Thus, EG students were offered simulations, business games, and role-playing games, which allowed them to test their soft skills in practical conditions and recreate professional situations, stimulating active participation in the digital field of

educational activity. Effective tasks included professional real situations, negotiations, group discussions and debates, and creating presentations, which provided practical experience.

Digital technologies played a significant role in developing soft skills in EG students and modernizing the educational process, in particular through guest lectures, video communication tools, interactive digital resources, and information and communication technologies.

Such innovative technologies opened up new opportunities for EG students to develop soft skills more actively, interactively, and effectively. EG students experimented with various digital technologies, demonstrating successful cases of implementing AI and social networks, online platforms, VR, and gamification. What was important was the development and use of pedagogically sound methods, not just the introduction of technologies into higher education.

So, EG students actively used various innovative technologies to develop soft skills. Let us name the most effective:

1. Virtual reality (VR) and simulations: creating immersive learning environments that simulate real professional situations. VR effectively contributed to the development of soft skills in EG students through modeling various social contexts. VR was used in problem-based learning, including teamwork, public speaking, leadership, and critical thinking.
2. Educational games and gamification: involvement of EG students in creating an educational interactive digital experience. Gamified tasks and games developed soft skills in university students, including creativity, critical thinking, cooperation and communication, and contributed to problem-solving. The study showed that gamification has a positive effect on the development of soft skills in university students and student motivation.
3. Online collaboration tools and platforms: promoting the development of soft skills in university students, teamwork, communication, and project management skills. Shared task management tools, brainstorming boards, and online documents allowed students to work together effectively regardless of location.
4. Artificial intelligence (AI) for the development of soft skills in EG students contributed to personalized feedback: providing students with detailed, individualized feedback on their soft skills, such as argumentation and communication.
5. Online forums and social networks: creating platforms for exchanging ideas and experiences, informal communication, and developing active listening skills. To develop soft skills in EG students, forums were created for discussing projects, professional materials, and exchanging ideas.

All these innovative technologies contributed to the development of key soft skills in EG students, such as critical thinking, problem-solving, and creativity. Their ability and interactivity in involving EG students in the process of active innovative learning contribute to deeper assimilation and understanding of professional material and the development of necessary professional skills.

EG students are offered the following pedagogical conditions to be implemented in the educational process:

1. Development of soft skills in students by creating a modern, innovative educational environment of higher education.

2. Involvement of students in communicative activities, development of creative abilities, formation of skills for rational use of time, etc.
3. Application of innovative learning technologies in the educational process of higher education to develop flexible or soft skills of future specialists: educational hackathon, project activities, training sessions, case method, virtual laboratories, digital platforms and technologies, artificial intelligence, technologies of augmented and mixed reality.

The main components of the developed methodological innovation system and pedagogical conditions for the development of soft skills in EG students by means of innovative technologies were determined:

- Technological component.
- Content component.
- Personal component.
- Activity component.

These components, based on systemic and synergistic approaches during the pedagogical experiment and through the implementation of the identified pedagogical conditions and the proposed system for the development of soft skills in students, formed relationships to achieve the maximum synergistic effect between these components.

The technological component provided for the definition by teachers and students of the main concepts and types of soft skills for successful life.

To ensure this component, the first pedagogical condition was implemented – the development of soft skills in students by creating a modern innovative educational environment of higher education.

The content component provided for familiarizing EG students with the content and implementation of life skills concepts, clarifying the essence of communicative activity, developing creative abilities, forming the ability to rationally use time, etc., for the development of soft skills.

The implementation of the second pedagogical condition was aimed at ensuring this component of the system – involving students in communicative activity, developing creative abilities, forming the ability to use time rationally, etc.

The personal component provided for the development of the necessary soft skills in the students themselves through a system of measures taken for this purpose: the use of innovative learning technologies in the educational process of higher education to develop flexible or soft skills of future specialists: educational hackathon, project activities, training sessions, case method, virtual laboratories, digital platforms and technologies, artificial intelligence, augmented and mixed reality technologies. To ensure this component of the system, the third pedagogical condition was implemented – the use of innovative learning technologies in the educational process of higher education to develop flexible or soft skills of future specialists: educational hackathon, project activities, training sessions, case method, virtual laboratories, digital platforms and technologies, artificial intelligence, augmented and mixed reality technologies.

The activity component is provided to increase students' ability to develop soft skills and to assess their level of formation of necessary life skills.

The implementation of all pedagogical conditions was aimed at ensuring this component of the system.

We note that there is a cyclical relationship between the components of the system and the pedagogical conditions for the development of soft skills in students.

In order to prove the non-randomness of the differences in the numerical values of the indicators in the experimental and control group, we used the formula (agreement criterion) for calculating the coefficient of significance of differences:

$$t = \frac{V_E - V_K}{\sqrt{\frac{V_E^2}{2n_E} + \frac{V_K^2}{2n_K}}}$$

Where –

$V_E = \frac{\sigma_E}{\bar{x}_E}$ and $V_K = \frac{\sigma_K}{\bar{x}_K}$, x_E – average value of indicators in the experimental group; x_K – average value of indicators in the control group.

The mean square deviation was calculated using the formula in each of the groups:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}},\ n = 20$$

We used the coefficient of significance of differences in pedagogical experiments to find out whether the observed differences between the experimental and control group are statistically significant, that is, whether it can be said that these differences are not accidental, but that they are due to the influence of the studied factor. Thus, in pedagogical research, the criterion of significance of differences is a key tool, which provides an objective assessment of their effectiveness in experimental methods.

Before the start of the experiment, the coefficient of significance of differences was calculated in two groups. The pre–post comparison in the control group yielded $t = 2.099$ ($df = 192$, $p \approx .037$, two-tailed), indicating a statistically significant but relatively small change in the control group. This within-group result should not, however, be interpreted as evidence that the experimental intervention was more effective. The relevant test of the research hypothesis is the direct comparison of change scores between the experimental and control groups.

Between the EG before and EG after the experiment, the calculation of the coefficient of significance of differences at the significance level $p < 0.05$ gave the following value $t = 12.192$, which proves that the difference in indicators is significant. This suggests that the increase in students' readiness for the development of soft skills was largely influenced by the implementation of the developed system and pedagogical conditions, which were proposed in the research process and implemented by us.

The next stage of the study was the analysis of the dynamics of all indicators of the development of soft skills in students according to the selected criteria: motivational criterion, cognitive criterion, activity criterion, and reflective criterion.

For the initial diagnostic assessment, students' soft skills were summarized using a three-level classification (low, medium, and high), which showed that 28.68% of

students were at the low level, 63.05% at the medium level, and 8.27% at the high level. This three-level classification was used only for the general diagnostic description at the ascertaining stage. For the subsequent analysis of the dynamics of soft skills development, a more differentiated four-level scale was applied: low, reproductive, search, and creative. These two classification systems should therefore not be interpreted as equivalent categories. The four-level scale was used for the comparative analysis of students' distributions at the final stage.

Table 1.
Changes in the Mean Scores According to the Four Criteria

Criterion	CG Before	CG Change	CG After	EG Before	EG Change	EG After
Motivational	3.30	+0.10	3.40	3.26	**+0.62**	3.88
Cognitive	3.10	+0.10	3.20	3.08	**+0.56**	3.64
Activity	3.08	+0.10	3.18	2.88	**+0.76**	3.64
Reflective	3.22	+0.14	3.36	3.12	**+0.68**	3.80

To directly test the study hypothesis, the magnitude of pre–post change was compared between the experimental and control groups. The experimental group demonstrated larger mean improvements than the control group across all four criteria: motivational (+0.62 vs. +0.10), cognitive (+0.56 vs. +0.10), activity (+0.76 vs. +0.10), and reflective (+0.68 vs. +0.14). The independent-samples comparison of change scores was used as the primary test of whether the improvement in the experimental group was significantly greater than that observed in the control group. The analysis first examined changes in the mean scores of students according to the four established criteria: motivational, cognitive, activity, and reflective. Table 1 shows the results for the experimental and control groups before and after the intervention.

The experimental group demonstrated substantially larger changes across all four criteria than the control group. The greatest increase in the EG was observed for the activity criterion (+0.76), followed by the reflective (+0.68), motivational (+0.62), and cognitive (+0.56) criteria. In contrast, changes in the CG ranged from +0.10 to +0.14. The baseline comparison indicated no statistically significant difference between the experimental and control groups ($t = 1.623$), supporting their initial comparability. Within-group analysis showed a statistically significant pre–post change in the experimental group ($t = 12.192$, $p < .05$). However, this within-group result does not by itself demonstrate that the experimental group improved significantly more than the control group. Because the research hypothesis concerned the relative magnitude of improvement between groups, the primary test of the hypothesis was based on the direct comparison of pre–post change scores between the experimental and control groups. The experimental group showed larger mean changes across all four criteria, with the greatest increase observed for the activity criterion (+0.76). The results therefore show a consistent pattern across all four criteria: the experimental group demonstrated larger changes than the control group, with the strongest change observed in the activity criterion.

To provide a more differentiated assessment of students' soft skills development, the final results were classified into four levels: low, reproductive, search, and creative. Unlike the three-level classification used for the general diagnostic description at the ascertaining stage, this four-level scale was applied to distinguish more precisely between students demonstrating different degrees of development at the final stage. The final distributions of the experimental and control groups are presented in Table 2.

Table 2.
Final distribution of students in the experimental and control groups according to the four levels of soft skills development

Group	Low level, n (%)	Reproductive level, n (%)	Search level, n (%)	Creative level, n (%)	Total, n
CG	28 (14.51%)	83 (43.01%)	67 (34.72%)	15 (7.77%)	**193**
EG	14 (7.22%)	68 (35.05%)	89 (45.88%)	23 (11.86%)	**194**

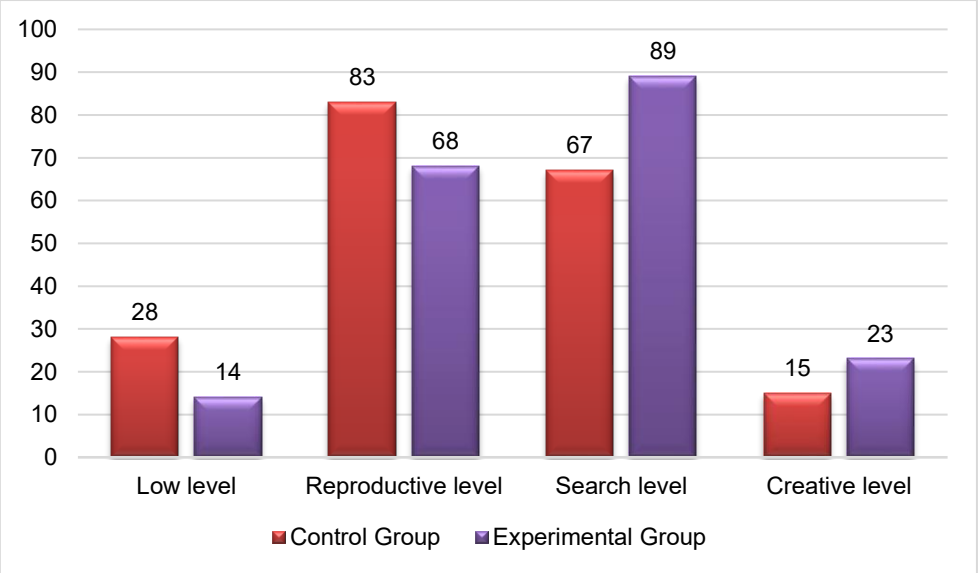


Figure 1. Distribution of students of the experimental and control groups by the levels of development of soft skills in students

At the final stage, the experimental group showed a more favorable distribution across the four levels than the control group. In the EG, 45.88% of students were classified at the search level and 11.86% at the creative level, whereas the corresponding proportions in the CG were 34.72% and 7.77%. Thus, the combined proportion of students at the search or creative levels was 57.73% in the EG, compared with 42.49% in the CG. At the same time, the proportion of students at the low level was lower in the EG (7.22%) than in the CG (14.51%).

These findings are consistent with the mean-score results presented in Table 1, which also showed substantially larger changes in the experimental group. However, the final distribution alone does not demonstrate the magnitude of within-group change from baseline. Therefore, conclusions about changes in the four-level distribution should be based on a direct comparison with the corresponding baseline distribution rather than on the final distribution alone.

Because the baseline assessment used a three-level classification, whereas the final analysis employed a four-level classification, direct before–after comparison of the four-level distributions was not possible. Therefore, Table 2 is interpreted as a cross-group comparison of the final distribution rather than as a direct measure of within-group change. The evidence for pre–post change is provided by the criterion-level mean scores reported in Table 1 and the corresponding statistical analysis.

The stronger improvement in the activity dimension is consistent with previous research emphasizing the role of active and experiential learning in soft skills development. Betti et al. (2022) reported that active learning can contribute to the

development of both professional and soft skills, while Almeida and Buzady (2022) demonstrated the potential of simulation-based learning for developing competencies such as teamwork, leadership, and decision-making. The present findings extend these observations by showing that a broader integrated intervention can be associated with improvements not only in activity-related competencies but also in motivational, cognitive, and reflective dimensions.

The increase in the reflective criterion (+0.68) is also noteworthy. This result may be related to the inclusion of activities requiring students to evaluate their performance, discuss outcomes, present project results, and engage in feedback and self-assessment. However, the present design does not allow the contribution of any single activity or technology to be isolated. The observed improvement should therefore be attributed to the integrated intervention rather than to AI, virtual reality, hackathons, or gamification individually.

The motivational and cognitive changes (+0.62 and +0.56, respectively) further suggest that the intervention was not limited to the behavioral application of soft skills. The combination of collaborative tasks, project activities, simulations, and digital learning environments may have provided students with opportunities to understand the relevance of soft skills and to apply this knowledge in practical situations. This interpretation is compatible with the literature emphasizing the multidimensional nature of soft skills and the importance of combining knowledge, practice, interaction, and reflection in their development.

The final group distributions provide additional evidence of a more favorable outcome for the experimental group. The proportion of students classified at the search or creative levels was 57.73% in the EG compared with 42.49% in the CG, while the proportion at the low level was 7.22% in the EG compared with 14.51% in the CG. These differences are consistent with the criterion-level results presented in Table 1. Nevertheless, because the four-level classification was not used consistently at the baseline stage, the final distribution should be interpreted as evidence of between-group differences at the final stage rather than as a direct estimate of the magnitude of pre–post change.

Several alternative explanations should also be considered. First, because the study used existing academic groups rather than individual randomization, differences between the groups that were not captured by the baseline comparison may have contributed to the observed outcomes. Second, the experimental group received a more intensive and varied learning experience, and therefore the effects may reflect increased engagement, interaction, or exposure to active learning rather than the specific contribution of individual digital technologies. Third, the study design does not permit determination of which component of the integrated system was most influential. These considerations suggest that the results support the effectiveness of the intervention as a whole but should not be interpreted as evidence that any single technology independently caused the observed improvements.

The findings nevertheless provide empirical support for the central hypothesis that students participating in the integrated pedagogical system would demonstrate greater improvement in soft skills than students participating in conventional educational activities. The results are particularly relevant because they show convergence between two forms of evidence: changes in mean scores across four criteria and differences in the final distribution of students across soft skills levels.

An additional limitation concerns the measurement instrument used to assess students' soft skills. The structured assessment instrument was developed specifically for the purposes of the present pedagogical experiment and included motivational, cognitive, activity, and reflective dimensions. Although the instrument provided a structured framework for assessing changes in students' soft skills, a separate psychometric validation, including formal assessment of construct validity and internal consistency reliability, was not conducted. Therefore, the measurement results should be interpreted with appropriate caution. Future research should further validate the instrument using established psychometric procedures and examine its reliability and validity in larger and more diverse student samples.

In addition, although students were classified into low, reproductive, search, and creative levels, the operational score thresholds for these classifications were not formally standardized or psychometrically validated, which represents an additional limitation of the study.

Conclusions

The study examined the effectiveness of an integrated pedagogical system based on innovative educational technologies for developing university students' soft skills. The quasi-experimental study involved 387 students from three Ukrainian higher education institutions, including 194 students in the experimental group and 193 in the control group. The intervention combined active and experiential learning activities with digital technologies within a coherent pedagogical framework comprising technological, content, personal, and activity components.

The experimental group demonstrated substantially greater improvements than the control group across all four assessed dimensions of soft skills. The mean changes were +0.62 versus +0.10 for the motivational criterion, +0.56 versus +0.10 for the cognitive criterion, +0.76 versus +0.10 for the activity criterion, and +0.68 versus +0.14 for the reflective criterion. Although a statistically significant pre–post change was also observed in the control group, the hypothesis concerning greater improvement in the experimental group should be evaluated on the basis of the direct between-group comparison of change scores. The results of this comparison provide the appropriate statistical basis for determining whether the integrated pedagogical system was more effective than conventional educational activities.

The final distribution of students also showed a more favorable pattern in the experimental group. At the final stage, 57.73% of students in the experimental group were classified at the search or creative levels, compared with 42.49% in the control group, while the proportion of students at the low level was 7.22% in the experimental group and 14.51% in the control group. However, because the baseline assessment used a three-level classification whereas the final distribution was reported using four levels, these data should be interpreted as a final between-group comparison rather than as a direct estimate of change across the four levels. The main contribution of the study is therefore the empirical evaluation of an integrated pedagogical system rather than the validation of any individual technology. Hackathons, project activities, simulations, gamification, collaborative digital platforms, artificial intelligence, virtual reality, forums, and other digital tools were implemented as interconnected elements of the same intervention. The present design does not permit their individual effects to be isolated, statistically compared, or ranked in terms of effectiveness. Accordingly, the observed improvements should be interpreted at the level of the integrated intervention and should not be attributed causally to any particular technology or learning activity.

The findings suggest that the systematic combination of active learning, collaborative interaction, practical tasks, digital technologies, and reflective activities may provide favorable conditions for the multidimensional development of students' soft skills. This interpretation is consistent with previous research emphasizing the value of active, experiential, collaborative, and digitally supported learning for soft skills development.

The study has several practical implications for higher education. The proposed system can serve as a framework for integrating innovative technologies into learning activities aimed at developing motivational, cognitive, activity, and reflective dimensions of soft skills. Its application should focus not on the adoption of particular technologies in isolation, but on their purposeful integration with pedagogical objectives, collaborative activities, practical tasks, feedback, and reflection.

The findings should nevertheless be interpreted in light of the study's methodological limitations. The use of existing academic groups and the absence of individual randomization limit causal inference and generalizability. In addition, the simultaneous implementation of multiple technologies and pedagogical strategies prevents the independent contribution of individual components from being determined. Future research should therefore employ randomized or factorial designs, separate intervention conditions, and longer-term follow-up assessments to examine the relative and interactive effects of individual technologies and to determine whether the observed improvements are sustained over time.

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Original Article

Desarrollar la competencia en diseño y modelado de los futuros profesionales en el entorno de la educación superior digital

Developing design and modeling competence of future professionals in the digital higher education environment

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Resumen

Se demuestra la necesidad de desarrollar la competencia de diseño y modelado de los futuros especialistas en el entorno digital de la educación superior, junto con sus componentes y estructura. Se demuestra el papel del entorno digital en la educación superior para el desarrollo de dicha competencia. Se describen los enfoques ampliamente utilizados en el entorno digital de la educación superior como base para el desarrollo de la competencia de diseño y modelado. Se caracteriza el estado de formación de la competencia de diseño y modelado de los futuros especialistas en el entorno digital de la educación superior. Los resultados del experimento de verificación han demostrado la necesidad de actualizar el currículo de educación superior y realizar un estudio experimental específico en la etapa formativa del estudio. Un análisis comparativo de los resultados (cualitativos y cuantitativos) de las secciones finales de los niveles de formación de todos los componentes de la competencia descrita en los encuestados, la dinámica positiva de su formación, demuestra de manera convincente la eficacia del sistema experimental desarrollado para la formación de estudiantes en el entorno digital de la educación superior y las condiciones pedagógicas. El estudio permitió identificar las principales vías para desarrollar la competencia descrita en el entorno digital de la educación superior entre los futuros especialistas.

Palabras clave: competencia en diseño y modelado; entorno digital; educación superior; componentes STEAM; recursos digitales.

Abstract

The necessity of developing the design and modeling competence of future specialists in the digital environment of higher education, along with its components and structure, is demonstrated. The role of the digital environment in higher education in the development of design and modeling competence is demonstrated. The approaches widely used in the digital environment of higher education as a basis for the development of design and modeling competence are outlined. The state of formation of design and modeling competence of future specialists in the digital environment of higher education is characterized. The results of the ascertaining experiment have shown the need to update the higher education curriculum and to conduct a special experimental study at the formative stage of the study. A comparative analysis of the results (qualitative and quantitative) of the final sections of the levels of formation of all components of the outlined competence in respondents, the positive dynamics of its formation convincingly proves the effectiveness of the developed experimental system of training students in the digital environment of higher education and pedagogical conditions. The study allowed us to identify the main ways of

developing the outlined competence in the digital environment of higher education among future specialists.

Keywords: design and modeling competence; digital environment; higher education; STEAM components; digital resources.

Introduction

The modern development of technologies worldwide requires a high level of design and modeling competence from specialists across all specialties.

Intensive development and systemic integration of digital technologies into educational practices significantly change the requirements for the professional activity of specialists, necessitating a rethink of the results of their training and the content of higher education institutions. The educational digital environment becomes a full-fledged space for each student's professional interaction. It ceases to be an auxiliary tool in the educational process, in which a specialist must use digital resources safely and ethically, apply them in practice, and not only master theoretical knowledge.

The formation of design and modeling competence of future specialists in the digital environment of higher education is a critically important task in the conditions of Industry 5.0 and the digitalization of education, since it is this process that ensures the ability of graduates to model professional processes, create new digital products, and work confidently with modern technologies.

A modern specialist must be able to develop their own educational products, organize professional activities in accordance with the principles of activity-based, competency-based, and personality-oriented approaches, and not only possess subject-matter knowledge. Therefore, the development of design and modeling competence is an important task in the professional training of future specialists.

In the practice of training future specialists, there is insufficient integration of competency outcomes into educational programs, fragmented implementation of the digital component, and limited consistency between practical and theoretical training. An additional complexity is the lack of a single scientifically based approach, taking into account European requirements, for assessing the quality of higher education and for determining the mechanisms and structure of developing design and modeling competence in future specialists. This necessitates a comprehensive analysis of organizational aspects and the content of professional training, identifying factors that influence the effectiveness of developing design and modeling competence in future specialists under the conditions of transformation of the educational space. Therefore, the outlined scientific research problem is necessary.

Literature Review

González-Mujico (2024) highlights the importance of assessing digital competence in students and educators beyond self-assessment approaches. The study proposes rubric-based frameworks that enable a more structured and objective evaluation of digital competence, providing relevant methodological foundations for assessing competencies developed in technology-enhanced educational environments.

In the works of Matjašič and Vogrinc (2024), research competence is analyzed as a multidimensional construct that combines attitudes, knowledge, and skills and

requires valid instruments and clear operationalization of assessment. Scientists emphasize the need to align theoretical models with teaching practice and discuss the gap between the actual development of research skills and subjective perception.

George-Reyes et al. (2023) in their study identify the mechanisms and structure of the formation of design and modeling competence in future specialists, the development of research competencies, which are linked in research with digital technologies, with the conditions of Education 4.0 and the development of complex thinking, which is necessary for the formation of the corresponding skills of the individual; emphasize the importance of the educational environment for the life of every person.

Sathya and Alamelu (2026) proposed the SmartPD model, an AI-assisted professional development framework designed to enhance teachers' digital competence in accordance with the DigCompEdu framework. Using a design-based research approach, the authors integrated micro-learning, artificial intelligence tools, and continuous feedback mechanisms into teacher training. Their findings demonstrated significant improvements across all DigCompEdu competence areas, particularly in teaching and learning practices and in facilitating learners' digital competence. The study highlighted the effectiveness of personalized and scalable digital professional development supported by AI technologies.

Amelia et al. (2024) emphasized the importance of Digital Didactical Design (3D) as a promising pedagogical competence in the digital era. Based on a systematic literature review, the authors argued that 3D enables teachers to design meaningful and student-centered learning experiences through the effective integration of digital technologies. The study demonstrated that participation in the design process helps teachers develop pedagogical knowledge and adapt learning activities to students' needs. According to the authors, detailed and well-structured digital instructional design contributes significantly to successful learning outcomes and the development of teachers' pedagogical competence.

Thus, the reviewed studies demonstrate that the development of future professionals in the digital higher education environment requires integrating digital competence, research skills, communication skills, instructional design, and innovative pedagogical approaches. Scholars have highlighted the significant role of digital technologies, artificial intelligence, digital leadership, and learner-centered educational design in enhancing professional preparation and competence development. At the same time, the analysis of the literature reveals that the issue of developing design and modeling competence as an integrated professional competence of future specialists has not been sufficiently explored. In particular, there is a lack of empirical research to identify and validate effective pedagogical conditions, digital tools, and instructional strategies for fostering design and modeling competence in digital higher education environments. Therefore, this study aims to address this research gap by substantiating and experimentally verifying approaches for developing design and modeling competence among future professionals in the context of digital transformation in higher education.

Research objective: To evaluate the effectiveness of a pedagogical system supported by digital technologies for developing design and modeling competence among university students by comparing the levels of its motivational, cognitive, and activity-related components between an experimental group and a control group.

Methodology

Research Design

This study employed a mixed-methods research design combining theoretical, empirical, and statistical approaches to investigate the development of design and modeling competence among future professionals in the digital higher education environment. The research was conducted in two stages: an ascertaining stage aimed at identifying the initial level of competence formation and a formative stage focused on implementing and evaluating an experimental training system supported by specific pedagogical conditions.

Participants

The study involved 346 undergraduate students enrolled in teacher education and educational sciences programs at three Ukrainian higher education institutions. Participants were recruited using purposive sampling because they were studying disciplines related to educational technologies, instructional design, and professional training.

The inclusion criteria were: (1) enrolment in the second to fourth year of undergraduate study; (2) participation in courses involving digital educational technologies; and (3) informed consent to participate in the research. Students who did not complete all stages of the experiment or were absent from more than 20% of the intervention sessions were excluded from the final analysis.

After the baseline assessment, students were assigned to a control group (CG, n = 173) and an experimental group (EG, n = 173) while maintaining comparable distributions regarding study year, mode of study (full-time/part-time), and initial competence levels.

Baseline comparability between groups was established by examining the distributions of competence levels across all assessed components, which showed highly similar initial characteristics in the control and experimental groups.

Research Instruments

The assessment of participants' professional competence was conducted using a structured diagnostic toolkit developed by the authors based on the defined competence framework. The instrument consisted of 36 items grouped into three dimensions corresponding to the conceptual model of competence: motivational (12 items), cognitive (12 items), and activity-based (12 items).

All items were evaluated using a five-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree). Higher scores indicated a higher level of competence development.

For each participant, scores were calculated separately for each dimension and as an overall competence index. Based on the percentage of the maximum possible score, participants were classified into three competence levels:

Low level: less than 60% of the maximum score.

Medium level: 60–79%.

High level: 80–100%.

The questionnaire combined self-assessment items with performance-oriented statements describing typical professional situations encountered in digital educational environments. The motivational dimension measured attitudes toward digital professional development, readiness for innovation, and learning motivation. The cognitive dimension assessed knowledge of digital technologies, pedagogical approaches, and inclusive educational practices. The activity-based dimension evaluated the practical ability to apply digital tools in solving professional tasks, organizing collaborative learning, and implementing inclusive instructional strategies.

Prior to the main experiment, the instrument was piloted with 30 students who were not included in the final sample. The pilot study confirmed the clarity and comprehensibility of all questionnaire items, resulting only in minor linguistic revisions.

Content validity was established through expert evaluation by seven university academics specializing in pedagogy, educational technology, and digital learning. Experts independently evaluated each item regarding relevance, clarity, and correspondence to the proposed competence components using a four-point relevance scale. The average Content Validity Index (S-CVI) was 0.92, indicating excellent content validity.

The internal consistency of the instrument demonstrated satisfactory reliability. Cronbach's alpha coefficients were 0.84 for the motivational dimension, 0.87 for the cognitive dimension, 0.89 for the activity-based dimension, and 0.91 for the overall questionnaire, indicating high internal consistency.

Construct validity was additionally examined through exploratory factor analysis, which confirmed the expected three-factor structure corresponding to the theoretical model. The extracted factors explained 68.4% of the total variance, supporting the construct validity of the measurement instrument.

Experimental Procedure

The formative intervention lasted one academic semester (16 weeks) and was integrated into the regular educational process.

Students in the experimental group completed a structured programme aimed at developing design and modeling competence through project-based and inquiry-based learning. The programme included weekly practical workshops, collaborative design projects, digital modeling tasks, case analysis, reflective activities, mentoring sessions, and portfolio development.

Participants designed educational products, developed conceptual and digital models, solved authentic professional problems, presented project outcomes, and received continuous formative feedback from instructors.

The control group studied the same academic content using conventional teaching approaches based on lectures, seminars, and standard practical assignments without the structured digital intervention.

The intervention incorporated several digital technologies. Google Workspace and Moodle were used for communication, learning management, and collaborative work; Canva supported the creation of educational products and visual materials; Padlet and Miro facilitated collaborative brainstorming and project planning; Trello supported project management; cloud services (Google Drive, Microsoft OneDrive, Dropbox, and Mega) enabled collaborative document sharing; and augmented reality, virtual reality, and gamification activities were integrated into selected learning tasks to enhance visualization, interaction, and student engagement.

Data Analysis

The collected data were analyzed using descriptive and inferential statistical methods. At the ascertaining stage, baseline comparability between the control and experimental groups was examined by comparing the distributions of competence levels across the motivational, cognitive, and activity-related components. The highly similar distributions observed across both groups supported their comparability before the intervention. At the formative stage, Pearson's chi-square test (χ^2) was used to examine differences in competence-level distributions between the experimental and control groups. Statistical significance was established at $\alpha = 0.05$.

The null hypothesis (H_0) assumed that the experimental training system and pedagogical conditions did not significantly affect the development of design and modeling competence. The alternative hypothesis (H_1) assumed that the implemented intervention produced statistically significant improvements in competence formation. The obtained χ^2 values were compared with the critical values to determine the statistical significance of the observed differences between the groups.

This methodological approach ensured the validity, reliability, and objectivity of the research findings. It enabled a comprehensive evaluation of the proposed system's effectiveness in developing design and modeling competence in the digital higher education environment.

Qualitative Data Analysis

To complement the quantitative findings, qualitative data were collected through semi-structured interviews and structured classroom observations.

Semi-structured interviews were conducted with 24 students from the experimental group after completion of the intervention. The interviews explored students' perceptions of the learning process, the usefulness of digital technologies, challenges encountered during project implementation, and perceived development of design and modeling competence.

Structured observations were carried out throughout the intervention using an observation protocol focusing on students' collaboration, problem-solving strategies, engagement in project activities, and application of digital tools.

Interview transcripts and observation records were analysed using thematic analysis to identify recurring patterns related to students' experiences and the development of design and modeling competence.

Ethics Statement

Participation in the research was voluntary. All participants received detailed information regarding the objectives, procedures, potential benefits, and confidentiality of the study before providing written informed consent. Participants were informed of their right to withdraw from the study at any stage without any academic consequences.

Confidentiality and Data Protection

All collected data were anonymised before statistical analysis. Personal identifiers were removed from the research database, and access to the data was restricted to the research team. The findings are reported only in aggregated form to protect participants' privacy.

Results and Discussion

The need to develop the design and modeling competence of future specialists in the digital environment of higher education, including its components and structure.

In this study, design and modeling competence is defined as an integrated professional competence that enables future specialists to identify professional problems, design evidence-based solutions, construct conceptual and digital models, implement projects, and evaluate their effectiveness within digital educational and professional environments. This competence integrates motivational readiness, theoretical knowledge, methodological understanding, and practical skills required for planning, modeling, implementation, reflection, and improvement of professional activities (Laakso et al., 2021).

To avoid conceptual ambiguity, this study distinguishes design and modeling competence from several related constructs frequently discussed in the literature **(**Hsiao et al., 2025).

Instructional (educational) design refers to a pedagogical methodology for planning learning experiences and educational environments. It represents one of the contexts in which design and modeling competence is applied rather than the competence itself.

Research competence is understood as the ability to formulate research questions, select appropriate methods, collect and analyze data, and interpret research findings. Within the present study, research competence supports evidence-based decision-making during the design process but does not constitute the primary construct being assessed.

Digital competence comprises the knowledge and skills required for the effective, safe, and ethical use of digital technologies. It functions as an enabling condition for developing design and modeling competence because digital tools facilitate planning, visualization, collaboration, and implementation of projects.

Three-dimensional (3D) modeling represents a specialized technological skill used to create and manipulate digital spatial models. In this study, it is considered one practical manifestation of design and modeling competence rather than an independent competence.

Project development and project-based learning are instructional approaches through which students apply design and modeling competence in authentic professional tasks. They constitute pedagogical methods used during the intervention rather than the competence itself.

Accordingly, the object of assessment in this research was design and modeling competence, operationalized through three interrelated components.

- The motivational component reflects students' readiness for innovative professional activity, their motivation to engage in design and modeling processes, and their willingness to continuously improve professional practice.
- The cognitive component includes knowledge of design principles, systems modeling, project planning, research methodology, and digital technologies required for solving professional problems.
- The activity-related component reflects students' ability to design, model, implement, test, evaluate, and refine professional projects using appropriate digital technologies and collaborative methods (Matjašič & Vogrinc, 2025).

Thus, instructional design, research competence, digital competence, project-based learning, and 3D modeling are treated in this study as supporting domains, pedagogical approaches, or technological means that contribute to the development of design and modeling competence, which remains the sole target construct evaluated throughout the experimental research (Canoğulları & Sarı, 2026).

The role of the digital environment of higher education in the formation of design and modeling competence. Approaches that are widely used in the digital environment of higher education as the basis for the formation of design and modeling competence.

Design and modeling competence is based on normative, variational, technological, partially methodological, control, and evaluation components; it involves the acquisition by future specialists of the ability to design professional activities, which is impossible without the presence of professional qualities. Thus, design and modeling competence occupies the highest level in the digital environment of higher education, the basis of which is formed by technological, partially methodological, variational, normative, control, and evaluation components, since all of them are implemented in the digital environment of higher education during the creation of a lesson project in the form of its outline. The internal reserve of design and modeling competence is the corresponding competencies, the basis of which is the ability to draw up practical characteristics, the ability to apply them during design and knowledge of the structure of thematic and calendar planning, knowledge of possible structures and types of classes, methods of organizing professional activities, and managing them; knowledge of the specifics of forms, means, and methods of teaching and the ability to select the necessary means, methods, and forms of teaching for a professional subject; the ability to create projects on individual course topics using different educational and methodological sets (Maisiri & van Dyk, 2020). Unlike the project method, the design method is a more universal approach used in science, engineering, and business, not only in education. It is guided by a needs analysis to create new solutions and develop testing, concepts, and implementation. Both methods (project and design) contribute to design and modeling competence, but the first is in the educational process, and the second is in a professional context. The design method effectively develops design, modeling, and research competence, since it is structured according to the logic of creative and search activities aimed at creating an innovative result in the digital environment of higher education – a design product that solves the current problems of harmonizing

augmented, virtual, and objective realities. The achievement of an innovative result demonstrates a high level of development in design and modeling competence.

The formation of design and modeling competence occurs within the digital environment of higher education amid the digital transformation of education, which involves the active use of information technologies in the educational process. Digital technologies are information tools that act as powerful means to ensure a high level of readiness among specialists and to optimize the process of their professional training for professional activity.

A specialist of the 21st century must perform engineering and graphic tasks, use the latest digital technologies and modern computer graphics programs and resources, have a high level of spatial representation, and not just navigate in drawings and diagrams.

In the global context, the training of future specialists in the digital environment of higher education is increasingly focused on developing design skills and forming design and modeling competence as key components of a specialist's professional competence.

The ability to implement educational processes, plan, and model using design is the basis for creating an innovative, flexible, individualized educational environment.

Thus, the Project-Based Learning (PBL) approach is widely used in the digital environment of higher education as a basis for developing design and modeling competence and practice-oriented thinking in future specialists. PBL aims to implement simulated or real educational projects, with an emphasis on research activities, group work, interdisciplinarity, and the presentation of results. For example, the creation of model educational courses by future specialists that integrate critical-thinking elements, STEAM components, and digital resources (Arvianto et al., 2023).

The Service Learning approach combines project-based learning with civic activity to solve important social problems. Educational initiatives implement the digital environment of higher education as a basis for the formation of design and modeling competence, where students implement and develop educational projects for cultural centers, local schools, libraries, etc., which contributes to the formation of students' practical skills, project management, and social responsibility in the educational environment.

The Inquiry-Based Learning approach is grounded in students' research skills across the stages of research design, hypothesis formulation, problem statement, and the implementation and analysis of research, thereby deeply developing students' design and analytical skills by directly involving them in the creation and evaluation of professional scenarios.

To develop design and modeling competence in the digital environment of higher education, the use of virtual design and digital platforms is widespread globally. The active use of digital learning tools: Google Workspace, Moodle, Canva, and Padlet allows students to work online on projects, in particular, create interactive models, carry out group work remotely, and visualize educational content. This is especially relevant in the context of distance and hybrid learning (Capperucci, 2020).

To form design and modeling competence, project mentoring and tutoring are necessary. When training future specialists in the digital environment of higher education, individual tutoring practices are widely used: mentors accompany them in creating original projects, helping improve the project's structure and content, and providing constructive feedback.

The high effectiveness of the project approach is evidenced by global practices in developing a specialist's design and modeling competence. Their common features are the development of critical thinking, digital support, connection with real educational tasks, interdisciplinarity, and active cooperation with communities. Such approaches and practices can be effectively adapted to the higher education system to develop design and modeling competence, in particular by creating conditions within the digital environment of higher education for updating curricula and educational projects in partnership with communities, and by integrating modern digital technologies into professional activities. In the current global transformation of education, it is increasingly important to train modern specialists to work in a digital environment and to design and implement professional processes based on innovative approaches independently. The development of design and modeling competence among future specialists is recognized as a key factor in professional growth, in which a person is not merely a program executor but a developer of their own professional content (Peng et al., 2020).

In the digital environment of higher education, the following are used to form design and modeling competence: modeling of fragments of classes, individual educational projects during practice, simulation and role-playing games, development of own methodological cases, creation of electronic blogs, portfolios where author's developments are recorded; systematic inclusion of project activity in the structure of educational programs; approaches that form the teacher's ability to identify learning problems, test and create professional solutions; use of digital tools for designing interactive content; use of modules from Inquiry-Based Learning and Educational Design Research to enable students to conduct their own micro-research and design the results in the form of educational projects; assessment of design skills through portfolio management, public defense, reflective analysis; digital design (e-learning design); development of digital educational products (web quests, mobile learning applications) by students as mandatory components of the course (Bielik et al., 2019).

The state of development of design and modeling competence of future specialists in the digital environment of higher education.

The purpose of the ascertaining stage of the experiment was to study the state of development of design and modeling competence of future specialists in the digital environment of higher education.

A significant number of students were involved in the experiment in order to ensure the reliability of the scientific research.

The ascertaining stage of the experiment covered students – applicants for the bachelor's degree in full-time and part-time forms of study.

The total number of participants in the ascertaining stage of the study, during which observations, questionnaires, interviews, and analyses of quasi-professional task performance were conducted, was 346 respondents, of whom 173 were in the control groups and 173 in the experimental groups.

In an experimental study on the structural dimension, we considered design and modeling competence and its formation in future specialists in the digital environment of higher education as a multidimensional system comprising motivational, cognitive, and activity components.

The motivational component reflects readiness for innovative activity, the student's positive attitude towards design and modeling, awareness of their professional significance, and the internal need for professional self-development.

The cognitive component covers the principles of scientific knowledge, the system of knowledge about the methodology of design, modeling, and research activities, and the logic of pedagogical research.

The activity component is reflected in the development of skills and practical abilities for organizing educational research and in the development and implementation of educational projects.

The set of these characteristics constitutes an ability that demonstrates a certain level of design and modeling competence (high, average, low).

At the stage of the ascertaining experiment, we investigated how well the design and modeling competence of future specialists is formed. The ascertaining stage made it possible to conclude that the outlined problem was not given due attention and showed that students are not sufficiently prepared for modeling and design in the conditions of educational and professional activity, do not pay enough attention to modern digital technologies and forms of self-development and self-improvement. All this convincingly proves the need for the formative stage of our study.

From among the students who participated in the ascertaining stage of the experiment, a control group and an experimental group were selected to participate in the formative stage.

Based on the general population, the sample size was calculated ($n = 346$). The marginal error of representativeness (0.05) and the reliability probability of the results (0.95) of the experimental study were taken into account.

The sample size was calculated using the formula:

$$n = \frac{N \cdot t^2 \cdot \overline{\sigma_l^2}}{N\Delta_x^2 + t^2\overline{\sigma_l^2}}$$

Where:

n – sample size.
t – standard deviation ($t = 1.96$).
N – population size.
p– level of trustworthiness ($\mathrm{p} = 0.954$).
$\overline{\sigma_l^2}$– average variance (maximum value accepted – 0.25) of a random variable.
Δ_x – acceptable (value chosen 0.05) margin of error.

The standard deviation t is consistent with the given confidence level p. The value of the t is determined using the normal distribution table, according to which $t = 1.96$ at $\mathrm{p} = 0.95$.

The maximum value was used to obtain more reliable results. =0.5 was adopted in the absence of statistical information, since this gives (0.52=0.25) the maximum variance. Thus, the obtained indicator is overestimated for the sample size, which adds to the reliability of the results. We calculate the sample size of students using the formula:

$$n = \frac{3466 \cdot 3.8416 \cdot 0.25}{3466 \cdot 0.0025 + 3.8416 \cdot 0.25} \approx 346$$

Analysis of the resource provision of higher education institutions provided grounds for asserting that the absolute number of respondents is sufficient to test the study's results.

Taking into account the above components and indicators of the formation of students' design and modeling competence, an ascertaining experiment was planned and conducted with separate control and experimental groups, the results of which allowed us to determine the current state of the levels of students' design and modeling competence. The results of the ascertaining experiment are summarized in Table 1 and Fig. 1.

Table 1.
Design and modeling competence levels by component (Ascertaining Stage)

Components	Groups	High Level, n (%)	Average Level, n (%)	Low Level, n (%)
Motivational	CG	30 (17.3%)	97 (56.1%)	46 (26.6%)
	EG	29 (16.8%)	99 (57.2%)	45 (26.0%)
Cognitive	CG	21 (12.1%)	97 (56.1%)	55 (31.8%)
	EG	19 (11.0%)	97 (56.1%)	57 (32.9%)
Activity	CG	27 (15.6%)	97 (56.1%)	49 (28.3%)
	EG	26 (15.0%)	96 (55.5%)	51 (29.5%)

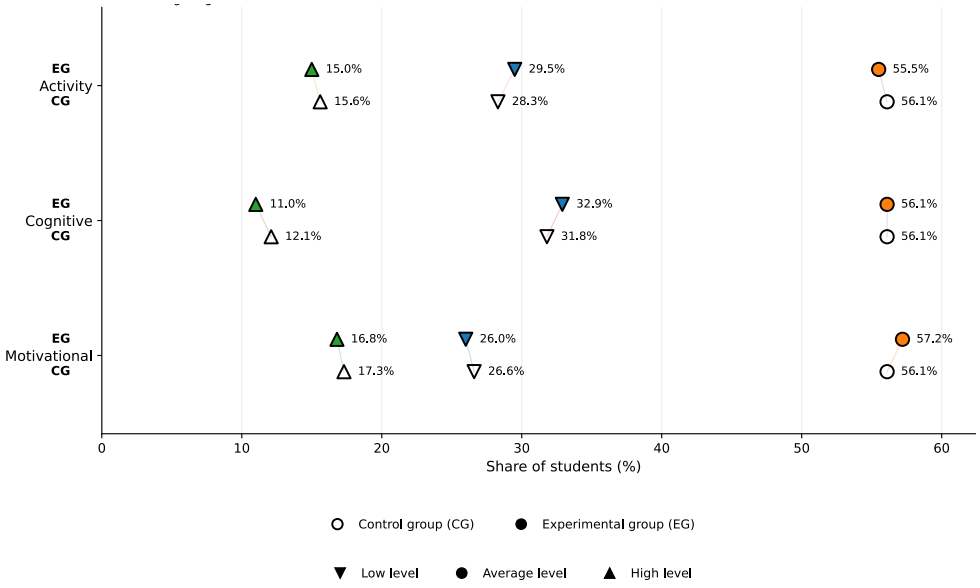


Figure 1. Baseline distribution of design and modeling competence (Ascertaining Stage)

In the ascertaining experiment, statistical processing of the data allowed us to say that the number of students in the experimental group, regarding the formation of design and modeling competence relative to the outlined levels, is as follows:

- According to the motivational component: a low level of formation in the EG is 26.0%, respectively in the CG – 26.6%; an average level – was found in the EG in 57.2% of students, in the CG this indicator is 56.1%; a high level of formation of the outlined competence was found in the EG – 16.8% and in the CG – 17.3%.
- According to the cognitive component: a low level of formation in the EG is 32.9%, respectively in the CG – 31.8%; an average level – was found in the EG in 56.1% of students, in the CG this indicator is 56.1%; a high level of formation of the outlined competence was found in the EG – 11.0% and in the CG – 12.1%.
- By activity component: low level of formation in EG is 29.5%, respectively in CG – 28.3%; average level was found in EG in 55.5% of students, in CG this indicator is 56.1%; high level of formation of the outlined competence was found in EG – 15.0% and in CG – 15.6%.

The objectivity of the experimental study's results is ensured by the equivalence of the two respondent samples, that is, the homogeneity of the experimental and control groups in terms of the level of development of the outlined competence at the beginning of the experiment.

At the ascertaining stage, the distributions of competence levels across the motivational, cognitive, and activity-related components were highly comparable between the experimental and control groups. The differences between the groups did not exceed 1–2 percentage points for most indicators. For example, the proportion of students with a high level of the motivational component was 17.3% in the control group and 16.8% in the experimental group; for the cognitive component, 12.1% and 11.0%, respectively; and for the activity-related component, 15.6% and 15.0%, respectively. Similarly, the proportions of students with low and average competence levels were nearly identical across both groups. These results indicate that the control and experimental groups were comparable at baseline and may be considered equivalent for the purposes of the subsequent formative experiment.

The results of the ascertaining experiment indicated the need to update the higher education curriculum and to conduct a special experimental study at the formative stage of the study.

In order to form the design and modeling competence of future EG specialists, we have identified the following key trends in the digital environment of higher education:

- A competency-based approach to the content of education, where the main attention is paid to the formation and development of students' design and modeling competence of future specialists, in particular the ability to design and analyze professional situations; the ability to interdisciplinary interaction and planning, implementation, and evaluation of educational projects in the digital environment of higher education.
- The spread of the Project-Based Learning (PBL) methodology in modern universities to actively implement project-based learning as a basic methodology for training future specialists in the digital environment of higher education, which is based on the principles of presenting results to an expert audience, using real educational cases, and students' autonomy in solving educational problems.

- Integration of digital technologies, use of digital platforms to form defined competence of future specialists, such as OpenEdu, Erasmus+ Virtual Exchange, eTwinning, which become a space for the implementation of international projects, where students from different countries develop training, joint educational products.
- Within the framework of dual education or professional practice − partnership with a practical environment, which ensures the involvement of students from the first years in professional life (conducting research, implementing innovations, participating in real educational projects), develops design skills in a real context
- Mentoring and professional incubation − creation by universities of professional design centers or teaching labs, educational laboratories for innovative education, where, under the guidance of mentor teachers, students design research models, interactive resources, and develop original methodologies.

We at the EG have proposed the implementation of the following measures in the digital environment of higher education to improve the process of forming design and modeling competence of future specialists:

- Integration of interdisciplinary projects into curricula, complex educational projects similar to the Project-Based Learning approach in the USA.
- Use of digital tools for the formation of design and modeling competence, active use of online platforms for creating projects (Miro, Trello, Canva for Education, Google Workspace for Education) in order to form the skills of future specialists in the digital environment of the higher school of virtual design.
- Introduction of a system of presentation of results and portfolios in order to assess design and modeling competence not only through theoretical tasks in the digital environment of the higher school, but also through the creation of an individual pedagogical portfolio by future specialists, which included original projects, digital products, innovative plans, and video lessons.
- Creation of training workshops, design laboratories to outline creative spaces where future specialists will be able to practically work out the stages of developing educational products in the digital environment of higher education – from the idea to its implementation – in practice.
- Involvement of students (similar to Service Learning) in real educational initiatives, joint projects with employers.
- Advanced training of teachers in order to ensure the professional development of higher education teachers in the field of digital technologies, project management, and facilitation of group work.

The formation of design and modeling competence of future specialists is impossible without taking into account the didactic and basic psychological and pedagogical conditions of developmental learning in the digital environment of higher education. We have developed a set of pedagogical conditions in the digital environment of higher education for the effective formation of a system of design and modeling competence of future specialists:

- Positive motivation of future specialists in the digital environment of higher education to form design and modeling competence.
- Taking into account the intellectual and psychological properties of the individual for work in the digital environment of higher education.
- The use of digital innovative methods and technologies of learning in the digital environment of higher education.

- Independent cognitive activity of students for the formation of design and modeling competence, the formation of design and construction skills, and spatial and critical thinking.

Design and modeling competence of future specialists in the digital environment of higher education provided for the formation of students' skills to work in two-dimensional and three-dimensional graphic environments, the basis of which is working with graphics, sketches, drawings, diagrams in a two-dimensional environment; the ability to compose, read, change, use and improve skills for building spatial models of various objects (surfaces of revolution, polygonal, procedural, mesh objects).

The following information technologies were of great importance for the formation of design and modeling competence among future EG specialists in the digital environment of higher education: game technologies (gamification); cloud technologies; augmented and virtual reality technologies. Let us consider these technologies in more detail, along with the features of their application in EG, in relation to the formation of design and modeling competence among future specialists in the digital environment of higher education.

The use of gamification in the digital educational environment of higher education contributes to increased motivation for learning, a deeper understanding of specialized disciplines, and improved professional training of specialists, during which design and modeling competence is formed.

Gamification, the application of game-based approaches in the digital environment of higher education to implement professional tasks effectively, enhances the efficiency and interactivity of the educational process. This allows future specialists to implement new technological concepts more productively by integrating virtual simulators, modeling production processes, and conducting practical simulations.

The introduction of cloud technologies in EG, the most common of which were eDisk, Mega, Microsoft OneDrive, Google Drive, and Dropbox, enabled remote data processing, storage, and analysis, ensuring security, accessibility, and efficiency.

The use of cloud services in the digital environment of higher education contributed to teaching professional disciplines in digital technology integration, laboratory work, modeling of production processes, and research. Higher education students gained access to shared workspaces and modern software.

The introduction of augmented reality technologies in the digital environment of higher education has significant potential for training specialists. They enabled the improvement of the efficiency of the educational process and design activities, combining digital models with real objects to develop design and modeling competence.

The implementation of virtual reality technologies into the digital environment of the university served to:

- Visualization of 3D models on a real scale, which made it possible to study the principles of work and educational design.
- Testing and design of products, and the creation of physical prototypes, which contributed to reducing resource and time costs.

- Learning through simulations and interactive instructions, which increased the quality of professional training and safety.
- Optimization through AR-assisted production processes, which contributed to the performance of technically complex operations.

The skills acquired by EG students in developing design and modeling competence were applied during production practice, in designing educational systems, and in implementing course projects in professional disciplines.

During the research, we considered the concept of design and modeling competence in the context of implementing a competency approach in the digital environment of higher education and the orientation of education toward the formation of an individual's ability to reflectively, innovatively, and creatively implement cognitive activity. The growing role of research and design methods in the actualization of this phenomenon, the need to integrate knowledge, and the development of skills for the independent construction of a digital educational environment are due to the developed system and the pedagogical conditions implemented in the EG.

Results of the formative experiment.

Taking into account the above-mentioned, as at the ascertaining stage, components and indicators of the formation of students' design and modeling competence, and the innovatively developed system implemented in the EG and the author's pedagogical conditions, made it possible to clarify the state of the levels of formation of students' design and modeling competence in the EG and CG. The results of the formative experiment are summarized in Table 2.

Table 2 and Fig 2. presents a comparative analysis of the formation of the cognitive-operational component of the design and modeling competence of the participants of the control and experimental groups at the end of the experimental study.

Table 2.
Design and modeling competence levels by component

Components	Groups	High Level, n (%)	Average Level, n (%)	Low Level, n (%)
Motivational	CG	34 (19.7%)	100 (57.8%)	39 (22.5%)
	EG	86 (49.7%)	76 (43.9%)	11 (6.4%)
Cognitive	CG	32 (18.5%)	92 (53.2%)	49 (28.3%)
	EG	69 (39.9%)	88 (50.9%)	16 (9.2%)
Activity	CG	29 (16.8%)	109 (63.0%)	35 (20.2%)
	EG	69 (39.9%)	85 (49.1%)	19 (11.0%)

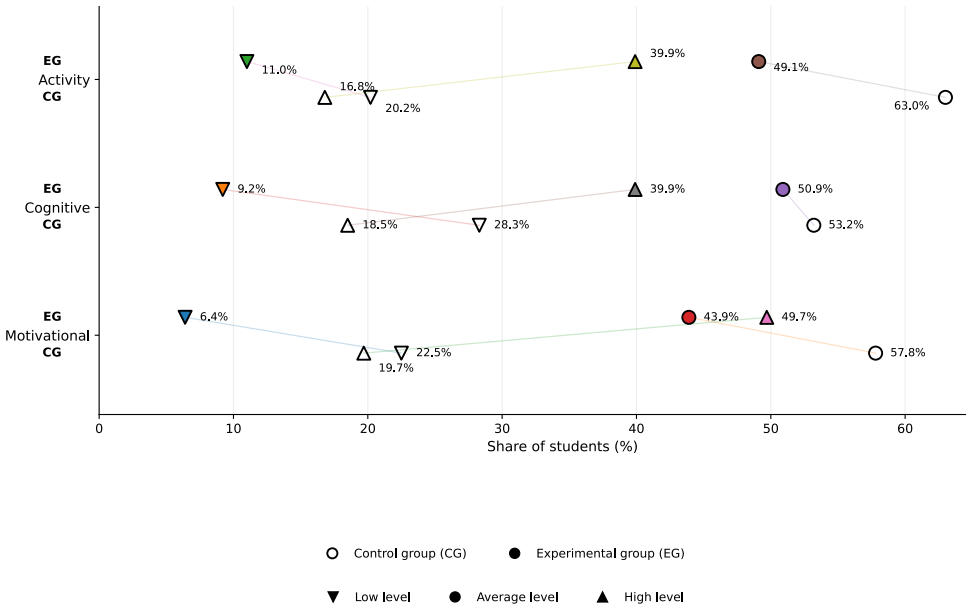


Figure 2. Distribution of design and modeling competence after the intervention (Formative Stage)

Pearson's chi-square analysis was conducted for the motivational component at the end of the intervention. The analysis demonstrated a statistically significant association between group membership and motivational competence level, $\chi^2(2, N = 346) = 41.49$, $p < .001$, Cramer's $V = .35$, indicating a moderate practical effect. The observed frequencies differed substantially from the expected frequencies, with the experimental group containing considerably more participants at the high motivational level and fewer participants at the low motivational level than expected under the null hypothesis. No expected cell frequency was below five, satisfying the assumptions of the Pearson chi-square test.

Table 3.
Observed and Expected Frequencies Used for Pearson's Chi-Square Test (Motivational Component, Formative Stage)

Competence level	Experimental group (Observed)	Experimental group (Expected)	Control group (Observed)	Control group (Expected)
High	86	60.0	34	60.0
Average	76	88.0	100	88.0
Low	11	25.0	39	25.0
Total	**173**	**173**	**173**	**173**

Expected frequencies were calculated according to the Pearson chi-square test assuming independence between group membership and competence level. All expected frequencies exceeded 5, satisfying one of the principal assumptions of the χ^2 test. Pearson's chi-square test indicated a statistically significant association between group and competence level, $\chi^2(2, N = 346) = 41.49$, $p < .001$, Cramer's $V = .35$, indicating a moderate effect size.

At the formative stage of the experiment, statistical processing of the data allowed us to say that the number of students in the experimental group, regarding the

formation of design and modeling competence relative to the outlined levels, is as follows:

- According to the motivational component: the low level of formation in the EG is 6.4%, respectively in the CG – 22.5%; the average level – was found in the EG in 43.9% of students, in the CG this indicator is 57.8%; the high level of formation of the outlined competence was found in the EG – 49.7% and in the CG – 19.7%.
- According to the cognitive component: the low level of formation in the EG is 9.2%, respectively in the CG – 28.3%; the average level – was found in the EG in 50.9% of students, in the CG this indicator is 53.2%; the high level of formation of the outlined competence was found in the EG – 39.9% and in the CG – 18.5%.
- According to the activity component, the low level of formation in EG is 11.0%, respectively in CG – 20.2%; the average level was found in EG in 49.1% of students, in CG this indicator is 63.0%; the high level of formation of the outlined competence was found in EG – 39.9% and in CG – 16.8%.

Analysis of the results of the formation of all components of design and modeling competence of students at the formative stage of the experiment allows us to state that a significant part of EG respondents had a high and average level, and CG students remained practically at the same level – we observe a predominance of low and average levels.

The qualitative analysis identified four recurring themes: increased confidence in solving professional design problems; improved collaboration and project planning; greater ability to integrate digital technologies into professional tasks; and enhanced reflective thinking regarding project implementation. These qualitative findings supported the quantitative results by demonstrating positive changes in students' professional behaviour and learning experiences.

The research results obtained required empirical confirmation of their objectivity and reliability, which was carried out using statistical methods. We used the nonparametric Pearson criterion (χ^2).

Statistical hypotheses were formulated:

Hypothesis H_0: The experimental training system and pedagogical conditions do not affect the qualitative changes in the level of formation of the outlined competence, and the results obtained are random.
Hypothesis H_1: The experimental training system and pedagogical conditions significantly affect the qualitative changes in the level of formation of the outlined competence, and the results obtained are not random.

We calculate the nonparametric evaluation criterion χ^2 using the formula:

$$\chi^2 = \sum \left(\frac{(f_E{}' - f_k{}')^2}{f_k{}'} \right)$$

Where $f_E{}'$– in the experimental group – is the relative frequency of the interval;
$f_k{}'$ – in the control group – relative frequency of the interval.

The number of degrees of freedom for χ^2 is

$$k = (R-1)(C-1) = (3-1)\text{x}(2-1) = 2$$

(2 – number of groups, 3 – number of levels).

The critical value of the $\chi^2_{crit.}$ criterion for the level of $\alpha = 0.05$ according to statistical tables, and the number of degrees of freedom k=2 was found. Therefore, $\chi^2_{emp} > \chi^2_{crit}$. The basis for rejecting the null hypothesis H_0 is the experimental value of the Pearson criterion, and accepting the alternative hypothesis H_1 about the influence of the experimental system of training students in the conditions of digitalization of education and pedagogical conditions on the formation of design and modeling competence.

It should be noted that the comparative analysis of the results (qualitative and quantitative) of the final sections of the levels of formation in respondents of all components of the outlined competence, the positive dynamics of its formation, convincingly proves the effectiveness of the developed experimental system of training students in the digital environment of higher education and pedagogical conditions.

The conducted study allowed us to identify the main ways of forming design and modeling competence in future specialists in the digital environment of higher education, namely:

1. Integration of elements of design and modeling competence in the digital environment of higher education into the content of professional disciplines. This involves the inclusion of practically oriented tasks, problem situations, and open-ended tasks in the educational process to stimulate applicants in the educational space to make assumptions, analyze the results obtained, and find ways to solve problems. This approach forms a research interest.
2. Creating a digital educational environment favorable for design and modeling activities, which involves the use of digital resources, interactive platforms, software tools, and interdisciplinary connections. This approach increases motivation to learn, expands research opportunities, and creates conditions for implementing individual educational trajectories for students.
3. Applying research methods of teaching, analyzing research data, modeling, observation, involving students in testing hypotheses, studying patterns, and generalizing results. This approach fosters the ability to work with abstract concepts and to think logically, which are essential components of design and modeling competence.
4. Using the project method of teaching in higher education. Implementation of group educational projects and individual (applied, research, informational), which allows students to present results, argue their own position, master the skills of planning activities, processing, and collecting information. This approach contributes to the development of independence, responsibility, and cooperation skills.
5. Stimulating students to self-analysis and reflection, aimed at understanding the stages of performing design and modeling tasks, evaluating the results of work, and their own contribution. This approach allows students to identify difficulties, understand the cognitive process, and outline ways to overcome them, thereby contributing to the development of educational autonomy.

Conclusions

The study confirmed the effectiveness of the proposed model for developing design and modeling competence among students enrolled in educational and pedagogical programmes within a digital higher education environment. The implementation of

the model contributed to positive changes across the motivational, cognitive, and activity-related components of competence.

The results of the formative experiment demonstrated that students in the experimental group achieved substantially higher levels of competence development than those in the control group. In particular, the proportion of students demonstrating a high level of competence increased considerably, while the proportion of students with a low level decreased. The statistical analysis confirmed the significance of the observed differences between the groups at the end of the intervention.

The findings suggest that the integration of digital technologies, project-based activities, collaborative learning, and practice-oriented tasks creates favourable conditions for the development of design and modeling competence in higher education students. The qualitative findings further support the quantitative results by indicating increased student engagement, confidence, collaboration, and practical application of acquired knowledge and skills.

The study has several limitations. The sample was restricted to students enrolled in educational and pedagogical programmes, which limits the generalisability of the findings to other academic fields. In addition, the qualitative component involved a relatively small number of participants. Future research should examine the applicability of the proposed model in other disciplinary contexts and explore its long-term impact on competence development through longitudinal studies.

Overall, the results provide empirical evidence that the proposed educational model can effectively support the development of design and modeling competence among students of educational and pedagogical specialities in a digital higher education environment.

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Original Article

Desafíos filosóficos y éticos del uso de neurotecnologías en la educación superior: Una crisis de identidad

Philosophical and ethical challenges of using neurotechnologies in higher education: A crisis of identity

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Resumen

El objetivo del artículo es determinar la dimensión filosófica y ética del uso de las neurotecnologías en la educación superior. El estudio distingue el problema de la neuroética de la tendencia más amplia hacia las soluciones tecnológicas. La base filosófica de la investigación se centra en las reservas éticas sobre el estatus de las neurotecnologías en la educación, consideradas junto con su validación epistemológica y la incertidumbre existencial asociada a este instrumento. La metodología combina enfoques científicos generales y filosóficos, integrando análisis comparativo, análisis del discurso, dialéctica y sinergia. Los resultados muestran la formación de un equilibrio entre las características tecnológicas de la neuroactividad en la educación superior y los principios mentales y de cosmovisión que regulan su aplicación. Las neurotecnologías, mediante el neuromonitoreo, las neurointerfaces y el mejoramiento cognitivo, influyen directamente en el potencial cognitivo de los participantes del proceso educativo. El dilema filosófico y ético subraya la necesidad de proteger la autoidentidad frente a factores externos agresivos. En el contexto posthumanista, caracterizado por la difuminación de la esencia humana y el predominio de soluciones pragmáticas, la crisis de identidad se intensifica. Las neurotecnologías pueden conducir tanto a la sustitución parcial o total del potencial cognitivo humano como a la expansión del repertorio intelectual y emocional sin amenazar la esencia humana.

Palabras clave: potencial cognitivo; tecnologías de la educación superior; dimensión humana de la educación; neuroética; discurso filosófico y antropológico.

Abstract

The aim of the article is to determine the philosophical and ethical dimension of the use of neurotechnologies in higher education. The objectives of the study are focused on distinguishing the problem of neuroethics from the broader trend of technological solutions. The philosophical foundation of the research is reduced to ethical reservations regarding the status of neurotechnologies in education, which are considered alongside the epistemological endorsement and existential uncertainty of this instrument. The research methodology is concentrated around an analytical cluster of general scientific and philosophical approaches. The scholarly vectors of comparative and discourse analysis are supplemented by corresponding philosophical cases of dialectics and synergy. The results of the study indicate the formation, within the contemporary scientific and philosophical worldview, of a balance between the technological characteristics of neuroactivity in higher education and the worldview-based and mental regulative principles governing its application. The role of neurotechnologies is realised through cases of neuromonitoring, neurointerfaces, and cognitive enhancement, which demonstrate an

unequivocal influence on the cognitive potential of participants in the educational process. The philosophical and ethical dilemma points to the need to protect self-identity from an aggressive external factor. Under posthumanist conditions of the blurring of human essence and the sociocultural dominance of pragmatic solutions, the crisis of self-identity deepens. Neurotechnologies may shape two scenarios of influence on the human-centred development of science and philosophy: a radical one, involving the replacement of human cognitive potential by technological solutions, with a partial or complete loss of identity; and an evolutionary one, in which they acquire the status of an epistemologically active instrument that expands the human intellectual and emotional repertoire without threatening the existential constants of human essence and nature.

Keywords: cognitive potential; higher education technologies; human dimension of education; neuroethics; philosophical and anthropological discourse.

Introduction

The integration of innovative achievements in science and technology into the education system is a familiar and inevitable process of sociocultural development. Universities emerge as a space in which scientific and technological trends are implemented in order to enhance the quality of education. The modern pragmatic world dictates the dominance of efficiency, which leads to the search for mechanisms to improve educational activity. Neurotechnologies, which have been successfully tested in other spheres of social activity, in particular in medicine (Boulos, 2024) and economics, are gradually being introduced into the educational strategies of higher education institutions.

Among the principal applications of neurotechnologies in higher education, four key positions are distinguished, encompassing different educational, organisational, and methodological dimensions:

- Neuromonitoring (EEG-based) (Jiao, 2025), which focuses on determining the cognitive state of participants in the educational process (students, lecturers, administrators) through the practical use of technological and digital devices (portable EEG headsets, wearable EEG devices);
- Brain-computer interfaces (BCIs) (Nieves-Méndez, 2026), which are intended to establish effective channels of communication between the human brain and computer resources in order to improve the transmission of educational information content;
- Neurogames (Wang et al., 2025), designed to create non-traditional educational environments in which cognitive abilities are developed and expressed under specific learning conditions;
- Cognitive enhancement resources (Bakker & Mostert, 2024), which involve the use of substances and practices for non-invasive brain stimulation, thereby improving indicators of cognitive activity, including perception, memory, and responsiveness.

It is evident that the use of such significant technological instruments among participants in the educational process generates a variety of risks, both organisational and semantic in nature. In order to assess the organisational challenges of using neurotechnologies, society employs familiar safeguards: legal norms, functional standards, parameters of expediency, and the like. At the same time, the use of neurotechnologies requires control at the level of values and meanings. This process is partly regulated by individuals' internal capacities through

self-determination, which governs emotions and transforms them into academic achievement (Zheng et al., 2026). However, there is a clear need for systematic theoretical and worldview-based regulatory frameworks.

In this article, neurorights is used as an emerging conceptual and normative framework, not as a uniform set of newly established legal rights. Some interests discussed under this label, including privacy, freedom of thought, and personal autonomy, are already protected within existing human rights frameworks. Proposals concerning mental privacy, cognitive freedom, and mental self-determination seek to clarify how such protections should apply to neural data and technological interventions. UNESCO's (2025) recommendation provides an international ethical framework, but its adoption should not be interpreted as creating an identical set of legally enforceable neurorights in every jurisdiction.

Philosophy traditionally acts as a regulator of scientific innovation at the worldview and mental level. A specific feature of scientific progress is the dynamism and variability of the processes and principles governing spheres of activity, including education. Philosophy, in turn, provides various value-oriented, purposive, and meaning-related vectors for scientific development. In this way, the boundary between perception and cognition can be prevented from becoming blurred (Bryce & Blown, 2025).

The cluster of neurotechnologies within the higher education system has come under philosophical scrutiny and has received multidirectional approaches to the assessment of its status and prospects in this sphere (see Fig. 1).

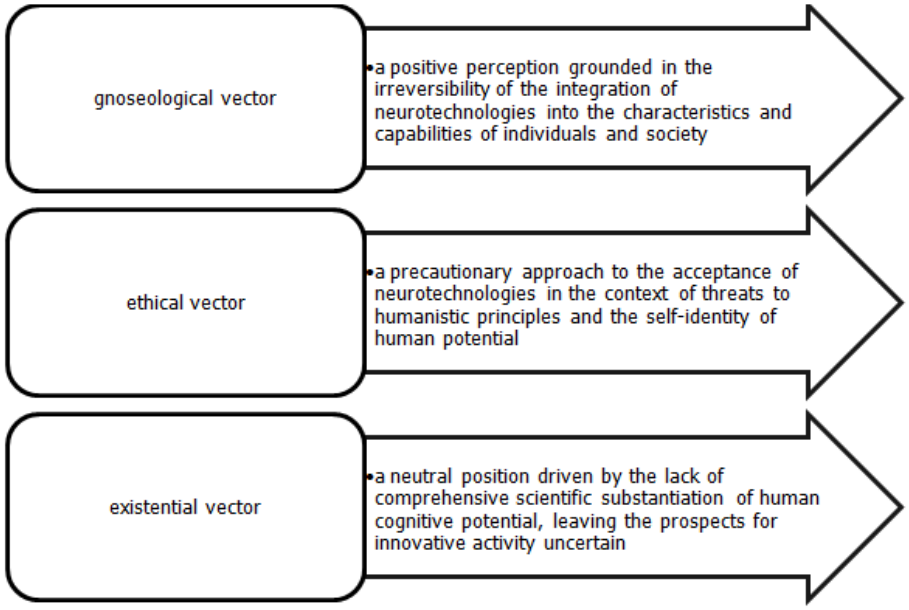


Fig. 1. The status of neurotechnologies in higher education through the prism of philosophical analysis.
Source: developed by the authors.

In general, philosophy provides a multidirectional characterisation of innovative trends in the use of neurotechnologies within the higher education system. At the same time, it is precisely the philosophical and ethical dimension that emerges as a restraining factor against the unsystematic integration of neurotechnologies into the educational process. Any innovative proposal encounters the problem of operational

management and strategic regulation. These aspects become a critical factor in the emergence of ethical problems.

Ding (2026) emphasises that “the governance of neurotechnologies faces a paradox: the spread of ethical concepts—cognitive liberty, mental privacy, neurorights, mental self-determination—has expanded the normative vocabulary without creating the corresponding institutional capacity to ensure compliance with norms” (p. 93). For the higher education system, this deficit in governance capacity is only intensified by the absence of legal mechanisms for internal regulation. At the same time, such realities reinforce the role and significance of the ethical dimension as a regulator of the use of neurotechnologies in the educational process.

The aim of this scholarly inquiry is to provide a philosophical analysis of the ethical dimension of the use of neurotechnologies in higher education. Philosophical reflection is important for balancing the status of neurotechnologies in relation to their scientific characteristics. The objectives of the study are focused on highlighting the philosophical and ethical dimensions of the use of neurotechnologies in the higher education system and on conducting a comparative analysis of axiological and ethical guidelines alongside epistemological and existential parameters.

Theoretical Framework or Literature Review

In contemporary scientific and philosophical discourse, the issue of innovation in higher education occupies an important and highly relevant place, shaping current trends in educational development (Sanabria-Z et al., 2025). The use of neurotechnologies in the organisation of the educational process, as well as in its instructional and methodological dimensions, creates a need to document the results of such innovations. The scholarly community has launched a number of projects aimed at monitoring and analysing the use of neurotechnologies, including the BRAIN Initiative (Eberwine & Kahn, 2020). One of the important points in the academic literature is the positioning of neurotechnology tools in the functioning of higher education from the perspective of:

educational expediency (Nouri, 2025);
educational development (Privitera & Du, 2022);
scientific activity (Cinel et al., 2019);
philosophical and worldview-based interpretation (Clark, 2003).

In the course of presenting the first results of the implementation of neurotechnologies in the higher education system, responses of an epistemological (Schleidgen et al., 2022), ethical, and existential nature began to emerge. It is worth emphasising separately the distinctive filtering function inherent precisely in the philosophical interpretation of the problem. Neurotechnologies have become a genuine scientific and popular trend of the present day, which has led to the appearance of a large number of publications concerning various aspects of the implementation of this instrument. In this context, the process of differentiating the academic body of work becomes increasingly relevant, with a distinction between studies:

that highlight technological characteristics, parameters of practical application, standards of implementation, and the like;
that raise questions concerning the value- and meaning-based dimensions of these technological solutions, drawing on cases of neuroethics, identity (or self-identity), and cognitive liberty.

As a result, the first studies and conclusions concerning the status of neurotechnologies in the higher education system acquired the character of philosophical analysis. In examining the ethical dimensions of the implementation of technological and digital solutions, Floridi (2023) points to the excessive systemic popularisation of these innovations and, alongside this, notes the irreversible formation of the infosphere, with its own functional and meaning-related characteristics, which are fully extrapolated to the educational sphere as well. Ricoeur (2004) notes the threat of the excessive influence of neurotechnologies on the human person, highlighting the blurring of the self and the prospect of technology functioning as an analogue of human cognitive potential. In the philosophical and ethical analysis of neurotechnologies in social activity, it is also worth turning to the postmodern tradition, within which Foucault (1995) points to the formation of the concept of biopower and the effective diminishing of the significance of personal potential.

In this context, it is important to consider the practical use of neurotechnologies in educational settings from different psycho-mental, pedagogical, and sociocultural perspectives. Building on the available evidence regarding the influence of neurotechnologies on educational processes, the present study proposes a synergistic approach to their interpretation within the higher education paradigm as a tool for identifying and overcoming the crisis of identity.

Methodology

The methodological framework of the present research is based on two fundamental approaches: the general scientific approach and the philosophical approach. The methodological procedure of the study can be divided into several consecutive stages.

1. Formation of the source cluster and selection criteria. The object of analysis consisted of scholarly publications published between 2015 and 2026 devoted to the implementation of neurotechnologies, including neuromonitoring, brain-computer interfaces (BCIs), and cognitive enhancement in higher education. Publications were identified through Scopus, Web of Science, and Google Scholar using the keywords "neuroethics in education", "cognitive enhancement ethics", and "crisis of self-identity neurotechnology". The principal inclusion criterion was a focus on ethical or existential risks associated with the use of neurotechnologies in educational environments. A total of 40 academic sources were selected and analyzed. In addition, five classical philosophical works examining the ethical foundations of transformative scientific innovations were reviewed.
2. Application of analytical methods. Discourse analysis was employed to establish a comprehensive understanding of the role of neurotechnologies in higher education and to identify the dichotomy between the pragmatic support of neurotechnological innovations and the ethical concerns associated with anthropological freedom and mental privacy. Comparative analysis was used to evaluate the positive and negative manifestations of neurotechnological support in educational processes, particularly through comparison of neuromonitoring, neurointerfaces, and cognitive-enhancement practices in terms of their effects on human cognitive potential. The dialectical method enabled the identification of contradictions between the cognitive benefits of neurotechnologies and the existential risks associated with the loss of the human-centred character of education and the emergence of identity crises. The philosophical-anthropological approach further clarified the role of neurotechnologies as educational instruments that require preservation of the learner’s autonomous

cognitive potential.

3. Research conceptualisation stage. The conceptualisation stage involved synthesising the collected data and constructing synergistic models of neurotechnologies in education. Conceptual categories were developed to explain the status of neurotechnologies in higher education, principles of their application, and risk algorithms associated with identity transformation. The resulting framework interprets neuroethics as a system of interaction between natural human cognitive potential and artificial technological tools. Finally, value-oriented guidelines were formulated to minimise ethical risks. A model was developed that compares the scale and intensity of neurotechnological influence with the philosophical assessment of potential loss of subjectivity. Within this framework, neurotechnologies are understood as instruments intended to strengthen the identity of participants in the educational process rather than merely improve learning productivity.

Results and Discussion

Ethical issues have emerged as a major point of debate in the use of neurotechnologies in higher education. At the same time, neuroethics has generated a number of related discourses concerned with the correlation between scientific and technological characteristics and philosophical and worldview-based principles in the educational sphere. The specific nature of higher education presupposes a constant balance between traditional foundational principles and innovative dynamic factors. In this context, neurotechnologies effectively serve as the exemplar of this dichotomy.

It should be noted that the worldview potential of the educational sphere is not yet prepared to resolve problems of this kind, since such contradictions, in institutional terms, are often addressed in an absolute manner: either by the complete prohibition of perceived threats or by their uncontrolled use. The scientific sphere, for its part, makes it possible to standardise the use of any instrument employed in the learning process. Consequently, neurotechnologies have acquired the status of technological support for educational activity and a factor in strengthening the cognitive potential of participants in the educational process. A distinct place in the understanding of the positioning of neurotechnologies within the higher education system is occupied by philosophical discourse. Traditionally, philosophy seeks to identify problematic aspects of a latent or delayed nature.

Educational neurotechnologies perform practical functions within the higher education system:

measuring the effectiveness of pedagogical and academic teaching strategies (Darvishi et al., 2022);
investigating the parameters of the neural correlation between learning and teaching (Peñafiel Villavicencio et al., 2025);
developing diagnostic tools for assessing the cognitive state of participants in the educational environment (Nouri, 2025).

Educational neuroscience not only affects cognitive activity, but also forms a qualitatively new configuration of “learning brains”, which become a space for neuropedagogical interventions: the plastic brain, the synchronised brain, the engaged brain, and the computational brain (Williamson et al., 2026). These clusters of brain structure encompass, in effect, all the activities necessary for the learning process. Accordingly, the question arises as to the potential replacement of human

effort, will, and aspiration by a technological analogue. It is evident that such a pragmatic approach, though acceptable from a scientific perspective, gives rise to concern within the philosophical community.

A separate cluster of philosophical research on neurotechnologies in higher education is the social factor of innovative development. Vidal (2024) points to the convergence of neurotechnologies and digital technologies in education, while distinguishing the ethical and social problems involved. The key positions of the socio-philosophical analysis of the use of neurotechnologies in higher education are as follows:

legal regulation of the use of innovation in education while preserving human rights to freedom, security, and identity (Ienca, 2021);
ensuring the confidentiality of personal neurobiological data (Sinaci & Hasmatuchi, 2023);
upholding the principles of integrity in neurotechnological activity (Eaton, 2024);
fostering trust in neurotechnologies in education at the individual, professional, and societal levels (Martinez et al., 2022).

The first results and consequences of the use of neurotechnologies in the university learning process have revealed a number of problems of an ethical nature (see Fig. 2).

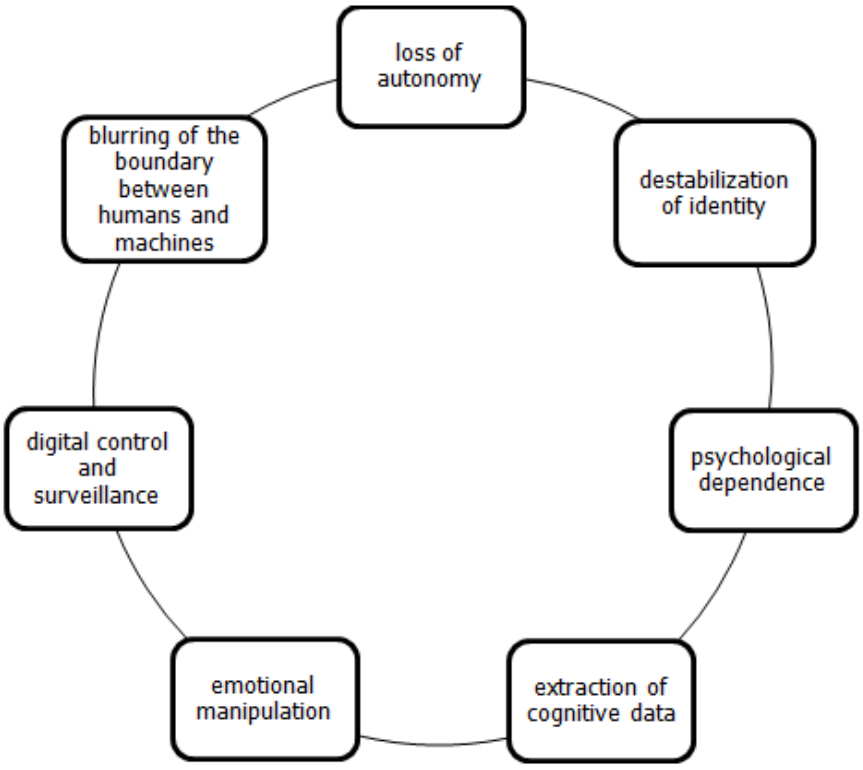


Fig. 2. Manifestations of ethical problems arising from the implementation of neurotechnologies in higher education
Source: developed by the authors.

Another socio-philosophical problem associated with the use of neurotechnologies is the disparity between universities in the scale of their adoption of innovative technologies, which is linked to financial capacity and prejudice regarding the use of

such instruments (Nouri, 2025). These realities result from the absence of a unified strategy for the use of neurotechnologies in the higher education system, leading to differing levels of perception and understanding of the status of neuro-instruments.

The socio-philosophical discourse of neuroethics in higher education analyses the responses of all its participants. Models of individual, professional, and institutional perceptions of neurotechnologies in the educational process are proposed:

from the perspective of the university, the level of implementation of neurotechnologies is assessed, along with academic readiness to use innovative instruments and control over the moral and integrity standards of the neuroeducational case (Alipoor & Pourrashidi, 2025);
from the perspective of the academic teaching community, the understanding of the expediency of using neurotechnologies and the individual position regarding their practical application are determined, together with the results and consequences of their implementation (Paredes Rosado & Rodríguez Flores, 2025);
from the perspective of higher education students, personal and collective cases of neurotechnological influence are formed, with the identification of algorithms for supporting or enhancing cognitive activity (Nieves-Méndez, 2026).

Philosophical approaches characterise neurotechnologies in terms of the worldview trend of the crisis of self-identity. Further analysis makes it possible to extrapolate these ideas to the use of neurotechnologies in the educational process of higher education (see Table 1).

Table 1
The impact of neurotechnologies on the crisis of self-identity in the educational space from the perspective of philosophical approaches

Philosophical approach and representatives	Ideological and worldview-based concepts of the human dimension	Manifestation of the crisis of self-identity in the educational environment
Post-structuralism Foucault (1995)	* Loss of subjectivity; * Blurring of the integrity and stability of the individual; * Formation of the dividual (a set of biological and digital parameters).	A participant in the educational process is subjected to total control and the intensive influence of technology and digitalisation, initially losing the need, and subsequently the ability, to respond independently and autonomously to problems and stimuli, delegating this function to technological and digital instruments. As a result, the degradation of cognitive potential occurs, accompanied by the unavoidable need to rely on an external resource. Consequently, self-identity becomes blurred, with the further prospect of its loss, whether complete or critically partial.
Phenomenological-hermeneutic approach Ricoeur (2004)	Human epistemological activity through personal experience, effort, and aspiration	Learning activity presupposes the constant actualisation of the cognitive process. A higher education student exerts intellectual and emotional effort in order to acquire knowledge and skills. In practice, neurotechnologies facilitate this process by reducing the share of effort involved, but in doing so they also take away part of the experience gained. The crisis of self-identity is formed through the loss of a degree of

		satisfaction derived from the achieved learning outcome. In effect, this occurs when a student receives knowledge, a skill, a grade, or approval while recognising the incompleteness of their own contribution to that process.
Transhumanism (Nitto, 2025) and posthumanism (Mayer & Mayer, 2025)	The prospect of overcoming the biological limitations of human capacities	The value- and purpose-oriented guidelines of the higher education system are characterised by realistic standards of human life and activity, integrating the potential of neurotechnologies into existing needs rather than probable scientific and technological prospects. Self-identity emphasises the role and status of the human being in the worldview. At the same time, the technological dimension requires the individual to constantly update their characteristics, following the model of technical devices, which potentially leads to the intellectual and moral exhaustion of participants in the educational environment.

Source: generalised by the authors on the basis of the sources cited in the table.

Contemporary innovative philosophical currents also offer their own assessment of neurotechnologies in the higher education system. One influential representative of neurophilosophy, Metzinger (2015), proposes the Self-Model Theory. In this context, an algorithm of risks to self-identity in the use of neurotechnologies in education is constructed (see Fig. 3).

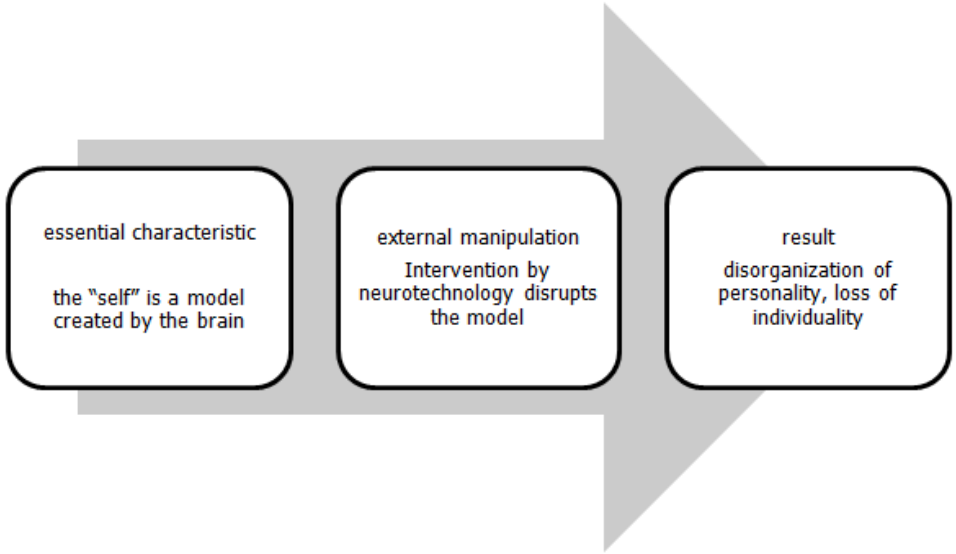


Fig. 3. Algorithm of neurotechnological risks to self-identity according to Metzinger's Self-Model Theory.
Source: interpreted by the author on the basis of Metzinger (2015)

For a fuller understanding of the potential of neurotechnologies in the higher education system, it is appropriate to turn to the term reversibility, which denotes the capacity of a system to return to its initial state. Such an approach partially resolves the ethical problem of preserving human control over cognitive activity (Yang, 2025).

By analogy with a technological device, at any moment, through an act of will, a person is able to return to their original state, rejecting the settings and changes introduced by neurotechnological instruments. Here one may observe an analogy with scientific advances in medicine, according to which, in the case of deep brain stimulation, both the impairment and the restoration of personal identity are possible (Yang & Zhou, 2025). The possibility of reversibility makes it possible to form other activities that are important for organising an effective learning process: the restoration and cancellation of cognitive experience.

Contemporary scientific and philosophical discourse offers a variety of formats for identifying the dominant component in the assessment of neurotechnologies in educational life. In particular, Walker and Mackenzie (2020), discussing neurotechnologies in social activity, note that “framing ethical debates in terms of authenticity is unhelpful” (p. 98), assigning these points instead to problems of autonomy. That is, the individual preserves their own uniqueness in educational activity, while neurotechnologies function as an instrument for enhancing cognitive and intellectual activity.

At present, attempts are being made to redirect the discussion of the advantages and disadvantages of neurotechnologies in education towards a different value- and purpose-oriented domain. In particular, the concept of neurodevelopment is being actively introduced into scientific and philosophical discourse (Astle et al., 2024), which in effect constitutes a synergetic approach to assessing the prospects of this instrument. Neurodevelopment presupposes the convergence of psychology, education, learning technologies, computer science, engineering, and informatics (Parsons, 2019). Neurodevelopment consists of several fundamental components that form the synergistic interaction of an interdisciplinary paradigm:

neuroengineering as a resource of technological solutions (Ramírez-Moreno et al., 2021);
neuroscience as a model for the theoretical verification of technological instruments (Cinel et al., 2019);
neuroeducation as a factor in the correlation between technology and learning (Gracia-Calandín, 2019).

The ethical discussion of educational neurotechnology must also account for recent international governance frameworks. The OECD Recommendation on Responsible Innovation in Neurotechnology, adopted in 2019, provides principles for responsible development and use. UNESCO’s Recommendation on the Ethics of Neurotechnology, adopted in November 2025, extends the discussion explicitly to education. It calls for educational uses to be evidence-based, assessed in advance, aligned with legitimate learning objectives, and subject to informed consent and independent oversight. It also addresses risks of inequality, dependency, and inappropriate use of neurotechnology in the evaluation of students and educators (UNESCO, 2025). A promising line of research is the transition of the philosophical analysis of the use of neurotechnologies in higher education from the ethical case to the existential dimension, with the establishment of new problematic questions (Ridolfi & Santos, 2025). In the synergistic model of the contemporary scientific and philosophical worldview, the case of neurotechnologies is a kind of bifurcation point in the question of the structure of a new human essence. The traditional system of “human being – culture (science, technology)” loses its stability and permanence when examined through the prism of the use of neurotechnologies in the educational process.

The present is in a state of anticipation of a new reality in which neurotechnologies may lead to the emergence of a posthuman technological "self", which will become the new norm (Giordano et al., 2024). At the same time, Nitto (2025) raises an intriguing question: "is the use of neurotechnologies a genuine evolutionary process, or, in a darker scenario, does it mark the beginning of the disappearance of the human species as we know it?" (p. 4). Evidently, the results and consequences of the implementation of neurotechnologies specifically within the higher education system will constitute the data that make it possible to outline answers to this question. At present, however, the first results and consequences of the implementation of neurotechnologies in higher education point towards optimistic forecasts. Lupton (2019) defines the role of neurotechnologies as a mechanism for forming the concept of the "more-than-human". On the whole, the philosophical tendency remains to position neurotechnologies in higher education as an enhancing instrument, while fully preserving the cognitive nature and essence of the human being.

The existential dimension of neurotechnology in higher education concerns the conditions under which students and educators remain agents of their own learning, decisions, and self-understanding. Whether and how neurotechnological interventions may transform subjectivity and personal identity remains an open philosophical and empirical question. Their use should therefore be assessed in relation to the scope of the intervention, the individual's capacity to understand and refuse it, the handling of neural data, and its possible effects on autonomy and self-perception. Legal and ethical safeguards cannot establish in advance that identity will remain unchanged; they can, however, set limits on permissible interventions and require continuing evaluation of their consequences.

Conclusions

Thus, the fundamental philosophical and ethical question regarding the use of neurotechnologies in higher education is not whether they can replace humans, but whether the individual remains the agent of their own decisions and self-determination when a portion of their cognitive processes is delegated to technological systems. It is precisely in this context that the question arises concerning the limits of permissible technological intervention in an individual's cognitive and mental spheres. Although neurotechnologies can enhance human cognitive capabilities, support educational activities, and create new forms of learning, their implementation must not result in a loss of autonomy, mental privacy, the right to make independent decisions, or the ability to critically evaluate technological recommendations. At the same time, the philosophical and ethical position retains a cautionary character because of concerns about the deepening crisis of self-identity caused by the influence of technology on the cognitive potential of students and lecturers. In the question of integrating neurotechnologies, philosophy performs the role of a worldview regulator, responding to threats that multiply under the pressure of the scientific and technological characteristics of artificial neuroactivity. Neuroethics is the result of balancing the positions of epistemological optimism, existentially neutral uncertainty, and the philosophical-axiological filter within the educational environment.

Science is guided by quantitative indicators of improvement in the level of higher education, proposing neurotechnologies as an instrument. Neuromonitoring, neurointerfaces, and cognitive enhancement solutions all constitute a set of instruments that may become a factor in the transformation of higher education in two respects: they may improve the cognitive abilities of participants in the educational process to the point of blurring human identity, while simultaneously

provoking unpredictable consequences through the loss of the structural essence of personality; or they may strengthen the cognitive state of the student or lecturer by providing them, under controlled conditions, with standardised—and therefore safe and necessary for the preservation of identity—neurotechnological solutions for the improvement of the intellectual and emotional development of the individual. Philosophy, in turn, through ethical imperatives, performs an operative control and regulatory function, preventing technological solutions from crossing the red lines of the humanistic foundations of the educational space; it also fulfils a strategic mission by preparing the ground for the existential recognition of scientific and technological cases within the conceptual dimensions of higher education.

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Original Article

Programas educativos digitales y su aplicación en el derecho público y privado

Digital educational programs and their application in public and private law

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Resumen

El artículo analiza los programas educativos digitales y su aplicación en el derecho público y privado. El objeto del estudio es el proceso de transformación digital de la educación jurídica, y la materia de estudio comprende el contenido, las tecnologías, los métodos pedagógicos, los resultados de aprendizaje y las particularidades de estos programas en ambas ramas del derecho. El objetivo es identificar sus características teóricas y prácticas, comparar los instrumentos y direcciones de uso en el derecho público y privado, y proponer un modelo estructural para su integración en la formación jurídica. La metodología se basa en investigación documental cualitativa, análisis de contenido, método comparativo y modelización. El estudio examina programas, cursos y módulos digitales seleccionados de universidades de Ucrania, Europa y América Latina. Los resultados muestran que el derecho público se orienta al gobierno digital, los servicios administrativos electrónicos, los datos abiertos, los derechos humanos digitales y la inteligencia artificial en la administración pública, mientras que el derecho privado se centra en contratos electrónicos, comercio electrónico, activos digitales, legaltech, propiedad intelectual y resolución de disputas en línea. Se propone un modelo basado en núcleo digital común, especialización sectorial, tareas prácticas digitales, evaluación por competencias y reflexión ética.

Palabras clave: educación jurídica digital; competencias digitales; derecho público; derecho privado; tecnología jurídica.

Abstract

The article examines digital educational programs and their application in public and private law. The object of the study is the process of digital transformation of legal education, while the subject covers the content, technologies, pedagogical methods, learning outcomes and specific features of these programs in both branches of law. The aim is to identify their theoretical and practical characteristics, compare the tools and directions of their use in public and private law, and propose a structural model for their integration into legal education. The methodology is based on qualitative documentary research, content analysis, comparative method and modeling. The study examines selected digital programs, courses and modules from universities in Ukraine, Europe and Latin America. The results show that public law is mainly oriented toward digital government, electronic administrative services, open data, digital human rights and artificial intelligence in public administration, whereas private law focuses on electronic contracts, e-commerce, digital assets, legaltech, intellectual property and online dispute resolution. The article proposes a model based on a common digital core, sectoral specialization, practical digital tasks, competency-based assessment and ethical reflection.

Keywords: digital legal education; digital competencies; public law; private law; legal technology.

Introduction

The European approach to digital education is based on the idea of high-quality, inclusive and accessible digital education, which should combine technological infrastructure with the development of digital skills and competences. The Digital Action Plan for Education for 2021–2027 (European Commission, n.d.) defines digital education not as an auxiliary tool, but as one of the key areas of modernization of education systems. At the same time, the DigComp 2.2 framework focuses on such components of digital competence as information literacy, communication and collaboration, digital content creation, security and problem solving (Vuorikari et al., 2022).

Despite the growing body of research on the digital transformation of higher education, digital competence and the use of artificial intelligence in teaching, the specific transformation of legal education remains insufficiently systematized. Existing studies predominantly examine digital education as a general pedagogical phenomenon or address individual technological aspects of legal practice, such as legaltech, artificial intelligence, e-commerce or online dispute resolution. However, less attention has been paid to the differentiated application of digital educational programs across the major branches of law. In particular, there is a lack of comparative research examining whether the digital competencies required for future lawyers are identical in public and private law, which technologies and professional tasks are common to both fields, and which should be differentiated according to the nature of legal relations and professional practice. This gap is scientifically relevant because the digital transformation of public law is primarily connected with the digitalization of government, administrative decision-making, public services and the protection of human rights, whereas the transformation of private law is increasingly associated with digital transactions, e-commerce, legaltech, digital assets and the automation of legal services. Treating digital legal education as a uniform process may therefore overlook substantial differences in the professional competencies required in these two areas. The novelty of this study lies in moving beyond a general discussion of digitalization in legal education and proposing a differentiated structural model that combines a common digital competence core with sector-specific educational components for public and private law.

The purpose of the article is to determine the theoretical and practical features of digital educational programs, compare the directions and tools of their application in public and private law, and develop a structural model of their integration into the legal education system.

The object of the research is the process of digital transformation of legal education. The subject of the research is the content, technologies, pedagogical methods, learning outcomes and features of the application of digital educational programs in public and private law.

In accordance with the goal and objectives of the study, the following research questions were formulated:

- Which digital technologies are most often integrated into educational programs in public and private law;
- Which digital competencies are common to both legal blocks;
- Which competencies, tasks and assessment methods are industry-specific;
- How digital tools are changing practice-oriented learning in public and private

law;
- What should be the structural model for integrating digital educational programs into the training of future lawyers.

The study has certain limitations. It is based on open sources and does not cover internal educational and methodological materials of universities. In addition, the study analyzes the content of the programs, and not the actual learning outcomes of students. At the same time, the chosen approach allows us to identify general trends, structural gaps and promising directions for the application of digital educational programs in public and private law.

Theoretical Framework or Literature Review

The European Digital Competence Framework for Educators DigCompEdu defines digital competence as the ability to effectively use digital technologies for professional activities, create and disseminate digital resources, organize learning, assess, support students and promote the development of digital competence of learners (Redecker, 2017). This framework is important for legal education, as the digital competence of a law teacher directly affects whether a student will acquire not only theoretical knowledge, but also practical skills for digital legal work.

Of particular interest in the context of this study are works devoted to the digital transformation of higher education in Latin America, as this region demonstrates a combination of the rapid development of digital educational practices with deep institutional, social and infrastructural inequalities. Researchers emphasize that the digitalization of university education in Latin America cannot be reduced to a technical transition to online platforms, as it requires a rethinking of pedagogical models, the organizational culture of universities, the accessibility of digital infrastructure and the ability of students and teachers to use technologies for active, reflective and practice-oriented learning (Cerdá Suárez et al., 2021; Useche et al., 2022).

The Latin American literature particularly emphasizes the distinction between formal digitalization and real educational transformation. Thus, an analysis of the experience of e-learning and b-learning in higher education shows that the successful use of digital technologies depends not only on the availability of platforms, but also on the coordination of educational, technological and organizational components of the educational process (Galvis & Carvajal, 2022). A similar conclusion is found in studies of distance education in Latin America, where digital educational environments are considered as a stage of transition from flexible learning to adaptive models capable of taking into account individual educational trajectories of students (Miralrio et al., 2024).

Another important aspect is the issue of digital inequality. A study of the digital divide in higher education using the example of a Latin American college during the COVID-19 period showed that inequality is manifested not only in physical access to devices and the Internet, but also in different levels of knowledge, confidence, duration of use and ability to apply digital tools for learning (García-Martín & García-Sánchez, 2022). For legal education, this finding is fundamental, since the digital training of a lawyer must take into account not only the technological infrastructure, but also the actual ability of the student to work with electronic sources, digital evidence, legal platforms and artificial intelligence tools.

A separate area of Latin American research concerns artificial intelligence in higher education. A systematic review of AI applications in Latin American universities

shows that the most common areas are predictive modeling, intelligent analytics, assistive technologies, automatic content analysis, and image analytics, and AI is used to support student learning, improve teaching quality, and improve university governance (Salas-Pilco & Yang, 2022). At the same time, more recent research by ChatGPT in Latin American higher education institutions suggests that generative AI creates not only opportunities for personalized learning and support for academic work, but also risks for academic integrity, critical thinking, and regulatory certainty (Rivadeneira et al., 2025).

For the article on digital educational programs in public and private law, works that link the digital transformation of education with a competency-based approach are of particular importance. A comparative study of the digital competence of university teachers in Spain and Peru based on DigCompEdu confirms that effective digital learning depends on the teacher's ability not only to use technologies, but also to integrate them into teaching methods, communication, assessment and student support (Martín-Párraga et al., 2023). In this context, ePortfolio, networked learning, reflective pedagogy and practical digital tasks can be considered as tools for the formation not only of digital literacy, but also of the student's professional autonomy (Roco & Barberà, 2022).

Finally, it is important for legal education to consider Latin American research that focuses specifically on technological innovation in legal training. Daniel Bonilla Maldonado views technological innovation in legal education not as a neutral instrument, but as a phenomenon related to student expectations, the needs of the legal market, the transformation of legal services, and a critical reflection on the power of technology in law (Bonilla Maldonado, 2020). This approach is important for this article because it allows us to consider digital educational programs not only as a means of modernizing training, but as part of a broader transformation of the professional identity of the lawyer in public and private law.

The theoretical framework of this study requires a distinction between the general digitalization of education and the digital transformation of legal education. In this article, a digital educational program is understood not merely as a program delivered through online platforms or distance-learning technologies, but as an educational structure in which digital technologies, digital legal phenomena and practice-oriented technological tasks are systematically integrated into learning objectives, content, teaching methods, practical activities and assessment. Digital legal competence may therefore be defined as the ability of a future legal professional to critically and effectively use digital technologies and information resources in the performance of legal tasks while understanding their legal, ethical and social consequences. Such competence goes beyond general digital literacy and includes digital legal research, work with electronic legal databases and digital evidence, responsible use of artificial intelligence, and the ability to apply digital tools to practical legal problem-solving.

The technological transformation of legal practice makes the development of such competencies an essential component of modern legal education. The expansion of legaltech, artificial intelligence, automated document generation, digital databases, online legal services and online dispute resolution is changing both the professional tasks performed by lawyers and the skills expected from law graduates. As Bonilla Maldonado (2020) argues, technological innovation in legal education should not be understood as a neutral introduction of new tools, since it affects the organization of legal knowledge, professional identity and the relationship between legal education and the changing legal services market. Consequently, digital legal

education should prepare students not only to use technology, but also to critically assess how technological systems affect legal reasoning, professional responsibility, access to justice and the protection of rights.

The analytical distinction between public and private law is particularly important because digital technologies transform professional legal tasks differently in these two areas. In public law, digitalization is primarily associated with e-government, digital administrative services, electronic justice, open data, automated administrative decision-making and digital human rights, requiring lawyers to assess the legality, transparency and human rights implications of digital state action. In private law, digital transformation is more closely connected with electronic contracts, e-commerce, digital assets, intellectual property, online platforms, legaltech and online dispute resolution. At the same time, areas such as artificial intelligence, personal data protection and cybersecurity have an interdisciplinary nature, which demonstrates the need to combine a common digital competence core for all future lawyers with sector-specific specialization. This distinction provides the theoretical basis for the comparative model of digital educational programs proposed in this study.

Recent scholarship increasingly examines the technological transformation of legal education as a distinct field rather than as a general extension of digital education. Research on technology-enhanced legal services demonstrates that law students and legal professionals require competencies that combine legal knowledge with technological understanding, particularly in relation to artificial intelligence, digital legal research and technology-supported legal services. Janeček et al. (2021) identify significant knowledge and skills gaps among legal professionals and argue for dedicated educational models capable of preparing students for technologically enhanced legal practice. Similarly, Kimbrough (2025) proposes integrating technology-driven lawyering skills into law school learning outcomes in order to reduce the gap between traditional legal education and contemporary legal practice. These studies indicate that digital transformation requires changes not only in teaching methods but also in the competencies and learning outcomes of legal education.

Artificial intelligence has become a particularly important area of research in legal education. Recent scholarship emphasizes that the integration of generative AI into law schools creates both pedagogical opportunities and new risks, including concerns about accuracy, academic integrity, critical thinking and professional responsibility. The American Bar Association's survey of law schools found that a substantial proportion of responding institutions had already introduced curricular opportunities for students to learn about AI and its use in legal practice. More recent research further argues that legal education should develop students' ability to use AI critically and ethically rather than treating it simply as another technological tool (Guglyuvatyy, 2026). This literature supports the need to conceptualize digital legal competence as a combination of technological proficiency, legal reasoning and ethical judgment.

Another important strand of research concerns practice-oriented digital legal education. Studies of online dispute resolution (ODR) demonstrate that simulations and technology-supported exercises can develop legal reasoning, problem-solving, digital communication and professional skills while exposing students to emerging forms of technology-enabled legal practice (Grant & Lestrell, 2020; Wang, 2026). Research on legaltech education likewise shows that practical projects involving automation and digital legal services can integrate substantive legal knowledge with transferable professional skills, including teamwork, task management and client-

oriented problem solving (Eaton, 2026). Taken together, this literature demonstrates that the technological transformation of legal education involves not only the digital delivery of courses, but also the substantive integration of legal technologies, practical simulations and competency-based learning outcomes. However, comparatively less attention has been devoted to how these developments should be differentiated between public-law and private-law education, which provides a basis for the comparative approach adopted in this study.

Methodology

Documentary analysis was used to study publicly available descriptions of educational programs, training courses, syllabi, university information pages and educational platform materials. This approach makes it possible to examine how digital technologies are integrated into legal education at the level of learning objectives, subject content, practical tasks, expected learning outcomes and assessment forms. Documentary analysis is understood as a systematic method of examining written and digital sources containing relevant information about the organization and content of educational processes (Bowen, 2009).

The empirical basis of the study consists of twelve digital educational programs, courses and modules selected through purposive criterion-based sampling of publicly available materials. The selection was not intended to produce a statistically representative sample, but rather to identify information-rich cases demonstrating different approaches to the integration of digital technologies into legal education. The sample includes programs from Ukraine, European countries and Latin American countries, allowing for comparison across different institutional and educational contexts. Programs were included if they met the following criteria: (1) an official description was publicly available; (2) the program had a direct connection with legal education; (3) its content included a significant digital, technological or online component; (4) sufficient information was available regarding learning objectives, content, teaching methods, learning outcomes or practical orientation; and (5) the program could be analytically classified according to its predominant orientation toward public or private law. Programs for which no meaningful description of the digital component was available were excluded from the analysis.

The public law block includes courses and programs related to e-government, digital administrative services, open data, digital human rights, automated decisions of government bodies and the use of artificial intelligence in public administration. The private law block includes programs related to e-commerce, IT law, digital assets, intellectual property, legaltech, online transactions, electronic contracts and personal data protection. This analytical division is based on the predominant nature of legal relations and professional tasks addressed by each program, while recognizing that certain areas, including artificial intelligence and personal data protection, may have an interdisciplinary character.

Content analysis was carried out using a pre-defined analytical matrix to ensure consistency and comparability across all twelve units. The matrix included the following variables: country and institution; type and format of program or course; predominant legal branch; digital technologies and legal phenomena addressed; use of electronic legal databases and digital platforms; practical digital tasks; expected professional competencies; teaching methods; assessment methods; use of artificial intelligence; attention to personal data protection; and ethical and human rights components. For each variable, the analysis determined whether digital

technologies functioned merely as auxiliary technical tools or were substantively integrated into the content, practical activities and expected learning outcomes of the program. This coding procedure made it possible to identify both recurring patterns and sector-specific characteristics across the selected cases.

A comparative method was subsequently used to identify common and distinctive characteristics of digital educational programs in public and private law. The comparison focused on recurring competencies, technologies, practical tasks and assessment approaches. Common elements included digital legal research, work with electronic sources, personal data protection, digital ethics, cybersecurity and the critical use of artificial intelligence. Sectoral differences were identified primarily through the types of professional legal tasks emphasized in the programs: in public law, these included work with e-government, administrative services, open data, automated decision-making and digital human rights; in private law, they included electronic contracts, e-commerce, digital assets, legaltech and online dispute resolution.

Finally, the modeling method was used to develop a structural model for integrating digital educational programs into legal education. The five components of the proposed model were derived from patterns identified through the analytical matrix. Recurring competencies and technologies common to both legal branches formed the common digital core. Sector-specific content and professional tasks provided the basis for sectoral specialization. The presence of simulations, case studies, document drafting and other applied activities supported the inclusion of practice-oriented digital tasks. The analysis of examinations, projects, portfolios and practical assignments informed the component of competency assessment. Finally, the recurring attention to data protection, algorithmic risks, professional responsibility, human rights and ethical consequences of technology led to the inclusion of ethical and human rights reflection. Thus, the proposed five-component model was developed through a sequential analytical process linking the coding of the twelve educational units with the comparative findings and subsequent conceptual modeling.

Table 1.
Selected educational programs and courses included in the analysis (Compiled by the author based on official descriptions of the selected educational programs and courses)

	Country	Institution	Program/Course	Type	Branch
1	Ukraine	Taras Shevchenko National University of Kyiv	Information Law	Elective block	Public
2	Ukraine	Odesa Polytechnic University	Electronic Administrative Services	Course	Public
3	UK	University of Edinburgh	E-governance and Digital Human Rights	Course	Public
4	Denmark	University of Copenhagen	Digital Government	Course	Public
5	Colombia	Universidad de los Andes	AI, Legality and Decision-Making	Course	Public
6	Ukraine	Taras Shevchenko National University of Kyiv	Intellectual Property / IT Law	Program	Private
7	Ukraine	Yaroslav the Wise National Law University	Law and Digital Technologies	Minor	Private

8	Netherlands	Tilburg University	International Business Law: Digital Innovation	Master's	Private
9	UK	University of Edinburgh	LLM in Information Technology Law	Master's	Private
10	Colombia	Universidad de los Andes	Digital Assets: Functioning and Regulation	Course	Private
11	Colombia	Universidad de los Andes	Legaltech Essentials	Course	Private
12	Chile	Universidad de Chile	Personal Data Protection	Diploma	Mixed

Note: The selected units were analyzed according to the following variables: digital technologies and legal phenomena addressed, practical digital tasks, professional competencies, teaching and assessment methods, use of artificial intelligence, personal data protection, and ethical and human rights components.

Results and Discussion

Digital educational programs in public law

Within the Ukrainian sample, the public law direction is most clearly represented by the elective block “Information Law” of the Taras Shevchenko National University of Kyiv and the course “Electronic Administrative Services” of the Odesa Polytechnic University. The elective block “Information Law” covers e-governance, e-democracy, e-justice, e-administrative services and electronic interaction of the state with citizens and business. This content indicates a gradual transition from the general study of information law to the formation of specialized competencies necessary for the analysis of the digital activities of public authorities (Taras Shevchenko National University of Kyiv, n.d.-a).

The course "Electronic Administrative Services" of Odesa Polytechnic University is more applied in nature, as it focuses on digital tools for providing administrative services. Its content is related to the use of state electronic platforms, electronic signature, BankID, MobileID, electronic queues, state registers and the Diya portal. This allows us to consider the course as an example of a digital educational program in which public law is studied not only through regulatory acts, but also through practical mechanisms of interaction between a person and the state in an electronic environment (Odesa Polytechnic University, n.d.).

European examples demonstrate the further expansion of the content of digital public law. The University of Edinburgh course “E-governance and Digital Human Rights” combines the issues of e-government with issues of digital human rights, democratic processes, administrative law and public services. Of particular importance is that digital technologies are considered here not only as a tool for the efficiency of public administration, but also as a factor that can affect freedom of expression, the right to a fair trial, access to public services, non-discrimination and democratic participation (The University of Edinburgh, 2026).

The University of Copenhagen course “Digital Government” also confirms that modern digital training in the field of public law should go beyond the boundaries of classical administrative law. Its content covers digitalized public administration, data-driven public authority, personal data protection, cybersecurity, accessibility of digital services, regulation of artificial intelligence and automated decision support systems. Such a structure shows that the future lawyer in the field of public law

should understand not only legal norms, but also the technological logic of digital administration, the risks of algorithmic governance and the requirements for the legality of digital decisions (University of Copenhagen, 2025).

A Latin American example, the Universidad de los Andes course “IA, legalidad y toma de decisiones para la Alta Gestión Pública” focuses on the use of artificial intelligence in public administration. Its inclusion in the sample is important because it demonstrates that digital education programs in public law are increasingly associated with legal criteria for the use of AI, responsibility, legality, strategic management and administrative decision-making. In this context, legal education should develop the ability not only to use AI tools, but also to assess their compliance with the principles of transparency, accountability, non-discrimination and the protection of human rights (Universidad de los Andes, n.d.-a).

Generalizing these programs allows us to conclude that the public law block of digital legal education should include at least five key components: e-government; digital administrative services; open data and e-participation; digital human rights; legal regulation of automated decisions and artificial intelligence in the public sector. It is these components that reflect the specifics of public law, as they relate to the organization of power, the legality of administrative decisions, access to public services and the protection of the individual in relations with the state.

Digital educational programs in private law

Private law digital programs are focused on preparing lawyers to work with electronic contracts, online transactions, digital assets, e-commerce, legaltech tools, digital platforms, personal data, and online dispute resolution.

In the Ukrainian sample, the private law direction is represented by the educational program "Intellectual Property" of the Taras Shevchenko National University of Kyiv, in particular its specialization related to IT law. The program covers contracts in the IT industry, personal data protection, legal regulation of e-commerce, corporate law in the IT industry and protection of rights in the digital environment. This indicates that the digital transformation of private law is most noticeably manifested in areas where technologies change the forms of concluding contracts, circulation of property rights, protection of intellectual property and organization of entrepreneurial activity (Taras Shevchenko National University of Kyiv, n.d.-b).

The minor “Law and Digital Technologies” of the Yaroslav the Wise National Law University also has a significant private law component, although it is generally an interdisciplinary program. Its content includes the legal foundations of e-business and e-commerce, circulation of virtual assets, FinTech, marketplaces, Big Data, blockchain, the EU digital economy and information security. This example shows that private law training in the digital age can no longer be limited to the classical institutions of contract, property and liability, as property circulation is increasingly carried out through digital platforms, automated services and technological infrastructures (Yaroslav the Wise National Law University, 2023).

In the European block, the Tilburg University Master's program "International Business Law: Digital Innovation in Commerce and Finance" is exemplary. It combines international business law, finance, innovation and digital technologies. Importantly, the program uses a blended learning format, combining online and offline components, as well as practical tasks related to real client cases. This approach demonstrates the transition from theoretical teaching of private law to a model in which the student learns to apply legal knowledge to digital business

processes, commercial risks and technological innovations (Tilburg University, n.d.).

The University of Edinburgh's online LLM in Information Technology Law is another example of private law digital education. Its content covers e-commerce, e-transactions, e-payments, online consumer protection, jurisdictional issues, cryptocurrencies, digital services, online privacy and platform regulation. This programme is important for research for two reasons. First, it demonstrates the digital content of private law training. Second, its online format itself is an example of a digital organisation of legal education, in which the learning process takes place through distance resources and digital interaction (Edinburgh Law School, n.d.).

In the Latin American bloc, the private law focus is traced in the Universidad de los Andes course "Activos digitales: funcionamiento y regulación". It focuses on digital assets, blockchain, Bitcoin, Web 2.0, Web 3.0, financial services, digital transactions and regulatory risks. Such a course is important for private law, as digital assets create new objects of economic turnover that require legal qualification, risk assessment, determination of the circulation regime and protection of the rights of transaction participants (Universidad de los Andes, n.d.-b).

Another relevant example is the Universidad de los Andes course "Legaltech Essentials: strategías para el abogado moderno". Its content is aimed at the practical use of legaltech tools in the work of lawyers, law firms and modern legal services. This course demonstrates that digital educational programs in private law have not only a substantive and legal dimension, but also a professional and organizational dimension. They form the lawyer's ability to work with digital tools for automating legal processes, managing information, preparing documents, interacting with clients and improving the efficiency of legal services (Universidad de los Andes, n.d.-c).

The Universidad de Chile program "Diploma en Protección de Datos Personales" occupies a special place in the sample. It has a mixed nature, since the protection of personal data concerns both private companies and public authorities. However, for private law, this program is particularly important, since it covers the processing of personal data in commercial, financial, labor, consumer and organizational contexts. Its content shows that data protection in digital legal education should be considered not only as a matter of public control, but also as an obligatory element of private law responsibility, contractual regulation and compliance (Universidad de Chile, 2026).

Thus, digital educational programs in private law should include the following main components: electronic contracts; electronic commerce; digital assets; intellectual property in the digital environment; legaltech; personal data protection; online consumer protection; automation of legal documents; online dispute resolution. Unlike the public law block, where the main focus is on control over the digital activities of the state and protection of the individual in relations with the authorities, the private law block is aimed at ensuring legal certainty, security of digital transactions, protection of property interests and efficiency of legal services in the digital economy.

Table 2.
Comparative findings from the analysis of digital educational programs

Criterion	Public law	Private law
Main digital focus	E-government, digital public services, AI in administration	E-commerce, e-contracts, digital assets, legaltech
Main professional tasks	Analysis of administrative decisions and digital public services	Analysis of transactions and digital legal services
AI	Automated public decision-making and governance	Legal research and legal services
Practical orientation	Public service and administrative case analysis	Contracts, transactions and legaltech cases
Assessment	Case analysis, policy tasks, simulations	Practical projects, contract drafting, case studies
Ethical dimension	Human rights, transparency, non-discrimination	Privacy, consumer protection, contractual fairness

(Source: Compiled by the author based on the analysis of the twelve selected educational programs and courses)

The comparative analysis of the twelve educational units revealed that digital technologies are not integrated into public and private law education in the same way. Public-law programs predominantly focus on technologies connected with the digital transformation of state institutions, including e-government, electronic administrative services, open data and artificial intelligence in public administration. Private-law programs, in contrast, are more frequently oriented toward technologies supporting digital economic activity and legal services, particularly electronic contracts, e-commerce, digital assets and legaltech. Thus, the main difference between the two groups lies not simply in the technologies studied, but in the professional legal tasks for which students are being prepared.

The analysis also demonstrated differences in the practical orientation of digital legal education. In public law, practical tasks are primarily connected with the assessment of digital public services, administrative procedures, automated decisions and potential risks to human rights. In private law, practice-oriented activities are more closely related to the preparation and analysis of electronic contracts, assessment of digital transactions, work with online platforms and the application of legaltech tools. These findings indicate that a uniform approach to digital legal training would not adequately reflect the different professional contexts of public and private legal practice.

The comparison further confirms the importance of competency-based assessment. Across the analyzed programs, traditional theoretical assessment is increasingly supplemented by practical cases, project tasks, simulations and the analysis of digital legal documents. However, the specific form of assessment depends on the legal branch and the professional task being simulated. This finding supports the conclusion that the assessment of digital legal competence should evaluate not only knowledge of digital legal phenomena but also the ability to apply technological tools and critically assess their legal and ethical consequences.

Comparative analysis of the application of digital educational programs in public and private law

Thus, the main difference between public-law and private-law digital programs lies in the nature of the legal interaction that they model. In public law, the vertical

connection between the individual and the state is central, so digital programs should form the ability to assess the legality of government actions, the transparency of administrative procedures, the risks of automated decisions and the impact of digital technologies on human rights. In private law, horizontal interaction between private entities prevails, so the skills of preparing electronic contracts, analyzing digital transactions, working with legaltech, protecting intellectual property and supporting e-commerce are prioritized. At the same time, individual components, in particular personal data protection and artificial intelligence, are interdisciplinary in nature, which confirms the need for a two-tier model of digital legal education: a common digital core for all law students and sectoral specialization for public and private law.

Discussion

Author's model of application of digital educational programs in public and private law. The proposed model consists of five interconnected elements:

The first element of the model is the common digital core. It should be mandatory for all law students, regardless of their further specialization. It includes digital legal research, working with electronic legal databases, checking the authenticity of digital sources, using electronic documents, protecting personal data, the basics of cybersecurity, academic integrity, digital communication, digital ethics, and the critical use of artificial intelligence. It is this level that forms the basic ability of a future lawyer to work in a digital legal environment. Its meaning is consistent with the logic of DigComp 2.2, where digital competence encompasses information literacy, communication, digital content creation, security, and problem solving (Vuorikari et al., 2022).

The second element is sectoral specialization. It is necessary because digital tools function differently in public and private law. In public law, digital specialization should cover e-government, digital administrative services, open data, e-democracy, e-justice, automated administrative solutions, digital human rights and the use of artificial intelligence in public administration. In private law, the corresponding block should include e-contracts, e-commerce, digital assets, smart contracts, legaltech, intellectual property in the digital environment, online consumer protection, digital evidence and online dispute resolution.

The third element of the model is a practice-oriented digital task. It should ensure the transition from the acquisition of theoretical knowledge to the professional application of digital tools. In public law, such tasks may include the analysis of an electronic administrative service, the preparation of a legal assessment of an automated decision of a government agency, the development of recommendations on the accessibility of a digital service, the analysis of open data, or the modeling of an individual’s application through an electronic platform. In private law, practical tasks may include the preparation of an electronic contract, the analysis of the terms of a digital platform, the assessment of the risks of a transaction with digital assets, the development of a privacy notice, the analysis of a smart contract, or the modeling of online dispute resolution.

The fourth element is competency assessment. It should be aimed not only at testing knowledge of legal norms, but also at assessing the student’s ability to apply digital tools in legal practice. A traditional written exam in this context is insufficient, as it does not always demonstrate whether the student is able to work with electronic sources, digital evidence, online platforms, automated documents or AI tools.

Therefore, it is advisable to use practical cases, electronic portfolios, simulations, project tasks, analysis of digital documents, preparation of legal opinions on digital services and presentation of the results of digital legal research.

The fifth element of the model is ethical and human rights reflection. It should conclude each digital training module, since the use of technology in law is always associated with risks for human rights, privacy, non-discrimination, access to justice, equality of arms, transparency and professional responsibility. In public law, such reflection should aim to assess whether digital tools create new forms of administrative arbitrariness, opaque control or discriminatory access to public services. In private law, it should concern the fairness of contractual terms, the protection of the weaker party, the transparency of digital platforms, liability for automated decisions and the security of personal data.

In general, the model can be presented as follows:

Common digital core → sectoral specialization → practice-oriented digital task → competency assessment → ethical and human rights reflection

This model has several advantages. First, it does not equate digital education with distance learning. The online format is only one possible tool, while a true digital educational program involves the meaningful integration of technology into the professional training of a lawyer. Second, the model avoids fragmentation, when individual digital tools are used without a connection to learning outcomes. Third, it takes into account the distinction between public and private law, without destroying the integrity of legal education. Fourth, it combines the technological, legal and ethical dimensions of the training of future lawyers.

The special significance of this model is that it allows us to distinguish three levels of digitalization of legal education:

The first level is instrumental and is associated with the use of digital platforms, electronic libraries, online communication and distance learning systems.

The second level is substantive and involves the inclusion of digital legal phenomena in the curricula: e-government, e-commerce, artificial intelligence, digital assets, data protection and legaltech. The third level is competency-based and involves the student's ability to independently apply digital tools, assess their legal consequences, prepare legal documents in a digital environment, protect individual rights and act in accordance with professional ethics.

It is the third, competency-based level that is most important for the modernization of legal education. If digitalization is limited only to the first level, it actually means a change in the form of education, but not a change in its content. If it stops at the second level, students gain knowledge about digital legal phenomena, but do not always acquire practical skills in their application. Only the third level allows for the formation of a lawyer capable of operating in the conditions of digital transformation of law, public administration, business and legal services.

The proposed model also allows for the identification of different educational outcomes for public and private law. For the public law block, the expected learning outcomes should be the ability to analyze digital administrative procedures, assess the legality of automated decisions, use open data, work with electronic public services, identify risks of human rights violations and propose legal mechanisms to minimize them. For the private law block, such outcomes should be the ability to

develop and analyze electronic contracts, assess the risks of digital transactions, work with legaltech tools, protect intellectual property in the digital environment, analyze the conditions of digital platforms, and provide legal support for e-commerce.

At the same time, both blocks should have common learning outcomes: the ability to conduct digital legal searches, critically evaluate electronic sources, comply with personal data protection requirements, use artificial intelligence responsibly, take into account the ethical consequences of digital decisions, and ensure the protection of human rights in the digital environment.

Conclusions

A comparative analysis of digital educational programs in public and private law showed that both directions have a common digital foundation, but differ in professional orientation. Common to them are digital legal research, work with electronic sources, protection of personal data, digital ethics, cybersecurity, academic integrity and critical use of artificial intelligence. These components form the basic digital core of legal education, necessary for all law students, regardless of future specialization.

At the same time, the public law block of digital legal education should be focused on e-governance, digital administrative services, open data, e-democracy, e-justice, automated administrative decisions, digital human rights, and the use of artificial intelligence in public administration. Its main task is to form the ability of a future lawyer to assess the legality of the state's digital activities, the accessibility of public services, the transparency of administrative procedures, and the risks of human rights violations in the digital environment.

The private law block, on the contrary, should be aimed at electronic contracts, electronic commerce, digital assets, smart contracts, legaltech, intellectual property in the digital environment, online consumer protection, digital evidence and online dispute resolution. Its specificity lies in preparing a lawyer for legal support of digital property turnover, business innovations, platform economy, automation of legal services and protection of the rights of subjects of private law relations.

The scientific result of the research is the proposed model of application of digital educational programs in public and private law. It includes five interrelated elements: a common digital core, sectoral specialization, practice-oriented digital task, competency assessment, ethical and human rights reflection. Such a model allows combining universal digital competencies of a lawyer with the specifics of specific legal areas and overcoming the fragmented approach to the digitalization of legal education.

The practical significance of the proposed model lies in the fact that it can be used to update educational programs of law faculties, develop digital modules, improve learning outcomes, create practical simulations and implement competency assessment. It is especially important that digital tools are not used in isolation, but are associated with specific professional tasks: analysis of an electronic administrative service, evaluation of an automated solution, preparation of an electronic contract, work with digital evidence, analysis of the terms of an online platform or legal support of a digital transaction.

Further research should be directed at empirically studying the effectiveness of

digital educational programs in legal education, in particular through surveys of students and teachers, analysis of learning outcomes, comparison of national models of digital legal training, and research into the impact of artificial intelligence on the formation of professional competencies of a lawyer. It is especially promising to study how digital simulations, legaltech tools, and AI systems can be integrated into the practical training of students without violating the principles of academic integrity, professional ethics, and the protection of human rights.

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Original Article

Entornos digitales y desarrollo de la competencia comunicativa en la educación superior

Digital environments and communicative competence development in higher education

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Resumen

El artículo revela la visión social del espacio de la educación superior. Se muestra el papel de las tecnologías digitales modernas y el entorno digital electrónico en la educación superior para la formación de la competencia comunicativa intercultural de los estudiantes. El análisis de la competencia comunicativa de los estudiantes, realizado por nosotros en la etapa de determinación, mostró un nivel predominantemente bajo e insuficiente de desarrollo de la competencia descrita. Esto nos permitió fundamentar las condiciones pedagógicas, diseñar trabajos experimentales adicionales y desarrollar un sistema de apoyo metodológico para la formación de la competencia comunicativa de los estudiantes en el entorno sociocultural de la educación superior. Los resultados sobre la formación de los indicadores de competencia comunicativa de los estudiantes en la etapa de control indican una efectividad significativamente mayor del experimento formativo en el grupo experimental, donde casi la mitad de los estudiantes alcanzó un alto nivel de competencia comunicativa en todos los criterios identificados. En contraste, en el grupo de control, este indicador es solo una cuarta parte del número total de estudiantes. La efectividad del experimento formativo realizado se confirma mediante el análisis estadístico utilizando el criterio t de Student. Los resultados obtenidos nos permiten hablar de la implementación efectiva y necesaria de las condiciones y el sistema pedagógicos desarrollados para la formación de la competencia comunicativa de los estudiantes.

Palabras clave: competencia comunicativa; entorno digital electrónico; entorno sociocultural de la educación superior; estudiantes; tecnologías digitales.

Abstract

The article reveals the social vision of the higher education space. The role of modern digital technologies and the electronic digital environment in higher education for the formation of intercultural communicative competence of students is shown. The analysis of students' communicative competence, carried out by us at the ascertaining stage, showed a predominantly low and insufficient level of development of the outlined competence. It allowed us to substantiate pedagogical conditions, design further experimental work, and develop a system of methodological support for the formation of students' communicative competence in the socio-cultural environment of higher education. The results on the formation of students' communicative competence indicators at the control stage indicate a significantly greater effectiveness of the formative experiment in the experimental group, where almost half of the students achieved a high level

of communicative competence across all identified criteria. In contrast, in the control group, this indicator is only a quarter of the total number of students. The effectiveness of the conducted formative experiment is confirmed by statistical analysis using the Student's t-criterion. The obtained results allow us to speak about the effective and necessary implementation of the developed pedagogical conditions and system for the formation of students' communicative competence.

Keywords: communicative competence; digital technologies; electronic digital environment; socio-cultural environment of higher education; students.

Introduction

The socio-cultural environment of higher education is a social institution in which students gain experience interacting with other individuals and the world as a whole, and acquire professional knowledge. Significant changes in cognition and human consciousness are driven by the rapid development of technology and science, which have led to technological breakthroughs for humanity. The emergence of modern communication needs has led to the development of new methods and forms of communication, including electronic learning. The modern system of higher education is characterized by the need to adopt a systemic approach to describing a student's education amid globalization and rising requirements for the quality of his professional training. Modern interaction of the individual with the world and with other people has intensified to the limit with the expansion of technical capabilities for exchanging digital information, as modern society has entered the stage of global mass communication and digitalization, in which information has become an important social resource.

The global information environment is developing under these conditions. It does not always provide favorable conditions for the assimilation and transmission of cultural patterns that align with individuals' values, and it does not sufficiently contribute to the development of communicative competence among the younger generation. Therefore, there is a need to create conditions for purposeful work to develop an individual's communicative competence and to optimize and manage this process. The search for modern innovative technologies that can ensure the process of forming communicative competence of students in the socio-cultural environment of higher education and the training of competitive future specialists with a high level of communicative competence will contribute to the development of a socially active personality and mobility, which is a full member in the socio-cultural environment (Palshkov et al., 2026).

In such conditions today, it is the higher education institution that should act as a generator of social progress for the student; a center for training a national network of specialists and for developing students' communicative competence, and for introducing innovative changes in production. The university's educational space should be oriented towards broad partnerships, interaction, and dialogue, in which technologies and educational systems enrich and interact with each other, affirming the high competitiveness of each specialist in the labor market.

The social vision of the higher education space is revealed through the processes of identification and socialization within the socio-cultural environment. Socialization, which ensures students’ personal and social development, occurs through interaction with the educational environment, society, and the immediate microsocial context (Ivenz & Reid, 2022).

The concept of communicative competence is closely related to an individual's ability to interact effectively. It includes communication skills, psychological stability, emotional regulation, planning and organizing interaction, and the ability to analyze and predict the consequences of communicative actions. Communicative competence is a multifaceted phenomenon that combines abilities, knowledge, skills, and acquired experience necessary for professional activity (Nyamekye et al., 2026).

The formation of communicative competence is influenced by several factors: motivation, professional orientation of learning, students' ability for independent study, appropriate teaching methods and forms, the need for self-improvement, and the use of digital technologies.

Among the forms of learning that contribute to communicative competence development are problem-solving situations, digital lectures, role-playing and business games, workshops, and artificial intelligence–supported activities that allow students to practice communication skills in realistic contexts (Sandal et al., 2020). Workshops, in particular, promote active student participation and serve as an effective form of professional preparation for social dialogue (Ertay & Gilanlioglu, 2024).

Communicative training is considered one of the most effective approaches to developing communicative competence. It fosters the ability to convey information, establish feedback, argue positions, express ideas clearly, understand others' viewpoints, manage emotions, and prevent conflicts within the socio-cultural environment of higher education. Consequently, these forms of learning enhance students' ability to engage in effective dialogue and professional communication (Kucherenko et al., 2020).

The development of digital educational ecosystems depends not only on technological infrastructure but also on the quality of communication among ecosystem participants. Existing communication deficits weaken the interconnectedness of educational actors, limiting opportunities for collaboration, knowledge sharing, and collective problem-solving. As a result, the potential of digital educational ecosystems to provide adaptive, learner-centered, and sustainable educational experiences remains only partially realized. This highlights the need to investigate communication mechanisms within multichannel digital environments and their contribution to ecosystem effectiveness.

Despite the growing number of studies devoted to digital educational ecosystems, insufficient attention has been paid to the role of multichannel communication environments in ensuring effective interaction among students, teachers, and institutional stakeholders. Existing research mainly focuses on technological infrastructure and digital tools, whereas the mechanisms through which integrated communication channels contribute to educational effectiveness remain underexplored. This theoretical gap is particularly significant in the context of rapidly developing digital educational ecosystems, where communication quality directly affects collaboration, knowledge exchange, learner engagement, and the overall sustainability of the educational environment. Therefore, further investigation of multichannel communication models is required to better understand their impact on the functioning and development of contemporary digital educational ecosystems.

Despite the rapid growth of research on digital transformation in education, the concept of digital learning ecosystems remains insufficiently explored from a

systemic perspective. Existing studies primarily focus on technological infrastructure, digital platforms, learning management systems, and the implementation of educational technologies, whereas the interactions among technological, pedagogical, organizational, and social components of educational ecosystems receive considerably less attention (OECD, 2023). Furthermore, scholars emphasize the need for more comprehensive investigations into stakeholder collaboration, communication processes, learner engagement, and governance structures within integrated digital educational environments (Castro Benavides et al., 2020; OECD, 2023). Therefore, further research is required to examine digital learning ecosystems as holistic educational environments and to identify the factors that contribute to their effectiveness in higher education.

The purpose of this study is to determine and experimentally verify the effectiveness of pedagogical conditions and innovative educational technologies for developing students' communicative competence within the socio-cultural environment of higher education institutions.

Literature Review

The need to study the issues of the formation of students' communicative competence and the quality of communication in the context of the digital socio-cultural environment of higher education was noted by scientists from different countries, who proposed various forms of innovative content.

The scientific works of Iswandari and Ardi (2022) confirm the universality and necessity of the problem of forming communicative competence in higher education students. Scientists emphasize the significant importance of communicative competence in the context of globalization, where communication requires taking into account tolerance and cultural differences.

The importance of developing intercultural communicative competence among university students was substantiated by Trang and Phuong (2023), who, based on a mixed-methods study involving 628 tourism undergraduates, identified a strong demand for authentic intercultural learning experiences and real-life communication tasks. Their findings demonstrated that students particularly valued activities aimed at improving discourse and behavioral competences, and that they exhibited positive attitudes toward intercultural interaction, highlighting the significance of integrating intercultural communication training into higher education curricula to enhance professional readiness in multicultural environments.

The role of communicative language teaching in fostering students' communicative competence through supportive educational interactions was highlighted by Zhou and Li (2025), who found that it positively influenced teacher–student developmental relationships, thereby significantly enhancing communicative competence among English language learners. Based on data collected from 891 Chinese university students, the authors demonstrated that the effectiveness of instructional approaches depends largely on the quality of teacher–student relationships, emphasizing the importance of fostering a collaborative and supportive learning environment to develop communicative skills.

Dai (2024) developed the interactional competence model, which clearly and reasonably emphasizes the importance of pedagogical strategies that foster students' ability to cooperate and engage in dialogue in intercultural contexts.

Today, new digital technologies are of great importance in education and

communication, posing significant competition to printed publications.

Al-Naabi (2020) substantiates the existing problem of interaction between electronic and traditional textbooks and shows the role of electronic didactics in higher education, which considers, as the main electronic-didactic tool, the automated educational system of higher education, because modern young people give digital media a significant advantage, be it magazines, books, or educational materials. The ways of using digital resources in the socio-cultural environment of higher education to form students' communicative competence are substantiated by Al-Naabi.

Ways of organizing the discussion of material in higher education using Internet technologies and forming students' communicative competence, including Multi User Domain (MUD), which organizes individual and group meetings of students using virtual boards, are shown by Khasanah and Anggoro (2022).

The use of digital technologies in blended learning conditions for students' formation of communicative competence is the subject of a study by Putri and Nurkhamidah (2023). Scientists consider a modern learning tool – Multiuser Object Oriented (MOO)- which helps in the formation of an object-oriented environment that provides real-time contact on the Internet and, through innovations, enables the computer to create virtual spaces.

Thus, the analysis of publications indicates the complexity of the problem of developing students' communicative competence in the socio-cultural environment of higher education. It is studied at the intersection of digital technologies and pedagogy, psychology, philosophy, as well as in the context of intercultural interaction and globalization of the world space. This allows us to consider the development of students' communicative competence as an integrative phenomenon, which is of key importance for training competitive specialists in the modern educational space.

Methodology

Research Design

The study employed a quasi-experimental research design to investigate the effectiveness of a system and pedagogical conditions in developing students' communicative competence within the socio-cultural environment of higher education. The research was based on the assumption that the purposeful organization of the socio-cultural environment, integration of digital technologies, and application of interactive teaching methods would contribute to the development of students' communicative competence.

The experimental study was conducted from 2022 to 2025 and consisted of three interconnected stages: ascertaining, formative, and control.

Participants

The study involved 210 undergraduate students enrolled in the second and third years of study. The participants took part in both the ascertaining and formative stages of the pedagogical experiment. During the formative stage, the participants were divided into an experimental group (EG) of 106 students and a control group (CG) of 104 students. Students in the EG implemented the developed system and

pedagogical conditions to develop communicative competence, whereas students in the CG continued their studies using the traditional educational methodology.

Participants were selected using purposive sampling. The inclusion criteria were: enrollment in the second or third year of undergraduate study, regular participation in the educational process during the experimental period, and informed consent to participate in the study. Students were assigned to the experimental and control groups according to existing academic groups in order to preserve the natural educational setting and ensure the ecological validity of the quasi-experimental design.

Operational Characteristics of Measurement Instruments

The assessment instruments were developed on the basis of the theoretical structure of communicative competence and included motivational, activity, and personal criteria. Content validity was established through expert evaluation by five university academics specializing in pedagogy, educational technologies, and communication studies. Based on their recommendations, several questionnaire items were revised to improve clarity and relevance.

A pilot study involving 32 students who did not participate in the main experiment was conducted to evaluate the psychometric properties of the instruments. Internal consistency was assessed using Cronbach's alpha coefficient. The obtained values were 0.86 for the motivational criterion, 0.84 for the activity criterion, 0.88 for the personal criterion, and 0.87 for the overall scale, indicating good reliability. Construct validity was examined through exploratory factor analysis, which confirmed the three-factor structure corresponding to the conceptual model of communicative competence.

To ensure objectivity of observational assessments, two independent experts evaluated students' performance using standardized observation protocols. Inter-rater reliability, calculated using Cohen's kappa coefficient, reached 0.81, indicating substantial agreement between raters. These procedures provide sufficient evidence of the reliability and validity of the measurement instruments and support the reproducibility of the study.

Research Methods

The study employed a combination of theoretical, empirical, experimental, and statistical methods.

Theoretical methods included systematic analysis, comparison, synthesis, and generalization of scientific approaches to the formation of communicative competence. These methods were used to identify the study's conceptual foundations, determine the structure of communicative competence, and substantiate the pedagogical conditions for its development within the socio-cultural environment of higher education.

Empirical methods included interviews, conversations, testing, questionnaires, and pedagogical observation. These methods were used to determine the levels of students' communicative competence and to assess the effectiveness of the educational interventions implemented during the experiment.

Experimental methods included a pedagogical experiment comprising an ascertaining, formative, and control stage. The experiment was conducted to verify

the effectiveness of the developed system and pedagogical conditions for forming students' communicative competence in the socio-cultural environment of higher education.

Statistical methods included quantitative and qualitative analyses to evaluate changes in communicative competence and determine the statistical significance of the results.

Assessment Framework

The formation of students' communicative competence was assessed according to three interrelated criteria: motivational, activity, and personal.

The motivational criterion reflected students' motivation for communicative interaction, their interest in communication, readiness for cooperation, and awareness of the importance of communicative competence in educational and professional activities.

The activity criterion reflected students' ability to apply communicative skills in various educational and social situations, participate in discussions, collaborate with others, solve communicative tasks, and effectively use verbal and non-verbal means of communication.

The personal criterion reflected students' individual qualities that facilitate effective communication, including self-confidence, empathy, tolerance, responsibility, openness to interaction, and the ability to establish constructive interpersonal relationships.

Based on the identified criteria and indicators, three levels of communicative competence formation were distinguished: high, sufficient, and low.

Experimental Procedure

The pedagogical experiment consisted of three interconnected stages.

During the ascertaining stage, the initial level of students' communicative competence was assessed according to the established criteria and indicators. The results demonstrated the predominance of low and sufficient levels of communicative competence and confirmed the need to improve the educational process in higher education institutions.

Analysis of the ascertaining-stage results made it possible to identify key directions for improving the socio-cultural environment of higher education. Particular attention was paid to creating a multi-channel digital educational environment that would enhance students' engagement, stimulate communicative interaction, and support a personality-oriented model of learning.

During the formative stage, the developed system and pedagogical conditions for developing students' communicative competence were implemented in the experimental group's educational activities.

The implementation was based on several pedagogical conditions:

– Creation of a multi-channel digital educational environment that supports

communicative interaction.
- Orientation of the educational process toward a personality-activity model of learning.
- Integration of digital technologies into educational and extracurricular activities.
- Intensification of educational work to develop students' communicative competence.

The formative program involved the use of modern digital technologies and interactive teaching methods, including virtual educational platforms, mobile applications, multimedia technologies, simulations, virtual laboratories, social networks, online courses, Massive Open Online Courses (MOOCs), discussions, debates, business games, role-playing activities, project-based learning, communicative trainings, and workshops.

These tools and methods were used to increase students' communicative activity, develop cooperation skills, stimulate social interaction, and create conditions for the practical application of communicative competence in educational and professional contexts.

The control group continued its educational activities using the traditional methodology, without implementing the developed pedagogical conditions.

During the control stage, repeated diagnostics were conducted to determine changes in students' communicative competence. The results obtained in the experimental and control groups were compared according to the established criteria and levels to evaluate the effectiveness of the implemented system and pedagogical conditions.

To improve the transparency and reproducibility of the study, the overall experimental procedure is presented in Figure 1.

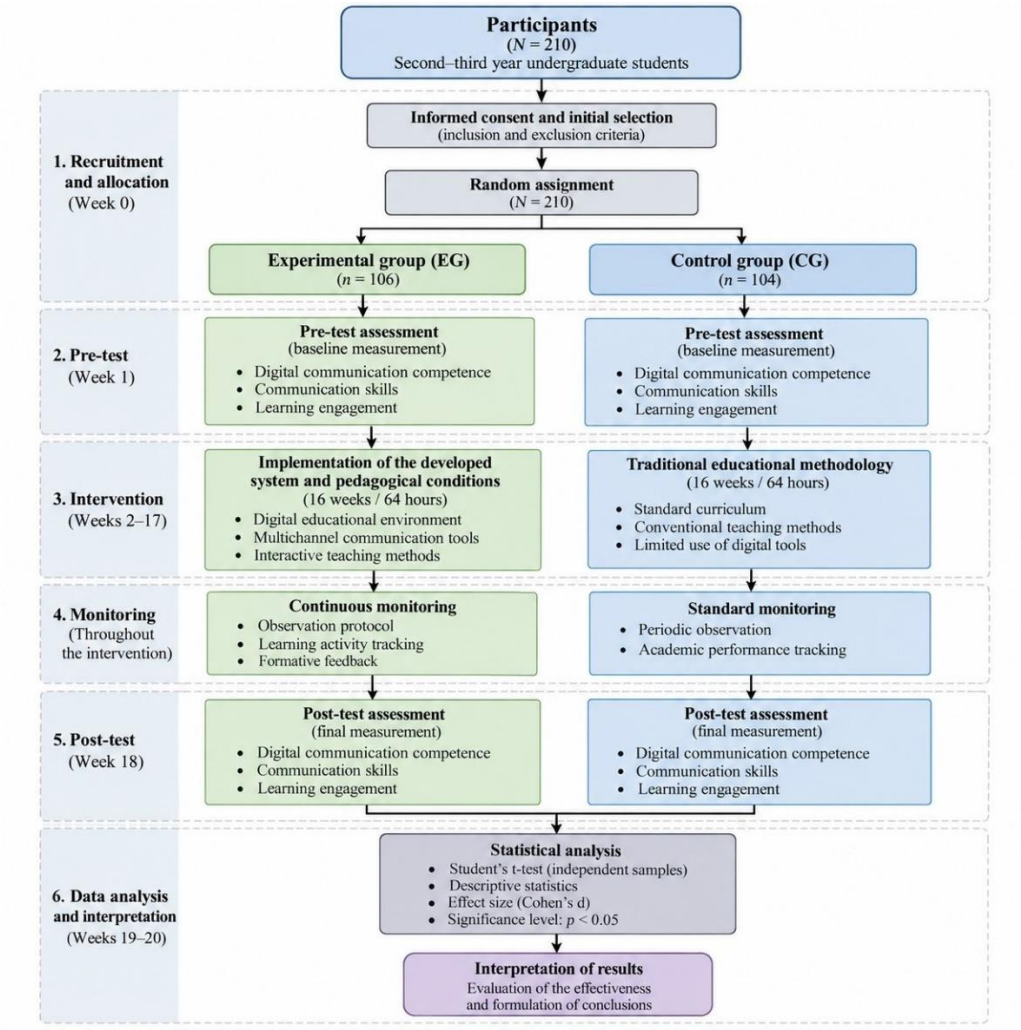


Figure 1. Experimental Design and Research Procedure.

Figure 1 illustrates the sequence of research stages, participant allocation, intervention implementation, assessment procedures, and statistical analysis.

Operational Characteristics of Measurement Instruments

Digital Communication Competence Questionnaire

Purpose: Assessment of students' digital communication competence.
Number of items: 24

Dimensions:

- Digital interaction (6 items)
- Online collaboration (6 items)
- Information exchange (6 items)
- Communication ethics (6 items)

Scale: 5-point Likert scale (1 = strongly disagree; 5 = strongly agree)

Score range: 24–120 points

Interpretation:

- Low level: 24–55
- Medium level: 56–87
- High level: 88–120

Reliability: Cronbach's α = 0.87

Multichannel Communication Skills Assessment

Purpose: Evaluation of practical communication performance in digital educational environments.

Tasks:

- LMS communication activities
- Video conferencing participation
- Collaborative cloud-based work
- Social communication tasks

Scoring system:
0–25 points for each task
Total score: 0–100 points

Interpretation:

- Low: 0–39
- Medium: 40–69
- High: 70–100

Student Engagement Scale

Purpose: Measurement of students' engagement in learning activities.

Components:

- Behavioral engagement
- Emotional engagement
- Cognitive engagement

Items: 18

Scale: 5-point Likert scale

Score range: 18–90

Reliability: Cronbach's α = 0.84

Observation Protocol

Purpose: Assessment of communication activity during learning.

Indicators:

- Frequency of student-teacher interactions
- Peer collaboration
- Feedback exchanges
- Participation in collaborative tasks

Observation frequency:

Once every two weeks during the intervention period.

Evaluation scale:

1–5 points for each indicator.

Statistical Analysis

The equivalence of the groups at the pre-test stage and differences at the post-test stage were determined using Student's t-test for independent samples. Statistical significance was established at $p < .05$. Effect size was additionally calculated using Cohen's d to determine the practical significance of the intervention effects.

Psycho-Educational Instruments

Digital Communication Competence Questionnaire

The level of students' digital communication competence was assessed using a structured questionnaire developed on the basis of the DigComp 2.2 (Vuorikari et al., 2022, 2022) framework. The instrument consisted of 24 items grouped into four dimensions: digital interaction, online collaboration, information exchange, and communication ethics. Responses were measured on a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). The internal consistency of the questionnaire was satisfactory (Cronbach's $\alpha = 0.87$).

Multichannel Communication Skills Assessment

Students' ability to operate within multichannel educational environments was evaluated through a performance-based assessment. Participants completed practical tasks requiring the use of learning management systems, video conferencing tools, collaborative cloud platforms, and social communication applications. Performance was evaluated according to standardized criteria developed by the research team.

Student Engagement Scale

To determine the influence of the intervention on learning engagement, a modified version of the Student Engagement Scale was applied. The instrument measured behavioral, emotional, and cognitive engagement in digital learning environments. Higher scores indicated stronger involvement in educational activities.

To assess student engagement, a modified version of the School Engagement Measure (SEM) developed by Fredricks et al. (2005) was used. The original instrument conceptualizes engagement as a multidimensional construct consisting of behavioral, emotional, and cognitive dimensions. For the purposes of the present

study, several items were adapted to reflect participation in digital learning environments while preserving the theoretical structure of the original scale.

Academic Interaction Observation Protocol

The quality of educational communication was additionally assessed through structured observation. Researchers evaluated the frequency of student-teacher interactions, peer collaboration, feedback exchange, and participation in collaborative tasks. Observations were conducted according to a standardized protocol throughout the experimental period.

Reliability and Validity Procedures

To ensure measurement reliability, all instruments underwent pilot testing prior to the main study. Internal consistency coefficients indicated satisfactory reliability of the measurement instruments. Content validity was established through expert evaluation by specialists in educational technology and pedagogy. Construct validity was verified through factor analysis.

Data Analysis

The study involved 210 participants who were divided into experimental and control groups. Descriptive statistics (mean values, standard deviations, frequencies, and percentages) were calculated for all variables. To determine statistically significant differences between groups, Student's t-test for independent samples was applied. Statistical significance was established at $p < .05$. All analyses were performed using SPSS Statistics software.

Quantitative analysis was used to determine the distribution of students across the identified levels of communicative competence formation and to compare results obtained before and after the formative intervention.

Qualitative analysis was used to interpret the direction and nature of changes in students' communicative competence and to determine the contribution of the socio-cultural environment, digital technologies, and interactive teaching methods to its development.

Statistical analysis was applied to assess the significance of differences between the experimental and control groups and to verify the effectiveness of the implemented pedagogical conditions.

The effectiveness of the formative intervention was evaluated using Student's t-test. The statistical analysis revealed significant positive changes in the experimental group across all criteria for the formation of communicative competence ($t = 5.176$, $p < 0.001$). In contrast, the changes observed in the control group did not reach statistical significance. The post-experimental comparison between the groups also demonstrated statistically significant differences ($t = 3.200$, $p < 0.01$), confirming the effectiveness of the developed pedagogical conditions and the system for forming students' communicative competence.

Ethical Considerations

The study was conducted in accordance with the ethical principles applicable to educational research. Participation in the study was voluntary, and the participants were informed about the purpose, procedures, and stages of the research before

taking part in the experimental work. The confidentiality and anonymity of the participants were maintained throughout the research process. The collected data were used exclusively for scientific purposes, and participants were informed of their right to withdraw from the study at any stage without any negative consequences.

Results

The results of the ascertaining stage demonstrated the initial distribution of students by levels of communicative competence formation in both the control and experimental groups. The analysis showed the predominance of low and sufficient levels of communicative competence, while the proportion of students with a high level remained relatively limited. The results obtained confirmed the need to improve the educational process and to create favorable pedagogical conditions for the development of students' communicative competence within the socio-cultural environment of higher education. The summarized results are presented in Table 1.

Table 1.
The level of formation of students' communicative competence at the ascertaining stage

Level	CG – 104		EG – 106	
	Abs.	%	Abs.	%
High	25	24.04	22	20.75
Sufficient	45	43.27	44	41.51
Low	34	32.69	40	37.74

Based on the results of the formation of students' communicative competence according to three criteria in the ascertaining experiment, we came to the following conclusions:

1. To increase students' communicative competence according to the three identified criteria, there is a need to adjust the higher education process.
2. Special attention should be focused on filling and organizing the socio-cultural environment of higher education – creating an educational multi-channel digital environment that contributes to better perception of information, arouses students' desire to take an active part in education and profession, maximally satisfies students' interests, and stimulates communicative interaction by reorienting education to a personal-activity model of interaction during classes.
3. It is necessary to introduce digital technologies (virtual educational platforms, mobile applications, multimedia technologies, simulations, virtual laboratories, social networks, online courses and massive open online courses (MOOCs), etc.) into the socio-cultural environment of higher education, and use interactive teaching methods (discussions, debates, business games, project methods, etc.)
4. It is urgent to intensify the educational work of higher education institutions in terms of forming students' communicative competence.

To form students' communicative competence, we have substantiated and implemented pedagogical conditions in the EG and developed an innovative methodology that should be implemented in the educational process of the socio-cultural environment of higher education:

– Creation of an educational multi-channel digital environment that contributed to a better perception of information.

- Implementation of psychological and pedagogical support for students and reorientation of education to a personal and activity model of interaction during classes.
- Introduction of digital technologies in the socio-cultural environment of higher education (virtual educational platforms, mobile applications, multimedia technologies, simulations, virtual laboratories, social networks, online courses and open mass online courses (MOOCs), etc.).
- Use of interactive teaching methods (discussions, debates, business games, project methods, etc.).

Therefore, our analysis of students' communicative competence at the ascertaining stage showed a predominantly low and sufficient level of formation of the outlined competence and allowed us to substantiate pedagogical conditions, design further experimental work, and develop methodological support for the formation of students' communicative competence in the socio-cultural environment of higher education.

The effectiveness of implementing pedagogical conditions and the proposed system for developing students' communicative competence in the socio-cultural environment of a higher education institution, in accordance with the tasks of the formative experiment, was assessed through the comprehensive development of motivational, activity, and personal criteria. The effectiveness of the implementation of pedagogical conditions and the system was assessed by comparing the results of the control groups and experimental groups before and after the formative experiment.

The level of formation of students' communicative competence indicators at the control stage was re-evaluated in the control and experimental groups. Mathematical statistics methods were used to verify the reliability of the results obtained.

According to the results of the experimental study, the re-evaluation of the level of formation of students' communicative competence indicators at a higher education institution after conducting a formative experiment across all criteria yielded the following statistical data.

Control group. In this group, moderate positive changes in the distribution of students (104 students) were observed in the levels of formation of communicative competence among respondents.

A high level was demonstrated by 26.92% of respondents – 28 students, which is 3 more than the initial indicators.

A sufficient level was demonstrated by 50.00% of respondents – 52 students, an increase of 7.

Accordingly, the number of students decreased to 23.08% (24 people), which is 10 respondents fewer than the initial indicators.

Experimental group: In this group (106 students), respondents experienced more pronounced positive changes in the levels of development of communicative competence.

A high level of development of communicative competence was demonstrated by 50.94% of respondents − 54 students, which is an increase, compared to the initial results, of 32 people.

A sufficient level was demonstrated by 33.96% of respondents − 36 students, which means a decrease of 8 people.

The number of students with a low level decreased significantly to 15.09% of respondents (16 people), which is 24 students fewer than the initial indicators.

The obtained results of the development of communicative competence indicators of students at the control stage indicate a significantly higher effectiveness of the formative experiment in the experimental group, where almost half of the students achieved a high level of development of communicative competence according to all the identified criteria. In contrast, in the control group, this indicator is only a quarter of the total number of students.

Using the Student's t-test, the reliability of the identified changes was assessed to determine whether the difference between the two samples' mean values is statistically significant.

In practice, this test allows us to determine whether two groups differ as a result of implementing a specific intervention (in our case, pedagogical conditions and the system) or whether the difference is attributable to random factors. Using the Student's t-test, we can objectively assess the effectiveness of the implemented pedagogical conditions and system in the experimental group in comparison with the control group.

Compared with the Pearson correlation coefficient, the Student's t-test was chosen because the purpose of the study was to determine differences between the groups (CG and EG), not to assess the degree of linear dependence between the two data sets. The Pearson correlation coefficient is more suitable for assessing the degree of dependence between variables, whereas the Student t-test allows us to assess whether the mean differences between the two groups (CG and EG) are statistically significant.

The effectiveness of the conducted formative experiment is confirmed by statistical analysis. Statistically significant positive changes are observed in the experimental group across all criteria for the development of students' communicative competence ($t = 5.176$, $p < 0.001$). In contrast, the changes in the control group are not statistically significant. The difference between the groups after the experiment is also statistically significant ($t = 3.200$, $p < 0.01$), demonstrating the effectiveness of the applied pedagogical conditions and the system for developing communicative competence.

To assess the effectiveness of the implemented pedagogical conditions and the developed system for forming students’ communicative competence, a comparative analysis of the control and experimental groups was conducted before and after the formative intervention. The dynamics of changes in students’ communicative competence levels are presented in Table 2.

Table 2.
The level of formation of the indicators of the identified criteria of students' communicative competence at the stage of the formative experiment

Level	CG Before (n=104)	CG After (n=104)	EG Before (n=106)	EG After (n=106)
High	25 (24.04%)	28 (26.92%)	22 (20.75%)	54 (50.94%)
Sufficient	45 (43.27%)	52 (50.00%)	44 (41.51%)	36 (33.96%)
Low	34 (32.69%)	24 (23.08%)	40 (37.74%)	16 (15.09%)

As shown in Table 2, both groups showed positive changes; however, the experimental group demonstrated substantially greater progress. The proportion of students with a high level of communicative competence in the experimental group increased from 20.75% to 50.94%, while the proportion with a low level decreased from 37.74% to 15.09%. In the control group, the changes were less pronounced, with the proportion of students demonstrating a high level increasing only from 24.04% to 26.92%. These results indicate that the implemented pedagogical conditions and the developed system significantly contributed to the formation of students' communicative competence within the socio-cultural environment of higher education.

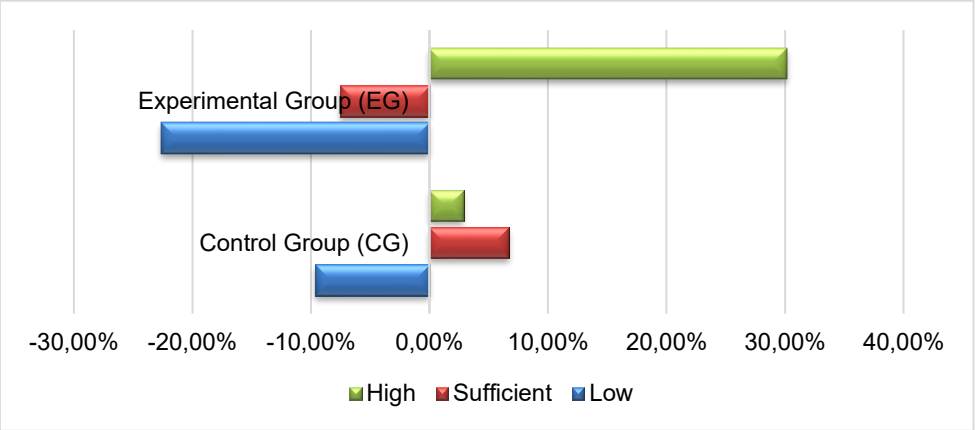


Figure 2. Changes in Students' Communicative Competence Levels During the Experiment

Figure 2 visually confirms the positive dynamics identified during the experiment. The graphical representation clearly demonstrates the substantial increase in the proportion of students with a high level of communicative competence and the simultaneous decrease in the proportion of students with a low level in the experimental group. Compared with the control group, the observed changes were considerably more pronounced, providing additional evidence of the effectiveness of the proposed pedagogical conditions and instructional system.

Discussion

The implementation of educational technologies in a multichannel digital environment enhances the quality of educational interaction and supports the development of student competencies. These findings confirm the increasingly important role of integrated digital ecosystems as a means of improving communication, collaboration, and student engagement in higher education.

The obtained findings are consistent with recent international studies emphasizing that educational technologies create conditions for more active student participation and strengthen collaborative learning processes. Previous research has demonstrated that digital ecosystems facilitate knowledge sharing, increase learning flexibility, and promote personalized educational trajectories. Contemporary theoretical approaches conceptualize digital educational ecosystems as interconnected networks of technological, pedagogical, and social elements that interact to support learning, communication, and knowledge construction (Dalsgaard & Ryberg, 2023; Mishra & Koehler, 2006; Otto & Kerres, 2023). Within such ecosystems, educational effectiveness depends not only on technological infrastructure but also on the quality of pedagogical design and social interaction among participants. The present study extends these findings by highlighting the role of multichannel communication environments as a critical component of ecosystem effectiveness.

The results also support contemporary theoretical approaches that view digital educational ecosystems as interconnected networks of technological, pedagogical, and social elements. Recent studies have emphasized that learning ecosystems are characterized by the interaction and interdependence of diverse educational resources, digital infrastructures, communication channels, and social actors, which collectively support knowledge construction and learning processes (Bozkurt & Stracke, 2023; Otto & Kerres, 2023). Digital educational ecosystems have also been shown to facilitate knowledge sharing, learner participation, flexibility, and collaborative learning through integrated technological and organizational structures (OECD, 2023). From this perspective, educational outcomes depend not only on the availability of digital tools but also on the quality of communication and interaction among ecosystem participants. The observed improvements may therefore be explained by the enhanced opportunities for continuous feedback, collaborative problem-solving, and learner-centered engagement provided by multichannel environments.

Furthermore, the findings align with international research on digital transformation in higher education, which emphasizes the growing significance of adaptive and technology-enhanced learning environments. Recent studies suggest that successful digital ecosystems foster greater learner autonomy, strengthen digital competence, and support sustainable educational development. The present study contributes to this body of knowledge by providing empirical evidence from a higher education context and demonstrating the practical value of integrating multiple communication channels into the educational process.

Despite these positive findings, several limitations should be acknowledged. The study was conducted within a specific educational context, which may limit the generalizability of the results to other institutional settings. Future research could examine the long-term effects of multichannel communication environments across different disciplines, educational levels, and cultural contexts.

Overall, the findings suggest that educational technologies integrated within digital educational ecosystems can enhance communication quality and support more effective learning experiences. These results contribute to the ongoing discussion on digital transformation in higher education and provide practical implications for the design of future educational environments.

Our result is consistent with the authors' conclusions (Kostikova et al., 2021) on the role of modern digital technologies and the electronic digital environment in higher

education in the formation of students' intercultural communicative competence. In particular, the professional level of future specialists and the development of communicative competence among higher education applicants, which, across all spheres of social life, is a vector of their success, positively affect creative self-realization. To a large extent, the transformations in the modern world brought about by the development of communication means are driven by global computer networks and mass media.

The authors note the role of modern digital technologies in shaping students' intercultural communicative competence. The development of students' intercultural communicative competence and the expansion of their horizons are facilitated by communication with peers from other countries. It is very important to pay attention to analysis and reflection, to adequate discussion, and to the exchange of information on various problems of our time. With the help of modern digital technologies in the process of forming intercultural communicative competence, teachers teach students to evaluate material critically; respond to messages and information in oral and written form; express their thoughts competently and correctly; work independently; engage in self-education; and defend their point of view. In order to effectively maintain multi-level and diverse contacts and forms of communication in the modern world, it is necessary, in addition to knowledge of the appropriate language, to also know the rules, norms, customs, traditions of another culture – you need to know the culture and history of your partners, know the mechanism of the communication process itself, the complex of forms of their communication behavior, in order to predict all the significant possibilities of misunderstanding partners (Kostikova et al., 2019). Therefore, authors also revealed the positive impact of digital technologies on the formation of students' communicative competence, as we have confirmed, that the creation of an electronic digital environment of a higher education institution for the formation of intercultural communicative competence of students is of great importance, in order to constantly ensure access to the work programs of disciplines, their modules, curricula, practices, access to electronic educational resources and publications of library electronic systems; obtaining the results of intermediate certification, recording the progress of the educational process, conducting all types of classes, interaction via the Internet between participants in the educational process, procedures for assessing learning outcomes, distance educational technologies. Therefore, the formation of communicative competence as an integrative indicator of the degree of mastery of digital competence, which is an integral part of the quality training of qualified specialists, is relevant.

In the experiment, we applied the main principles of learning and multifunctional components to form the successful communicative competence of a higher education applicant, in harmony with the authors (Kostikova et al., 2019).

In order to form successful communicative competence of students, it is important to adhere to the basic principles of learning:

- Taking into account alternative forms of speech training, educational and methodological base, free time, specific conditions of activity in order to master language norms and organize dialogical skills.
- Complexity in solving problems of professional activity (independent isolation of communication issues by the student).
- Identification of the main elements of communicative competence that require improvement and orientation towards self-education of the personality.
- Openness and humanization (combination of traditions and innovations; introduction of socio- and culturally relevant measures in the socio-cultural

environment of higher education), because communication itself is a component of the motivational and needs sphere of the student and is associated with the orientation of each individual, encourages the choice of value orientations, the formation of a person's worldview, and the development of his or her intellect.

The findings of the study demonstrate that the implementation of the proposed pedagogical conditions and the developed system for fostering students' communicative competence contributed to statistically significant improvements in the experimental group compared with the control group. The positive dynamics observed across all criteria suggest that the integration of targeted pedagogical interventions within the socio-cultural environment of higher education can effectively support the development of communicative competence.

These findings are consistent with previous studies emphasizing the importance of active learning environments, collaborative interaction, and student-centered educational approaches for developing communication skills (Fredricks et al., 2005; OECD, 2023). The results also support contemporary views that communicative competence develops most effectively when students engage in continuous interaction, collaborative problem-solving, and reflective learning activities within digitally enriched educational environments.

At the same time, the present study extends previous research by demonstrating that the effectiveness of communicative competence development depends not only on instructional methods but also on the systematic implementation of pedagogical conditions that promote meaningful communication among participants in the educational process. The observed improvements suggest that creating opportunities for sustained interaction, feedback exchange, and cooperative learning may strengthen students' ability to communicate effectively in academic and professional contexts.

Nevertheless, the findings should be interpreted with caution. Several methodological limitations may have influenced the results. First, the study was conducted within a limited number of higher education institutions, which may restrict the generalizability of the findings to other educational contexts. Second, the use of self-report instruments may have introduced response bias, as students could overestimate their level of communicative competence. Third, the duration of the intervention was limited to a single experimental period, making it difficult to determine the long-term sustainability of the observed effects. Fourth, although efforts were made to ensure the equivalence of the experimental and control groups, the quasi-experimental design does not completely eliminate the influence of external variables that may have affected participants' development.

Future research should involve larger and more diverse samples, include longitudinal designs to assess the stability of outcomes over time, and combine self-report measures with observational and performance-based assessment methods. Further studies may also examine how specific components of the proposed pedagogical system contribute to the development of different dimensions of communicative competence.

Overall, the results provide empirical support for the effectiveness of the developed pedagogical conditions and suggest that their implementation can contribute to enhancing students' communicative competence in higher education settings.

Limitations

Several limitations should be considered when interpreting the results of this study. First, the research was conducted with 210 undergraduate students from a limited number of higher education institutions, which may restrict the generalizability of the findings to other educational contexts and student populations. Second, the study focused on assessing communicative competence using motivational, activity, and personal criteria; therefore, other potentially relevant dimensions of communicative competence were not examined. Third, the formative experiment evaluated the overall effectiveness of a комплекс pedagogical intervention that included digital technologies, interactive teaching methods, communicative training, and psychological-pedagogical support. Consequently, it was not possible to determine the individual contribution of each component to the observed improvements. Finally, the study assessed the immediate outcomes of the intervention and did not investigate the long-term sustainability of the achieved results. Future research should involve larger and more diverse samples, longitudinal designs, and comparative analyses of specific educational technologies to provide a deeper understanding of their impact on students' communicative competence.

Conclusions

The study confirms the effectiveness of educational technologies for enhancing students' communicative competence within multichannel digital learning environments. The obtained results demonstrate that the integration of digital communication tools, collaborative platforms, and interactive educational technologies contributes to more active educational interaction, learner engagement, and the development of communication skills required in contemporary digital educational ecosystems.

At the same time, several limitations should be acknowledged. The study was conducted within a specific institutional context and involved 210 participants from a limited educational environment. Consequently, the findings should be interpreted with caution when generalized to other higher education institutions, disciplines, cultural settings, or educational systems. In addition, the quasi-experimental design and the duration of the intervention may not fully capture the long-term effects of technology-enhanced communication development.

Future research should focus on expanding the geographical and institutional scope of investigations, incorporating longitudinal research designs, and examining the sustainability of communication competence development over time. Particular attention should be devoted to the use of artificial intelligence technologies, including generative AI systems, intelligent tutoring systems, conversational agents, and AI-supported feedback mechanisms, as tools for developing communicative competence in higher education. Further studies may also investigate how AI-driven personalized feedback, adaptive learning environments, virtual simulations, and multimodal communication platforms influence students' communication skills, learner autonomy, engagement, and collaboration within digital educational ecosystems. Recent international research highlights the need for longitudinal, comparative, and process-oriented studies of AI-supported communication learning, particularly regarding feedback quality, communicative competence development, and human–AI collaboration in educational settings.

Overall, the findings contribute to the growing body of research on digital educational ecosystems and provide practical implications for the design of technology-

enhanced learning environments aimed at fostering students' communicative competence in the era of artificial intelligence.

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Original Article

Aplicaciones móviles y sistemas pedagógicos para fomentar la competencia digital en la educación superior

Mobile applications and pedagogical systems for fostering digital competence in higher education

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Resumen

Objetivo de la investigación: fundamentar teóricamente y verificar experimentalmente las condiciones pedagógicas y el sistema desarrollados para fomentar la competencia digital de los estudiantes durante su formación profesional. El análisis de los datos obtenidos durante el experimento inicial (formativo) reveló que los estudiantes, tanto del grupo de control como del experimental, mostraban predominantemente niveles iniciales o intermedios de competencia digital. Esto evidenció la eficacia limitada del proceso actual de fomento de la competencia digital en la educación superior y puso de manifiesto la necesidad de implementar, en el proceso educativo, las condiciones pedagógicas propuestas y el sistema desarrollado por el autor para el desarrollo de dicha competencia mediante aplicaciones móviles. Los datos agregados del experimento formativo relativos a la competencia digital de los estudiantes del grupo experimental indican cambios dinámicos positivos y significativos en el nivel general de competencia. Los cambios más sustanciales en el grupo experimental se produjeron en el nivel inicial, mientras que en el grupo de control fueron insignificantes; esto confirma la eficacia del sistema y de las condiciones pedagógicas propuestas. Se realizó un análisis estadístico de los resultados experimentales utilizando la prueba de chi-cuadrado (χ^2) de Pearson para fundamentar que los resultados obtenidos no se debían al azar.

Palabras clave: competencia digital; sociedad digital; tecnologías digitales; educación superior; aplicaciones móviles.

Abstract

Research objective: to provide a theoretical rationale for, and experimentally verify, the developed pedagogical conditions and the system for fostering students' digital competence during their professional training. Analysis of data obtained during the baseline (formative) experiment revealed that students in both the control and experimental groups predominantly demonstrated initial or intermediate levels of digital competence. This showed the limited effectiveness of the existing process for fostering digital competence in higher education and highlighted the need to implement the proposed pedagogical conditions and the author's system for developing digital competence through mobile applications in the educational process. Aggregated data from the formative experiment regarding the digital competence of students in the experimental group indicate significant positive dynamic changes in the overall level of competence. The most substantial changes in the experimental group occurred at the initial level,

whereas changes in the control group were negligible; this confirms the effectiveness of the system and pedagogical conditions we proposed. We performed statistical processing of the experimental results using Pearson's chi-squared (χ^2) test to substantiate the claim that the obtained results were not due to chance.

Keywords: digital competence; digital society; digital technologies; higher education; mobile applications.

Introduction

The rapid development of modern information society necessitates the modernization and significant transformation of the higher education system (Bilyk et al., 2023). One way to motivate students to study specialized disciplines, stimulate their cognitive interest, and improve the quality of the educational process in universities is to implement digital technologies for e-learning, mobile learning, and distance learning (Nikolopoulou, 2018).

A key step in modern education is integrating mobile applications into the educational process, reflecting the significant role of digital technologies in modern society. As tablets and smartphones become more common among students, using these devices for educational purposes is a logical development and a necessary adaptation to the constant changes in the educational process (Miyer et al., 2023).

The ongoing digital transformation of education has become a strategic priority worldwide, requiring higher education institutions to redesign teaching, learning, and assessment practices in response to technological advancements and the demands of the digital society (European Commission, 2020; UNESCO, 2023).

Mobile applications enable the exchange of information for educational purposes, the creation and opening of multimedia files, and access to adapted reference and educational resources via the Internet – including specialized websites featuring practical exercises, online tests, and more (Fernández-Batanero et al., 2022).

The popularity of various mobile applications is growing alongside the proliferation of mobile devices (Palshkov et al., 2026). Researchers have identified key advantages of mobile applications: they must be accessible via the Internet; they must resume from where work was interrupted and be compact; they should enable productive use of spare time; and they must synchronize with mobile learning devices (Sandoval-Henríquez & Badilla-Quintana, 2022).

Mobile applications in higher education represent a promising avenue for developing the education sector; therefore, we selected the following research topic: "Mobile applications in higher education: an experimental study".

Despite the growing body of research on mobile applications in education, several important gaps remain. Existing studies have primarily examined the technical characteristics, usability, accessibility, and general educational benefits of mobile applications (Fernández-Batanero et al., 2022; Nikolopoulou, 2018; Sandoval-Henríquez & Badilla-Quintana, 2022). Recent research has also highlighted the potential of mobile technologies to support personalized learning, student engagement, and flexible access to educational resources. However, limited attention has been paid to the systematic development of students' digital competence through the purposeful integration of mobile applications within higher education curricula. Furthermore, there is a lack of experimentally validated

pedagogical conditions and comprehensive instructional systems that combine mobile applications with digital technologies, artificial intelligence tools, collaborative platforms, and digital learning environments. Empirical evidence regarding the effectiveness of such integrated approaches in developing cognitive, activity-based, and motivational components of digital competence also remains insufficient.

Based on these research, the following hypotheses were formulated:

H1: Students exposed to the proposed pedagogical system integrating mobile applications will demonstrate significantly higher levels of digital competence than students in the control group.
H2: The implementation of the pedagogical conditions will positively affect all three components of digital competence: cognitive, activity-based, and motivational.
H3: The experimental group will demonstrate statistically significant improvements in digital competence levels between the baseline and formative stages of the experiment.

Accordingly, the study aims to provide a theoretical rationale for and experimentally verify the effectiveness of the developed pedagogical conditions and instructional system for fostering students' digital competence during professional training.

Literature Review

Recent advances in educational technology have significantly increased scholarly interest in the use of artificial intelligence (AI) and mobile learning (m-learning) within higher education. The rapid digital transformation of universities has stimulated the development of innovative learning environments that combine mobile technologies, intelligent systems, learning analytics, and personalized educational approaches. Contemporary research increasingly recognizes that mobile applications and AI-based tools are becoming essential components of modern university teaching and learning processes.

A substantial body of recent literature has examined the adoption and effectiveness of mobile learning in higher education. A systematic review by Valencia-Arias et al. (2024), based on studies indexed in Scopus and Web of Science, demonstrated that mobile learning improves flexibility, accessibility, and student engagement while supporting personalized learning experiences. The authors identified behavioral intention, attitude toward technology, and perceived usefulness as the primary factors influencing successful m-learning adoption in university settings.

A comprehensive meta-review conducted by Bond et al. (2024) further demonstrated that AI-based educational systems enhance personalization, learner support, and adaptive instruction. However, the authors also identified important challenges related to ethics, transparency, methodological rigor, and responsible AI implementation in higher education. These findings suggest that the educational value of AI depends not only on technological capabilities but also on pedagogically sound integration strategies.

Boiko et al. (2024) and Hunko (2023) emphasize that mobile applications expand access to education, promote educational equity, and support personalized learning experiences. Their findings suggest that mobile technologies increase student engagement and provide more flexible opportunities for acquiring professional knowledge and skills.

The second area focuses on technological and pedagogical challenges associated with mobile learning. Vinodhini et al. (2021) identified several limitations of existing applications, including inconvenient interfaces, outdated information, insufficient notification systems, and difficulties in information retrieval. Similarly, Opryshko et al. (2024) highlighted infrastructural and organizational barriers, stressing the importance of reliable Internet access and adequate digital infrastructure for the successful implementation of mobile learning. These studies demonstrate that the effectiveness of mobile applications depends not only on their pedagogical design but also on technological and institutional conditions.

The third area addresses the integration of innovative digital technologies into educational environments. Soliar et al. (2021) demonstrated the educational value of cloud-based applications and online resources for developing students' creativity and professional competencies. Likewise, Hu et al. (2019) emphasized the importance of technical quality, usability, and platform compatibility in the development of mobile applications, which directly affect user experience and educational effectiveness.

Research on intelligent educational technologies additionally demonstrates the growing importance of AI-supported personalized learning. Recent systematic reviews indicate that intelligent educational systems facilitate adaptive instruction, self-regulated learning, and individualized educational pathways that accommodate learners' diverse needs and learning preferences. These technologies have proven particularly valuable in higher education environments characterized by increasing diversity and growing demands for flexible learning opportunities.

Despite the substantial growth of research on mobile learning and artificial intelligence, several gaps remain. Most existing studies examine either mobile learning adoption or AI implementation separately. Limited attention has been devoted to experimentally validating comprehensive pedagogical systems that integrate mobile applications, artificial intelligence tools, collaborative digital platforms, and digital learning environments for the systematic development of students' digital competence. Furthermore, empirical evidence regarding the impact of such integrated approaches on cognitive, activity-based, and motivational dimensions of digital competence remains insufficient. These gaps justify the need for the present study and determine its research objectives.

Methodology

Research Design

The study used a quasi-experimental research design to investigate the effectiveness of pedagogical conditions and an author-developed system for fostering students' digital competence through mobile applications in higher education. The research assumed that purposefully integrating mobile applications, digital technologies, artificial intelligence tools, and a stimulating digital educational environment into the educational process would contribute to the development of students' digital competence.

The experimental study consisted of two interconnected stages: **ascertaining** and **formative**. The research aimed to provide a theoretical justification for the proposed pedagogical conditions and to experimentally verify their effectiveness in developing students' digital competence during professional training.

Participants

The study involved 193 higher education students, including 95 students in the control group (CG) and 98 students in the experimental group (EG). The same participants took part in both the ascertaining and formative stages of the experiment, and the group composition remained unchanged throughout the study.

Students in the experimental group implemented the developed pedagogical conditions and the author's system for developing digital competence through mobile applications, while students in the control group continued their studies under traditional educational conditions.

Research Methods

The study employed a combination of theoretical, empirical, experimental, and statistical methods.

Theoretical methods included analysis, synthesis, comparison, systematization, and generalization of scientific literature related to digital competence, mobile learning, educational technologies, and digital transformation in higher education. These methods were used to determine the conceptual foundations of digital competence development and to substantiate the pedagogical conditions for its formation.

Empirical methods included surveys, questionnaires, pedagogical observation, testing, and diagnostic procedures. These methods assessed students' levels of digital competence and identified changes during the implementation of the pedagogical intervention.

Experimental methods involved a pedagogical experiment consisting of an ascertaining stage and a formative stage. The experiment was conducted to verify the effectiveness of the proposed pedagogical conditions and the author's system for developing digital competence through mobile applications.

Statistical methods included quantitative and qualitative analysis and the application of mathematical statistics to verify the significance of differences between the experimental and control groups. The reliability of the results was assessed using Pearson's chi-squared (χ^2) test.

Assessment Framework

The development of students' digital competence was assessed according to three interrelated criteria: **cognitive, activity-based, and motivational**.

The **cognitive criterion** assessed students' theoretical knowledge regarding mobile applications, digital technologies, and digital safety. Its indicators included knowledge of terminology, understanding of digital processes and technologies, and awareness of safety principles associated with mobile applications.

The **activity-based criterion** reflected students' practical skills in using mobile applications and digital technologies. Indicators included accuracy in task performance, effectiveness and speed of using digital tools, and the ability to collaborate in online environments.

The **motivational criterion** reflected students' attitudes toward mobile applications and digital technologies, readiness for independent learning, digital values, initiative in educational activities, online responsibility, and adherence to ethical standards in digital environments.

Based on these criteria, four levels of digital competence development were distinguished: **initial, intermediate, sufficient, and high.**

Intervention Procedure

The formative intervention lasted 16 weeks (one academic semester) and included 64 contact hours (4 hours per week) supplemented by independent learning activities.

The intervention in the experimental group was organized according to a structured weekly routine:

Week 1–2. Orientation and baseline diagnostics

- Initial assessment of digital competence.
- Introduction to mobile learning platforms and digital tools.
- Training in the use of Google Classroom and cloud-based collaboration services.

Week 3–6. Mobile learning implementation

- Use of mobile applications for content access, communication, and project activities.
- Weekly completion of mobile learning tasks (2 hours in class, 2 hours independent work).
- Continuous interaction through mobile educational platforms.

Week 7–10. Cloud-based collaborative learning

- Use of Google Drive, Google Docs, OneDrive, and Padlet.
- Collaborative projects and shared content creation.
- Weekly group assignments requiring online cooperation.

Week 11–13. Artificial intelligence integration

- Use of AI-supported educational tools for information retrieval, content generation, feedback, and problem-solving.
- Weekly AI-supported practical tasks.
- Reflection activities focused on responsible and ethical AI use.

Week 14–15. Gamification activities

- Implementation of gamified learning scenarios, quizzes, badges, leaderboards, and challenge-based tasks.
- Use of educational platforms supporting gamification elements.
- Evaluation of engagement and motivation indicators.

Week 16. Final assessment

- Post-test diagnostics.
- Collection of experimental data.
- Comparative analysis of control and experimental group outcomes.

The average weekly workload consisted of:

- Mobile applications: 2 hours/week.
- Cloud technologies: 1 hour/week.
- Artificial intelligence tools: 0.5 hour/week.
- Gamification activities: 0.5 hour/week.

Control of Confounding Variables

To ensure the internal validity and replicability of the quasi-experimental design, several procedures were implemented to control potential confounding variables.

1. **Equivalent participant groups.** The control group (CG, n = 95) and experimental group (EG, n = 98) demonstrated comparable baseline levels of digital competence during the ascertaining stage.
2. **Identical curriculum content.** Both groups studied the same academic disciplines, learning objectives, instructional materials, and assessment criteria.
3. **Equivalent instructional time.** Students in both groups received the same number of contact hours and independent learning tasks throughout the semester.
4. **Common teaching staff.** The same instructors participated in teaching both groups, reducing instructor-related variability.
5. **Standardized assessment procedures.** The same diagnostic instruments, criteria, indicators, and evaluation procedures were applied before and after the intervention.
6. **Controlled technological access.** All participants had access to institutional digital infrastructure and Internet connectivity required for participation.
7. **Isolation of the intervention effect.** The principal difference between groups was the implementation of the developed pedagogical conditions and integrated technological environment (mobile applications, AI tools, cloud technologies, and gamification) in the experimental group.

These procedures minimized external influences and increased the reliability and reproducibility of the results.

Data Analysis

The collected data were processed using quantitative, qualitative, and statistical methods.

Quantitative analysis was used to determine the distribution of students across the established levels of digital competence and to compare results before and after the formative intervention.

Qualitative analysis was used to interpret the nature and direction of changes in students' digital competence and to evaluate the contribution of mobile applications and digital technologies to its development.

Statistical analysis was performed using Pearson's chi-square (χ^2) test, which is widely recommended for examining differences between categorical variables and frequency distributions in educational and behavioral research. The test allows researchers to determine whether observed differences between groups are statistically significant and not attributable to random variation. Pearson's chi-square test is particularly appropriate for studies involving categorical levels of competence development and comparisons between control and experimental groups (Franke et al., 2012; Rossi, 2010).

Ethical Considerations

The study followed the ethical principles applicable to educational research. Participation was voluntary, and participants were informed about the purpose, procedures, and stages of the experiment before taking part in the research. The study maintained confidentiality and anonymity throughout and used the collected data exclusively for scientific purposes.

Results

We view the development of students' digital competence in higher education as a comprehensive set of measures involving the creation of pedagogical conditions, the development of a mobile-application-based system, and the effective organization of this process. We identify the following key areas:

- Substantiating and developing a learning system that utilizes mobile applications to foster students' digital competence.
- Implementing principles for developing students' digital competence through the use of mobile applications.
- Adjusting and monitoring the system of targeted measures aimed at developing students' digital competence through the use of mobile applications.

A primary objective in developing digital competence is adopting a practice-oriented approach to using mobile applications while enabling students to master critical thinking, digital literacy, and safety and ethics standards.

In our study, we have identified the main criteria corresponding to the specific indicators of this competence:

1. The cognitive criterion assesses the level of theoretical knowledge regarding mobile applications, digital technologies, and safety rules. Assessment indicators: command of terminology; understanding of the algorithms underlying the phenomenon in question and the knowledge system regarding its digitalization; and knowledge of the safety rules necessary for the successful use of mobile applications.
2. The activity-based criterion assesses skills and practical abilities. Assessment indicators: accuracy in task execution; speed in using mobile applications and the efficiency of digital tools; and the ability to collaborate online.
3. Motivational criterion: evaluates attitudes toward mobile applications and digital technologies, online activity, readiness for independent learning, and responsibility for one's own digital activities.

Assessment indicators: persistence in using mobile applications; established digital values; attitudes and demonstrated personal initiative in educational activities; and adherence to online responsibility and the ethics of mobile application use.

Based on these criteria, and for diagnostic measurement within the context of the research topic, we identified the following levels of digital competence development among higher education students:

1. Initial level: the student possesses basic skills and knowledge but lacks consistency in their activities; frequently requires instructor assistance.
2. Intermediate level: the student has sufficient skills and knowledge but cannot always apply them in standard situations.
3. Sufficient level: the student can analyze information, independently solve most tasks in standard situations, and create content.
4. High level: the student demonstrates a high level of motivation and proficiency; can creatively use mobile applications and digital technologies in non-standard situations; and acts as a mentor to others.

A total of 193 respondents participated in the experiment, comprising a control group (CG) of 95 students and an experimental group (EG) of 98 students. Analysis of the data obtained during the baseline experiment indicates that, across all applied criteria, the majority of students in both the control group (CG) and the experimental group (EG) demonstrate only initial or intermediate levels of digital competence – competence acquired through the digitalization and use of technologies within the higher education learning process.

Regarding the cognitive criterion, the following was established: in the CG, an initial level of digital competence – necessary for acquiring theoretical knowledge about mobile applications, digital technologies, capabilities, and safety rules, as well as for understanding netiquette – was observed in 25.3% of students; an intermediate level in 36.8%; a sufficient level in 24.2%; and a high level in only 13.7%. In the EG, 26.5% of students had an initial level, 36.7% an intermediate level, 23.5% a sufficient level, and only 13.3% a high level (Table 1).

Table 1.
Results of the baseline assessment of students' digital competence development in higher education based on the cognitive criterion

Level	CG (n = 95)		EG (n = 98)	
	%	Abs.	%	Abs.
High	13.7	13	13.3	13
Sufficient	24.2	23	23.5	23
Intermediate	36.8	35	36.7	36
Initial	25.3	24	26.5	26

Source: Authors' own elaboration.

The distribution of indicators based on the cognitive criterion allows an objective analysis of the level at which students have mastered theoretical knowledge of the operating principles of mobile applications, information flows, and the use of modern digital tools. The results provided an empirical basis for adjusting the methodology for using mobile applications, fostering students' digital culture, and identifying problem areas in professional training.

Regarding the activity-based criterion, the results of the baseline assessment of students' digital competence – specifically concerning the use of mobile applications during professional training – revealed the following: in the control group (CG), an initial level of theoretical preparation and understanding (encompassing task execution, tool effectiveness, digital environment formation, application usage speed, and online collaboration skills) was observed in 29.5% of students, an

intermediate level in 38.9%, a sufficient level in 23.2%, and a high level in only 8.4%. In the experimental group (EG), 30.6% of students were at the initial level, 40.8% at the intermediate level, 21.4% at the sufficient level, and just 7.1% at the high level.

The data from the baseline experiment stage indicate relative homogeneity between the CG and the EG, thereby confirming the objectivity of the subsequent comparative analysis. At the same time, the prevalence of the initial and intermediate levels in both groups, based on the activity-oriented criterion, indicates the need to implement pedagogical conditions and a proprietary system for developing students' digital competence in higher education institutions through mobile applications in the educational process (Table 2).

Table 2.
Results of the baseline assessment of students' digital competence development in higher education based on the activity-oriented criterion

Level	CG (n = 95)		EG (n = 98)	
	%	Abs.	%	Abs.
High	8.4	8	7.1	7
Sufficient	23.2	22	21.4	21
Intermediate	38.9	37	40.8	40
Initial	29.5	28	30.6	30

Source: Authors' own elaboration.

Based on the motivational criterion, the results of the baseline assessment regarding the development of students' digital competence during higher education studies were determined: in the control group (CG), an initial level of students' drive to use mobile applications, development of digital values, attitudes, and demonstration of personal qualities – such as initiative, online responsibility, and ethics – was found in 31.6% of students; an intermediate level in 37.9%; a sufficient level in 25.3%; and a high level in only 5.3%. In the experimental group (EG), 29.6% of students had an initial level, 39.8% had an intermediate level, 25.5% had a sufficient level, and only 5.1% had a high level (Table 3).

Table 3.
Results of the baseline assessment of students' digital competence development during higher education studies based on the motivational criterion

Level	CG (n = 95)		EG (n = 98)	
	%	Abs.	%	Abs.
High	5.3	5	5.1	5
Sufficient	25.3	24	25.5	25
Intermediate	37.9	36	39.8	39
Initial	31.6	30	29.6	29

Source: Authors' own elaboration.

The overall level of students' digital competence development, as determined during the baseline experiment stage of higher education studies based on three criteria, was as follows: in the control group (CG), an initial level was observed in 28.4% of students, an intermediate level in 37.9%, a sufficient level in 24.2%, and a high level in only 9.5%. In the experimental group (EG), 29.6% of students had an initial level, 38.8% an intermediate level, 23.5% a sufficient level, and only 8.2% a high level (Table 4).

Table 4.
Aggregated results of the baseline assessment of students' digital competence development in higher education

Level	CG (n = 95)		EG (n = 98)	
	%	Abs.	%	Abs.
High	9.5	9	8.2	8
Sufficient	24.2	23	23.5	23
Intermediate	37.9	36	38.8	38
Initial	28.4	27	29.6	29

Source: Authors' own elaboration.

The analysis of the results of the ascertainment experiment with the students who took part in it proved the insufficient efficiency of the process of organizing the formation of digital competence of students in the higher school, the need to implement pedagogical conditions, and the developed author's system of forming the digital competence of students in institutions of higher education through the use of mobile applications in the educational process of the higher school.

Planning, organization, and results of a formative experiment.

The purpose of the formative experiment was to test the effectiveness of the developed pedagogical conditions and the author's system for forming students' digital competence through mobile applications in the higher school educational process.

The quantitative composition of the students who participated in the formative experiment, as well as the diagnostic tools we used, remained unchanged during both the ascertainment and formative stages. In CG, we did not implement the pedagogical conditions we proposed, whereas in EG we implemented the author's work we developed.

This made it possible to track dynamic changes based on three criteria for the formation of digital competence and to compare quantitative and qualitative changes before and after introducing the author's system and pedagogical conditions.

The verification of the levels of formation of digital competence of students in institutions of higher education was carried out in CG, where pedagogical conditions and the author's system were not implemented, and in EG, where pedagogical conditions were implemented and an author's system of formation of digital competence of students in institutions of higher education was developed through the use of mobile applications. During the formative evaluation, analysis of the experimental data helped identify changes in students' levels of formation of the defined competence across all criteria.

Thus, according to the cognitive criterion of the formation of digital competence of students, it was found: in CG, 21.1% of students showed an initial level of formation of the studied competence, an intermediate level – 34.7% of students, a sufficient level – 29.5% of students, and a high level – only 14.7% of students. In the EG, 16.3% of students had an initial level, 29.6% an intermediate level, 33.7% a sufficient level, and 20.4% a high level (Table 5).

Table 5.
The results of the formative assessment of the formation of digital competence of students in the process of studying in higher education according to the cognitive criterion

Level	CG (n = 95)		EG (n = 98)	
	%	Abs.	%	Abs.
High	14.7	14	20.4	20
Sufficient	29.5	28	33.7	33
Intermediate	34.7	33	29.6	29
Initial	21.1	20	16.3	16

Source: Authors' own elaboration.

Based on the motivational criterion, the results of the formative experiment regarding the level of students' digital competence development during higher education studies were as follows: in the control group, an initial level of the phenomenon was observed in 27.4% of students, an intermediate level in 33.7%, a sufficient level in 30.5%, and a high level in only 8.4%. In the experimental groups, 14.3% of students had an initial level, 30.6% an intermediate level, 33.7% a sufficient level, and 21.4% a high level.

Table 6.
Results of the formative assessment of students' digital competence development during higher education studies, based on the activity-based criterion

Level	CG (n = 95)		EG (n = 98)	
	%	Abs.	%	Abs.
High	10.5	10	18.4	18
Sufficient	29.5	28	43.9	43
Intermediate	35.8	34	26.5	26
Initial	24.2	23	11.2	11

Source: Authors' own elaboration.

At the formative assessment stage, the overall generalized level of students' digital competence – developed during higher education studies – was determined based on all criteria (cognitive, activity-based, and motivational) as follows: in the control group, an initial level was observed in 25.3% of students, an intermediate level in 34.7%, a sufficient level in 29.5%, and a high level in only 10.5%. In the experimental groups, 12.2% of students had an initial level, 27.6% an intermediate level, 39.8% a sufficient level, and 20.4% a high level.

Table 7.
Results of the formative assessment of students' digital competence development during higher education studies based on the motivational criterion

Level	CG (n = 95)		EG (n = 98)	
	%	Abs.	%	Abs.
High	8.4	8	21.4	21
Sufficient	30.5	29	33.7	33
Intermediate	33.7	32	30.6	30
Initial	27.4	26	14.3	14

Source: Authors' own elaboration.

The results presented in Table 7 indicate substantial improvements in the motivational component of students' digital competence in the experimental group. The proportion of students demonstrating a high level increased to 21.4% in the

experimental group compared to only 8.4% in the control group. Simultaneously, the percentage of students with an initial level decreased to 14.3% in the experimental group, whereas it remained considerably higher in the control group (27.4%). These findings suggest that the integrated use of mobile applications, artificial intelligence tools, cloud-based learning environments, and gamification strategies positively influenced students' motivation, engagement, and readiness for independent digital learning.

Table 8.
Generalized results of the formative assessment of digital competence development during higher education studies

Level	CG (n = 95)		EG (n = 98)	
	%	Abs.	%	Abs.
High	10.5	10	20.4	20
Sufficient	29.5	28	39.8	39
Intermediate	34.7	33	27.6	27
Initial	25.3	24	12.2	12

Source: Authors' own elaboration.

The generalized results presented in Table 8 demonstrate substantial improvements in the overall level of students' digital competence following the implementation of the proposed pedagogical system. In the experimental group, the proportion of students achieving sufficient and high levels reached 60.2%, compared with only 40.0% in the control group. At the same time, the percentage of students with an initial level of digital competence decreased to 12.2% in the experimental group, whereas it remained considerably higher in the control group (25.3%). The proportion of students demonstrating a high level of digital competence in the experimental group (20.4%) was almost twice that observed in the control group (10.5%). These findings confirm the effectiveness of the developed pedagogical conditions and indicate that the integrated use of mobile applications, artificial intelligence tools, cloud technologies, and gamified learning activities contributes significantly to the development of students' digital competence in higher education.

Thus, the aggregated data from the formative experiment regarding the development of digital competence among students in the experimental group (EG) indicate significant positive dynamic changes in its overall level. The most substantial changes in the EG occurred at the initial level, whereas the dynamics in the control group (CG) were negligible.

Based on the data, we conclude that the system we substantiated and the implemented pedagogical conditions were effective; students in the EG showed significantly greater quantitative changes than the CG across all criteria for the development levels of the competence under study.

We statistically analyzed the experimental results using Pearson's chi-squared (χ^2) test to support the claim that the results were not due to chance and that the difference in digital competence levels between EG and CG students following the formative training process was significant. This demonstrates a meaningful interrelationship between the implemented system and pedagogical conditions and the resulting levels of student digital competence.

We attribute the lack of significant differences in the competence levels of CG students – when compared to the results of the initial baseline (diagnostic) experiment – to the students' existing cognitive interests and general development.

The analysis of the experimental verification results and the statistical assessment of the system's implementation – along with the pedagogical conditions for developing students' digital competence – revealed positive trends within the experimental group regarding the levels of competence achieved across cognitive, activity-based, and motivational criteria.

Discussion

During the baseline stage of our research, we needed to provide a theoretical rationale for a set of pedagogical conditions designed to ensure the effectiveness of the process under study.

The first condition involved creating a stimulating digital educational environment in higher education. This entailed using collaboration platforms (such as Padlet and Google Classroom) and adopting an innovative approach to learning through gamification – specifically, utilizing the "Be Internet Awesome" program to foster high levels of student engagement and motivation.

The second condition involved integrating artificial intelligence technologies to serve as an intelligent partner, enabling students to realize their creative potential at a qualitatively new, innovative level.

The third condition focused on using mobile applications to cultivate digital values and foster personal qualities such as initiative in educational activities, online responsibility, and ethical mobile app use.

One key advantage of using mobile applications in the experimental group was the ability to individualize the learning process. These applications offered a personalized approach that adapted to each student's specific needs.

Mobile applications assessed the students' current knowledge levels and adapted content to ensure accessibility, avoiding cognitive overload from overly complex material; this fostered individual development and allowed students to work at their own pace – revisiting difficult topics as needed while accelerating through areas of strength. These applications provided a wide range of learning tools and up-to-date information, offering diverse resources such as interactive simulations, e-books, podcasts, and videos tailored to various learning preferences.

By incorporating gamification and interactive elements, mobile apps made learning more active and engaging, encouraged consistent study habits, and used visual and practical experiences to illustrate complex concepts, improving retention and comprehension. They also helped students prioritize tasks, organize study schedules, meet deadlines, become more autonomous learners, better prepare for the job market, and track their own progress. Platforms like Coursera and Khan Academy offered a wide range of courses and educational materials accessible on mobile devices. Educational apps such as Duolingo (for language learning) and Mathway (for solving math problems) also gained popularity among students. At the same time, Wilma facilitated communication by enabling students to share assignments, grades, and feedback.

Ultimately, mobile applications supported personalized learning and transformed the educational landscape for these students by providing unique access to knowledge and learning resources.

Integrating applications such as Google Classroom, Google Suite, and Quizlet into the educational process for EG students facilitated feedback, streamlined assignment management, and enabled discussions on a centralized digital platform.

Beyond classroom management and individualized learning, mobile apps provided access to educational content and high-quality online courses. Leading platforms included Coursera, AnkiDroid Flashcards, Edmodo, and Photomath, exemplifying how modern technologies integrate into education.

Thus, integrating mobile apps into higher education showed significant potential for EG students by boosting motivation, improving academic performance, and offering an individualized, flexible approach to professional training; implementing mobile technologies added value by expanding and enhancing educational capabilities.

A key feature of using AI solutions in the experimental group was their practical orientation; this allowed students to use intelligent systems to analyze production processes, hone practical skills, simulate professional scenarios, and develop solutions. Consequently, this ensured higher-quality training for future professionals and aligned the vocational training process more closely with real-world professional conditions. At the same time, integrating artificial intelligence into the educational process transformed approaches to assessing learning outcomes. It paved the way for a shift toward more objective and flexible assessment models.

The findings of the present study are generally consistent with contemporary international research on mobile learning, digital competence development, and the educational application of artificial intelligence in higher education. The generalized results obtained during the formative stage demonstrated that 60.2% of students in the experimental group achieved sufficient or high levels of digital competence, compared to 40.0% in the control group. Simultaneously, the proportion of students with an initial level of digital competence decreased to 12.2% in the experimental group, whereas it remained considerably higher in the control group (25.3%). These results indicate the effectiveness of the proposed pedagogical system in fostering students' digital competence.

The observed improvements correspond with the findings of recent systematic reviews on mobile learning in higher education. Previous research has demonstrated that mobile learning environments enhance flexibility, learner engagement, collaboration, and self-directed learning, which positively influence the development of digital skills and competencies. Researchers emphasize that the educational benefits of mobile learning are most evident when mobile technologies are integrated into pedagogically structured learning environments rather than used as standalone technological tools.

The substantial increase in the proportion of students achieving high and sufficient competence levels in the experimental group may be explained by the comprehensive nature of the intervention. Unlike many previous studies that focused exclusively on mobile applications, the present research integrated mobile learning, cloud technologies, artificial intelligence tools, collaborative digital platforms, and gamification strategies into a unified pedagogical system. This finding supports recent frameworks suggesting that AI-powered mobile learning environments can generate stronger educational outcomes when multiple digital technologies operate synergistically.

The results obtained for the motivational criterion are also consistent with international evidence. In the experimental group, the percentage of students demonstrating a high motivational level reached 21.4%, compared with only 8.4% in the control group. Similar findings have been reported in studies showing that mobile learning environments increase student motivation through personalization, immediate feedback, flexibility, and learner autonomy. Gamification elements and adaptive AI-supported learning environments have also been identified as significant factors influencing learner engagement and persistence.

At the same time, certain differences between our findings and previous research should be critically considered. Several systematic reviews report that the effectiveness of mobile learning interventions varies substantially across educational contexts. Some studies demonstrate only moderate improvements in learning outcomes because the implementation of technology is frequently limited to content delivery rather than being embedded within a comprehensive pedagogical framework. Therefore, technology alone does not automatically improve competence development; the educational benefits depend on instructional design, learning activities, and the quality of pedagogical support.

From a theoretical perspective, the stronger results obtained in the present study may be explained by the integration of constructivist and learner-centered principles. Students actively created digital content, collaborated through cloud environments, solved practical tasks using mobile applications, and interacted with AI-supported tools. These activities promoted active engagement, self-regulation, and authentic digital practice, which are recognized as critical factors in competence development. International reviews similarly conclude that digital competence develops most effectively within comprehensive digital learning ecosystems combining technological tools, learning methodologies, and virtual environments.

From a practical perspective, the findings suggest that universities should move beyond isolated technology adoption and instead implement integrated educational ecosystems that combine mobile applications, artificial intelligence, collaborative platforms, cloud technologies, and pedagogically grounded instructional strategies. Such an approach appears to provide more substantial improvements in digital competence than interventions focused on a single technology. This conclusion is consistent with recent international reviews emphasizing the growing importance of holistic digital transformation strategies in higher education.

Limitations of the Study

Several limitations should be considered when interpreting the findings of this study. First, the research employed a quasi-experimental design and involved 193 students from higher education institutions. Although the sample size was sufficient for statistical analysis, the findings may not be fully generalizable to all higher education contexts, academic disciplines, or national educational systems.

Second, the study was conducted within the context of Ukrainian higher education, which has specific organizational, technological, and socio-cultural characteristics. Therefore, caution should be exercised when transferring the results to other educational environments.

Third, digital competence was assessed through three dimensions—cognitive, activity-based, and motivational. While these dimensions provide a comprehensive framework for evaluating students' digital competence, other potentially relevant

aspects, such as digital creativity, digital citizenship, cybersecurity behavior, and long-term technology adoption, were not examined.

Fourth, the intervention combined multiple educational components, including mobile applications, digital platforms, cloud technologies, artificial intelligence tools, collaborative environments, and gamification approaches. Consequently, it was not possible to determine the individual contribution of each component to the observed improvements in students' digital competence.

Finally, the study evaluated the immediate effects of the implemented pedagogical conditions and the author-developed system. Further longitudinal research is needed to determine the sustainability of the obtained results and to assess the long-term impact of mobile applications on students' digital competence development.

Conclusions

The results of the quasi-experimental study demonstrated the effectiveness of the developed pedagogical system for fostering students' digital competence through the integrated use of mobile applications, artificial intelligence tools, cloud technologies, collaborative digital environments, and gamification strategies in higher education.

The statistical analysis revealed significant positive differences between the experimental and control groups. Following the intervention, 60.2% of students in the experimental group achieved sufficient and high levels of digital competence, compared with 40.0% in the control group. Simultaneously, the proportion of students demonstrating an initial level of digital competence decreased to 12.2% in the experimental group, whereas it remained at 25.3% in the control group. These results confirm the effectiveness of the proposed pedagogical conditions and the author-developed instructional system in improving students' digital competence.

The theoretical contribution of the study lies in the development and experimental validation of an integrated pedagogical system that combines mobile learning technologies, artificial intelligence, cloud-based collaboration, and gamified educational approaches within a unified framework for digital competence development. Unlike many previous studies that examine these technologies separately, the present research demonstrates the educational value of their systematic integration and provides empirical evidence regarding their combined impact on cognitive, activity-based, and motivational components of digital competence.

The practical and institutional significance of the study is associated with the possibility of implementing the proposed pedagogical system in various higher education institutions seeking to strengthen students' digital competence and support digital transformation processes. The developed pedagogical conditions may be adapted to different academic disciplines, educational programs, and institutional contexts where digital technologies constitute an essential component of professional training. However, the transferability of the findings should be considered in relation to local organizational, technological, and educational conditions.

The conclusions of this study are limited to the results obtained from the comparison of the experimental and control groups and should not be generalized beyond the investigated context without further empirical verification. Although the findings

indicate the effectiveness of the proposed pedagogical system, additional studies involving different student populations, academic disciplines, and national educational systems are required to confirm its broader applicability.

Future research should focus on longitudinal investigations examining the sustainability of digital competence development over extended periods following the completion of educational interventions. Such studies would make it possible to evaluate whether the competencies acquired through mobile learning technologies and AI-supported educational environments remain stable over time and continue to influence students' educational and professional activities. Further research should also explore the individual contribution of specific technological components, including mobile applications, artificial intelligence tools, cloud technologies, and gamification, to the development of different dimensions of digital competence.

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