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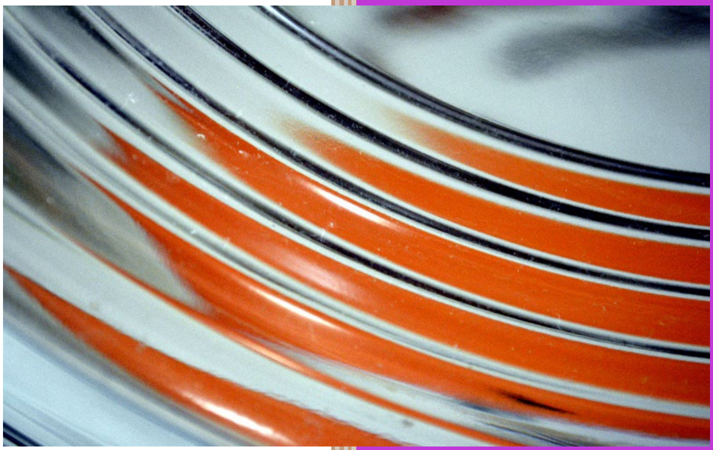

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Development and Validation of an AI Literacy Scale for Pre-Service Teachers in Thailand

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Abstract: Artificial intelligence (AI) is having a significant impact on contemporary lives, especially in learning and instruction design. The exploration of AI literacy in teacher education is an essential foundation for the redesign of instructional approaches to enhance pre-service teachers' AI literacy. This study aimed to develop the scale of AI literacy by employing exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to develop the items and validate a self-assessment AI literacy scale for pre-service teachers for practical implementation for teacher development courses in undergraduate curricula. In this study, AI literacy, synthesized from relevant studies and drawing on experts in educational technology, includes four constructs: 1) recognition, 2) fundamental comprehension, 3) pedagogy, and 4) ethical use of AI, offering a comprehensive and versatile instrument for the measurement of AI literacy in teaching professional development. The instrument's reliability and construct validity were confirmed using statistical analyses of data collected from 1,673 undergraduate pre-service students studying teaching and education at Thai universities, including both public and private universities. The findings indicated that the four constructs proposed had a good fit and showed excellent internal consistency ($\alpha = 0.94$). The average variance extracted, and composite reliability (CR) values met the criteria for validity. In the EFA, the items were reduced from 42 items to 39 items, which had a Kaiser-Meyer-Olkin of 0.993 and a significant test of sphericity (p-value $< .0001$). The CFA results revealed a chi-Square value of 480 ($p < 0.001$), an RMSEA of 0.035, an SRMR of 0.022, a comparative fit index (CFI) of 0.974, and a GFI of 0.974. Thus, the AI literacy scale for pre-service teachers developed in this study is a valid and reliable instrument for assessing pre-service teachers' AI literacy. Although it was not yet implemented in classroom settings, the established validity and reliability of the scale provide a foundation for future research and practical applications in teacher education.

Keywords: AI literacy for teacher, AI for teacher development, AI for education, Pre-Service teachers, Teacher education, Confirmatory factor analysis

1. Introduction

The cutting-edge of digital technologies, in particular in the case of artificial intelligence (AI) technology, has significant impacts on people's means of working and designing instruction in the twenty-first century (Kanont, et al., 2024; Ng, et al., 2021b; UNESCO, 2023; Wong, et al., 2020). Generative AI (Gen-AI) refers to artificial intelligence which, capable of producing muti-type content such as text, images, audio, or video. Hence, the widespread usage of Gen-AI applications among learners and instructors heavily plays a role in shifting contemporary learning and teaching norms, including the opportunities, imperatives, and risks that are inherent to the use of Gen-AI (Ajevski, et al., 2023; Bastani, et al., 2024; Oster, Henriksen and Mishra, 2024). Consequently, the future of educators necessitates the design of learning and integration with digital technology to align with the relevant and important needs of present society (Anders, 2023; Chen and Lin, 2023; Weston, 2023). Thus, pre-service teachers across multiple fields require the development of AI literacy, one of the future digital competencies of the framework for educators (UNESCO, 2023; Vuorikari, Kluzer and Punie, 2022). In addition, AI literacy is aligned with The National AI Action Plan for Thailand's Development (2022–2027), which is intended to develop human resource skills in AI for teachers, lecturers, and students, leading to improvements in the economy and in quality of life of the people by 2027 (Ministry of Higher Education, 2023).

Recent research has endeavored to evaluate AI literacy and to develop key components of AI literacy, e.g., Dai, et al. (2020), Ng, et al., (2021a), Davy Tsz Kit, et al. (2022), Wang, Rau and Yuan, (2022), Williams, et al. (2022) Biagini, Cuomo and Ranieri (2023), and UNESCO (2024). Then, several studies presents AI literacy relates to the recognition and distinguishing the content or systems that use AI using knowledge, concepts, and basic understanding of AI technology, the ability to use AI in various contexts, and the critical evaluation and selection of AI that is appropriate to a given issue or problem, under the ethical framework of the use of AI. However,

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while several researchers have studied AI Education, it was found that most research relates to the development of K-12 AI curriculum, which refers to the formal methods, courses, and pedagogical strategies used to achieve that goal (Eguchi, Okada and Muto, 2021; Jang, Jeon and Jung, 2022; G. Steinbauer, et al., 2021), while AI literacy emphasize on critically aware, recognize, evaluate, communicate, collaborate with, and use AI technologies responsibly in education.

To address this gap, the present study develops and validates an AI literacy scale for pre-service teachers to capture their knowledge, attitudes, and readiness to integrate AI in educational contexts. The scale aims to support teacher education programs in enhancing AI literacy and technology-enhanced learning practices. This study draws upon recently introduced frameworks and instruments (Ng, Wu, et al., 2023; Zhao, Wu and Luo, 2022) designed to measure AI literacy across four dimensions: affective, behavioral, cognitive, and ethical. Following these frameworks, the current study operationalized AI literacy using these four dimensions and employed exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to validate the structure of the scale for pre-service teachers. Two research questions guided the study:

RQ1: What constructs and factors of an AI literacy scale for pre-service teachers?

RQ2: Is the AI literacy scale for pre-service teachers reliable and valid?

Overall, the findings of this study help support the development of an AI literacy scale that takes into account recent AI developments and is relevant to undergraduate pre-service teachers and teacher education in higher education. In addition, applications could be beneficial for developing learning, establishing, and integrating practical AI methods of instruction, and implementing policies to improve AI abilities and support future AI proficiency in pre-service teachers.

2. Literature Review

2.1 AI in Teacher Education

AI is widely utilized worldwide, in particular large language models (LLMs), which are the foundation of current Gen-AI. LLMs have been applied in various industries to generate media and information to enhance user productivity, such as consultation, learning, and decision-making in multiple fields (Burgsteiner, Kandlhofer and Steinbauer, 2016; Ghallab, 2019; Ng, et al., 2021a). Recent studies and emerging trends show that AI for education can assist teachers in teaching and learning, including in designing instruction, delivering lessons, generating educational media, providing personalized feedback, and enhancing professional development (Fernández Jiménez, 2024; Kim, 2024; Younis, 2025). AI thus can process vast amounts of data and information that go far beyond human capabilities. AI can learn and generate new content across various types of media, identify patterns in data, and facilitate human decision-making with predictive analytics (Hwang, et al., 2020; Ng, et al., 2021a; UNESCO, 2024). The integration of AI into teacher education will improve education and enable new forms of teaching, learning, and educational management, enhancing learning experiences and supporting teacher tasks. For instance, AI-driven adaptive learning systems can personalize educational content and make it more suitable for student needs, increasing learning engagement and improving learning outcomes and skills (Ahmad, et al., 2022; Davy Tsz Kit, et al., 2022; Sukkeewan, Songkram and Nasongkhla, 2024). In addition, AI tools can help teachers develop professional competencies through the provision of real-time feedback, analytics on student performance, and access to and generation of in-time educational resources, including through edcafe.ai, ChatGPT, Fliki, DALL-E, Botnoi, Gemini Code Assist, etc. (Chaudhry and Kazim, 2022). At present, AI, Gen-AI in particular is reshaping the educational landscape and redefining educators' competencies. As noted, a concerted effort is required to develop AI literacy in teacher education to ensure that teachers can effectively integrate technologies into their pedagogical practices (Seo, et al., 2021). Understanding and leveraging the capabilities of AI is becoming increasingly important for educators who intend to enhance learning experiences for their students and prepare them for a future where AI plays a significant role (Markauskaite, et al., 2022; Davy Tsz Kit, Ng et al., 2023).

2.2 Definitions and Components for AI Literacy in Pre-Service Teachers

AI literacy is increasingly being conceptualized as a multifaceted construct in teacher education that combines a technical understanding of AI with practical and ethical competencies. On the one hand, AI literacy includes technical knowledge, such as, the ability to explain how machine learning algorithm's function and the ability to understand the basic techniques and concepts behind the AI that is embedded in modern tools. This technical perspective aligns with calls for teachers, especially teachers of computer skills or technology teachers, to grasp what makes up AI and how it operates (Chiang and Yin, 2022; Kandlhofer, et al., 2016; Kong, Man-Yin Cheung and Zhang, 2023). In addition, AI literacy also entails having practical skills and ethical awareness, including the use of AI-driven applications in the classroom and critical evaluation of AI outputs and impacts. Researchers have shown that AI-literate educators should be able to leverage AI as a teaching assistant as well as recognizing its limitations and adhering to principles of fairness, transparency, and responsibility. Thus, pre-service teachers need to have a balance of both perspectives: a solid foundation in how AI works and sufficient discernment to apply AI tools pedagogically and ethically (Hua Du, et al., 2024; Kong, Man-Yin Cheung and Zhang, 2021; Long, Blunt and Magerko, 2021; Ng, et al., 2021a; Gerald Steinbauer, et al., 2021). In this study, the authors adopt a definition of AI literacy that refers to its general applicability and specify it for teacher education. This includes having fundamental knowledge and understanding of AI technology, critically and appropriately applying AI technology in pedagogy, and remaining aware of its ethical impacts and its proper use in the present societal and educational context, including ethical unitization (Hua Du, et al., 2024; Ng, et al., 2021a; Ng, et al., 2023a; UNESCO, 2024; Wilton, Sharma and Fan, 2022; Zhao, Wu and Luo, 2022). This concept is also suitable for teaching professionals who are not involved in AI development and AI scientists who use AI as an educational assistant tool.

The recently research on the components of AI literacy has shown that many researchers have proposed different components for it in relation to various contexts and study objectives, including AI awareness, knowing and understanding AI, using AI, evaluating and creating AI, and AI ethics (Davy Tsz Kit, et al., 2022; Ng, et al., 2021a; Ng, et al., 2023b), which is based on the digital literary concept. While, several studies have examined the structure of AI literacy, which involves several dimensions and definitions of AI literacy in various settings through employing qualitative and quantitative methods (Pinski and Benlian, 2023; Yetişensoy and Rapoport, 2023; Zhao, Wu and Luo, 2022). In the other perspective UNESCO (2024) defines 15 competencies across five domains, notably, AI foundations and applications, AI pedagogy, and the ethics of AI. These domains emphasize that teachers must have a solid understanding of what AI is and how it works, strategies of integrating AI into teaching practice, and a strong commitment to the ethical use of AI in education. This global policy perspective validates the inclusion of AI recognition, AI fundamental comprehension, AI pedagogy, and AI ethical use as crucial dimensions for the preparation of teachers. Moreover, Ng, et al. (2021c) and Ng, et al. (2023b) conducted an exploratory review of the AI literacy literature, distilling four overarching aspects of AI literacy: knowing and understanding AI, using and applying AI, evaluating and creating with AI, and addressing ethical issues. Similarly, Wang, Rau and Yuan (2022). in the course of developing an AI literacy scale, partitioned AI literacy into four factors: awareness of AI, practical skills in using AI, critical evaluation of AI outputs, and understanding AI ethics. Celik (2023b) argued that to effectively integrate AI into education, teachers must go beyond developing technological knowledge of AI to create pedagogical strategies for the use of AI, combined with the ability to address ethical issues to do with AI. In that study, an AI literacy scale was developed to measure teachers' knowledge for the instructional use of AI, extending Technological Pedagogical Content Knowledge (TPACK) including explicit ethical considerations. The results of this process showed that greater knowledge of how to interact with AI tools leads to a better understanding of AI pedagogical contributions, and pure technical knowledge needed to be coupled with pedagogy to be meaningful.

The findings indicated that the authors were motivated to extend the existing framework through integrating concepts of AI literacy (Ng, et al., 2021a; Ng, et al., 2021c; Wang, Rau and Yuan, 2022), the TPACK-AI framework (Celik, 2023b; Kim, et al., 2021), and the AI competency (UNESCO, 2024); which emphasis muti-levels of AI knowledge and skills based on human-centric, teacher development and responsibilities toward AI; for to teacher education contexts, in particular in various field of study in pre-service contexts, including the recognition, fundamental comprehension, pedagogy, and AI ethical use of AI. Hence, the researchers synthesized and conceptualized four aspects of AI literacy for pre-service teachers identified from the reviews.

AI Recognition refers to the acknowledgment of the comprehensive potential and impact of AI in educational settings. It involves an overview of the concept of AI processes in applications and services that critically distinguishes between human- and AI-generated content and explains the reasons for these distinctions. AI recognition entails a self-reflective process that occurs both before and after engagement with AI technology, as highlighted in several studies (Celik, 2023a; Laupichler, et al., 2022; Lee, et al., 2021; Wang, Rau and Yuan, 2022; Yetişensoy and Rapoport, 2023). According to this process, learners can critically assess their recognition of AI capabilities and limitations before its use. Before utilizing AI tools, learners contemplate the impact those AI tools can have on learning design, teacher tasks, and the teaching profession. The postunitizing learner's reflection allows them to identify misconceptions, understand AI's effects on their cognitive processes, and make informed adjustments for the case of future interactions.

Fundamental Comprehension of AI refers to the capacity to explain the essential workings of AI and classify several types of AI that may be useful for educational management. This incorporates articulation of the functions of specific AI technologies, reasoning concerning AI-generated content, identifying the advantages and precautions that are associated with AI usage, and discussing AI-related issues that impact teaching and education (Celik, 2023a; Davy Tsz Kit, et al., 2022; Laupichler, et al., 2022; Lee, et al., 2021; Ng, et al., 2021a; Williams, et al., 2022). This would include understanding such fundamental concepts as machine learning, the basic techniques behind AI products and service processes, LLMs, and various types of AI in the educational landscape. In line with this, Kim and Kwon (2023) emphasized that educators should have a basic understanding of AI in the TPACK framework used for elementary teachers. Moreover, for computer science teachers, Kim, et al. (2021) suggested that the requirements for K-12 teacher competencies in AI education should include the ability to construct programming environments, use web or API-based online education platforms for use in AI project education, and understand the fundamentals of AI, computer science, and applied mathematics, together with AI ethics. These competencies ensure that teachers are sufficiently well-equipped to integrate AI concepts into their curricula and guide students as they navigate the evolving technological landscape.

AI Pedagogy with reference to AI involves integration into teaching and learning to address educational problems and enhance instructional outcomes. Such integration includes demonstration of the use of AI in various educational contexts, the effective management of AI tools in both classroom and online environments, and the promotion of practical and ethical AI usage in learners (Celik, 2023b; Dai, et al., 2020; Davy Tsz Kit, et al., 2022; Kim, et al., 2021; Ng, et al., 2021a; Wang, Rau and Yuan, 2022; Williams, et al., 2022; Yetişensoy and Rapoport, 2023). Moreover, Celik (2023b) and Kim, et al. (2021) suggested that the enhancement of AI integration in pedagogy can be achieved through use of the AI-TPACK framework, which supports learners in its use of and becoming familiar with AI technologies in their application in teaching practices and strategies. This framework offers AI tools that are embedded in the learning ecosystem that enable educators to integrate AI directly into the educational experience for enhanced learning outcomes.

AI Ethical Use of AI refers to acting in a way that is critically aware of and in adherence to ethical frameworks that govern the use of AI in educational institutions, together with complying with government policies and service provider guidelines. This includes the following terms of use for the use of AI-generated content and management of data for AI processing without violating institutional regulations (Celik, 2023a; Kong, Man-Yin Cheung and Tsang, 2022; Laupichler, et al., 2022; Ng, et al., 2021a; Wang, Rau and Yuan, 2022; Williams, et al., 2022; Yetişensoy and Rapoport, 2023). Moreover, Khammarnia, et al. (2022) note that professional ethics include commitment and conscientiousness toward an individual's work, responsibilities, and commitments, as influenced by knowledge, desire, capability, and attitudes. These ethical considerations relate to rational thinking process that enables individuals to discern the values that should be preserved and disseminated in an organization. In particular, H. Du, et al. (2024) showed that AI ethics, including transparency, responsibility, justice, and sustainability, indirectly influence the behavioral intention to learn AI and directly affects teachers' perceptions of the use of AI for social good. Further, pre-service teachers should learn that their professional judgment and values are crucial for AI use. They need to understand the relevant ethical principles (e.g., fairness, nondiscrimination, and privacy) and should be prepared to apply them in the use of AI tools (UNESCO, 2024). Studies have found that teachers at present do not have sufficient training in these areas. In a recent study, pre-service teachers voiced concerns regarding data privacy and algorithmic bias as critical issues (Kohnke, et al., 2025). To respond to this, a large number of ethical principles or guidelines for teachers and educators have been developed to promote the proper understanding and use of AI (Richards and Dignum, 2019; U.S. Department of Education, 2023; UNESCO, 2023).

Previous findings have suggested that scholars were motivated to extend existing frameworks by integrating AI literacy concepts (Ng, et al., 2021a; Wang, Rau and Yuan, 2022), TPACK-AI framework (Celik, 2023b; Kim, et al., 2021), and the AI competency framework of UNESCO (2024) to teacher education contexts, in particular in various fields of study in pre-service contexts, including 1) AI recognition, 2) AI fundamental comprehension, 3) AI pedagogy, and 4) AI ethical use. Researchers have thereby developed four constructs for AI literacy for pre-service teachers. The theorical definitions of the constructions are presented in Table 1. Following this, the authors plan to validate these proposed constructs by assessing the reliability and validation of the AI literacy scale serve as an instrument to measure preservice teachers' AI literacy levels within teacher education.

While previous studies have proposed multiple frameworks and dimensions for AI literacy, this study focuses on four key factors; AI Recognition, AI Fundamental Comprehension, AI Pedagogy, and AI Ethical Use; because these dimensions consistently appear across the most influential frameworks (Ng et al., 2021a; Wang et al., 2022; Celik, 2023b) and align with the professional competencies among pre-service teachers. The selection of these four factors reflects both theoretical parsimony and contextual relevance for pre-service teacher education. Given that these constructs were conceptually derived from well-validated international frameworks, a confirmatory rather than exploratory approach was employed to evaluate their applicability within this context. The theoretical definitions of the constructions are presented in Table 1.

Table 1: Summary definitions of AI literacy for pre-service teachers

AI literacy	Definitions
AI recognition (RECO) (Celik, 2023a; Laupichler, et al., 2022; Lee, et al., 2021; Wang, Rau and Yuan, 2022; Yetişensoy and Rapoport, 2023)	Ability to recognize the potential and scope of AI that can be beneficial, understand its impacts, and appreciate its importance in general and educational scope. This includes identifying the fundamental processes of AI technology when using applications or services derived from AI implementation, critically distinguishing between content created by humans and that generated by AI, providing reasons for such distinctions.
AI fundamental comprehension (COMP) (Celik, 2023a; Davy Tsz Kit, et al., 2022; Laupichler, et al., 2022; Lee, et al., 2021; Ng, et al., 2021a; Williams, et al., 2022).	The capability to explain the basic working processes of AI and classify the types of AI that can be utilized in educational management. This would involve stating the functions that specific AI technologies can perform, offering reasoning when observing content produced by AI, identifying the advantages and precautions of AI usage for others, and discussing issues related to AI that affect teaching management and educational settings.
AI pedagogy (PEDA) (Celik, 2023b; Dai, et al., 2020; Davy Tsz Kit, et al., 2022; Kim, et al., 2021; Ng, et al., 2021a; Wang, Rau and Yuan, 2022; Williams, et al., 2022; Yetişensoy and Rapoport, 2023).	The ability to proceed through the process of integrating AI into the design or solution to problems in teaching and learning management. This includes demonstrating examples of using AI in various educational contexts, managing, and controlling the use of AI in both classroom and online learning environments, and promoting practical and ethical AI usage among learners.
AI ethical use (ETHIC) (Celik, 2023a; Kong, Man-Yin Cheung and Tsang, 2022; Laupichler, et al., 2022; Ng, et al., 2021a; Wang, Rau and Yuan, 2022; Williams, et al., 2022; Yetişensoy and Rapoport, 2023)	The ability to employ AI morally, fairly, and transparently in full compliance with institutional regulations, government policies, and any usage restrictions imposed by AI service-providers while actively detecting and mitigating algorithmic bias, safeguarding privacy, and copyright, and retaining clear human accountability for AI-driven decisions. This requires teachers to observe formal terms-of-use (e.g., data-handling, academic-integrity, and content guidelines), to interrogate AI outputs for potential inequities or harms, and to ensure that all students benefit equitably from AI under explicit human oversight.

3. Method

In this study, the authors applied the scale development and validation research approach presented by Boateng et al. (2018) to develop an AI literacy scale for students in education. The approach consists of four phases: Phase 1: item development, to define domain boundaries, generate suitable questions, and evaluate item representativeness for the target population; Phase 2: questionnaire implementation, to ensure accurate data collection and data availability for scale validation; Phase 3: item reduction, to identify the optimal factor structure for the item set; and Phase 4: construct validity, to examine latent structures and relationships among items.

The population of this study comprised pre-service teachers enrolled in teacher education programs across universities in Thailand. A stratified random sampling method was used to ensure representation from the from four groups of universities in Thailand. The target sample size was calculated using the Soper (2022) online calculator, with the following parameters: anticipated effect size = 0.1, desired statistical power level = 0.8, number of latent variables = 5, number of observed variables = 14, and probability level = 0.05. The calculation yielded a recommended minimum sample size of 1,599 participants.

In this research, data were analyzed using SPSS V.29.0 and Jamovi V.2.3 to explore descriptive and factor analyses. Factors were analyzed using EFA, and structural validity was established using confirmatory factor analysis (CFA). The Goodness of Fit Index (GFI) was assessed in this study, along with Root Mean Square Error of Approximation (RMSEA), comparative fit index (CFI), and Adjusted Goodness-of-Fit Index (AGFI). As literature indicates, when a model's CFI, GFI, and AGFI values are more than 0.95, this represents an excellent fit. Likewise, the value for RMSEA, which was below 0.05, also indicated an excellent fit. (Fan, Thompson and Wang, 1999; Hair, et al., 2018; Jöreskog and Sörbom, 1986; MacCallum, Browne and Sugawara, 1996; Tabachnick and Fidell, 2013). The research procedures and results for each research phase were presented as follows.

3.1 Results

3.1.1 Phase 1: Item development

In this phrase, all of the AI literacy scale items were created through synthesizing the educational technology literature, international organization reports, and relevant research in both international and national contexts, and then they were adjusted by the researchers according to the theoretical definitions for each construct (Table 1) and all of the items are listed in the Appendix. Eight experts in the field of educational technology and communications then reviewed the items for their wording and quality of the items to minimize misperceptions. The experts also assessed the items' content validity to align with the theoretical definitions. Then, the authors have reviewed and edited AI literacy scale items as the experts recommend. Following this, the researchers conducted a pilot test of the measurement instrument in a sample of 30 students to verify the items' clarity and make appropriate adjustments to align with the context of pre-service teachers studying in Thailand. Cronbach's alpha coefficients were calculated for each construct, which helped verify the items' internal consistency, where values above 0.7 were considered acceptable and ready for next phase implementation. Cronbach's alpha values for internal consistency and reliability obtained from the data analysis for each construct were as follows: AI recognition = 0.941, AI fundamental comprehension = 0.971, AI pedagogy = 0.962, and AI ethical use = 0.966.

The research instrument used was an online survey questionnaire administered using JotForm. This instrument was designed to gather data for the study and was divided into two parts. Part 1 focused on the collection of demographic information from the sample, and Part 2 focused on the collection of AI literacy items. These were 42 items formatted to the 7-point level of agreement on a Likert scale ranging from "totally disagree" (1) to "totally agree" (7). (Likert, 1932; Vagias, 2006). A 7-point Likert scale was used to provide finer distinctions in participants' perceptions and enhance measurement reliability (Preston, C., and Colman, A., 2000). In the initial scale, there were 9 items for AI recognition, 12 items for AI fundamental comprehension, 9 items for AI pedagogy, and 12 items for AI ethical use, total were 42 items.

3.1.2 Phase 2: Questionnaire implementation

As the results, Between Q3 and Q4 of 2024, the research team distributed digital questionnaires to pre-service teachers across universities in various regions of Thailand. The survey was shared through selected academic units or departmental contacts within each university or faulty. Within these units, students were invited to participate on a voluntary basis, and responses were collected from those who chose to complete the questionnaire. Before conducting the analysis, data cleaning procedures were applied to identify missing values, and remove inconsistent responses by examining straight-lining behavior. The results are 1,673 higher education students studying in education departments or faculty across the from four groups of universities in Thailand, concentrating in the following areas: 1) global and frontier research, 2) technology development and innovation, 3) area-based and community engagement, and 4) private and other. Among these samples, 570 were men (34.07%), and 1,103 were women (65.93%); 487 (29.11%) were first-year students, 654 (39.09%) were sophomores, 312 (18.65%) were juniors, and 220 (73.33%) were seniors. Most participants were studying at area-based and community engagement universities (n = 776, 46.38%), technology development and innovation universities (n = 464, 27.73%), global and frontier research universities (n = 276, 16.50%), and private and other universities (n = 157, 9.38%).

3.1.3 Phase 3: Item reduction

Item reduction was designed to ensure that sufficient items representing the four AI literacy constructs were retained, providing evidence of construct validity (Hinkin, 1998). A reduction in the number of items can also enhance the usability of the scale in various contexts, such as in the teaching profession. For this, we conducted an EFA. EFA is used to uncover fundamental structures in multivariate observed variables and to address dimensionality reduction. Thus, EFA can condense a set of variables that show complex interrelationships into a few core factors. We calculated item-total correlations to select the most appropriate items for the four constructs.

We initially evaluated the suitability of the data for factor analysis using the Kaiser-Meyer-Olkin (KMO) test, which produced a sampling adequacy measure of 0.993. This value exceeds the recommended threshold of 0.95, thereby confirming that the data were appropriate for use in EFA. Moreover, Bartlett's test of sphericity found significant differences from an identity matrix (p-value < .0001), and the cumulative value was 73.786, which shows a greater than 60% share of the total variance explained by the factors (Hair, 1998). Therefore, we conducted four-factor EFA utilizing maximum likelihood estimation and varimax rotation with Kaiser normalization. This procedure was intended to verify that the items corresponded with the theoretical framework for each construct and to detect any items loaded on multiple factors. The results revealed that three items (PEDA 9, RECO 9, and PEDA 1) loaded on multiple factors. The three cross-loaded items showed semantic overlap across constructs, indicating conceptual rather than data issues; prior studies did not specify their original loadings.The outcomes of the EFA are presented in *Table 2*.

Table 2: Results of exploratory factor analysis

	ETHIC	COMP	RECO	PEDA		ETHIC	COMP	RECO	PEDA
ETHIC 7	**0.721**				**RECO 7**			**0.502**	
ETHIC 6	**0.712**				**RECO 3**			**0.655**	
ETHIC 10	**0.692**				**RECO 1**			**0.648**	
ETHIC 11	**0.687**				**RECO 2**			**0.642**	
ETHIC 4	**0.680**				**RECO 5**			**0.603**	
ETHIC 3	**0.675**				**RECO 6**			**0.588**	
ETHIC 12	**0.668**				**RECO 4**			**0.570**	
ETHIC 5	**0.665**				**RECO 8**			**0.525**	
ETHIC 2	**0.662**				**PEDA 7**				**0.571**
ETHIC 8	**0.643**				**PEDA 4**				**0.556**
ETHIC 9	**0.635**				**PEDA 5**				**0.553**
ETHIC 1	**0.601**				**PEDA 3**				**0.553**
PEDA 9	0.519				**PEDA 2**				**0.538**
COMP 3		**0.729**			**PEDA 6**				**0.534**
COMP 5		**0.684**			**PEDA 8**				**0.522**
COMP 6		**0.682**			PEDA 1				0.472
COMP 9		**0.678**							
COMP 8		**0.673**							
COMP 4		**0.671**							
COMP 7		**0.668**							
COMP 2		**0.654**							
COMP 1		**0.581**							
COMP 12		**0.576**							
COMP 11		**0.567**							
COMP 10		**0.527**							
RECO 9		0.524							

Note. Extraction Method: Maximum Likelihood. Rotation Method: Varimax with Kaiser Normalization.

Bartlett's Test of Sphericity; $p < .0001$, Model Fit Measures; root mean square error of approximation (RMSEA) is 0.0333,

Next, the authors used CFA, which leverages sample data to validate a hypothesized factor structure that is based on a theoretical framework. In CFA, the factor structure that was established in existing theories enables us to create an estimated covariance matrix. The researchers performed CFA on each subscale to assess the factor loadings that are associated with their respective constructs. In addition, we calculated item-total correlations, seeking to identify items deviating from the overall response patterns. Factor loadings and item-total correlation coefficients for each of the four constructs are presented in Table 3. We selected items using the following criteria: (a) factor loadings in EFA exceeding 0.50 within their factor group, (b) factor loadings in CFA greater than 0.30 (Costello and Osborne, 2005), and (c) item-total correlation coefficients above 0.60 (Hair, 1998). The researchers thereby eliminated three items that did not meet the criteria and were loaded with multiple constructs. We then refined the scale to exclude three items from constructs, resulting in 39 items as the revised scales selected from the 42 initial items.

Table 3: Descriptive statistics and principal factor analysis results

	Mean	S.D.	α	Loading	Item-total correlation		Mean	S.D.	α	Loading	Item-total correlation
RECO 1	5.64	1.343	0.954	0.741	0.706	PEDA 1	5.53	1.364	0.937	0.730	0.695
RECO 2	5.44	1.346	0.952	0.771	0.732	**PEDA 2**	5.37	1.314	0.934	0.792	0.754
RECO 3	5.66	1.355	0.952	0.768	0.728	**PEDA 3**	5.40	1.315	0.932	0.818	0.776
RECO 4	5.29	1.387	0.953	0.794	0.754	**PEDA 4**	5.39	1.356	0.933	0.808	0.763
RECO 5	5.40	1.341	0.952	0.807	0.763	**PEDA 5**	5.41	1.372	0.931	0.837	0.795
RECO 6	5.38	1.371	0.952	0.791	0.751	**PEDA 6**	5.41	1.333	0.934	0.792	0.757
RECO 7	5.32	1.411	0.952	0.797	0.763	**PEDA 7**	5.38	1.385	0.933	0.804	0.757
RECO 8	5.40	1.380	0.952	0.792	0.756	**PEDA 8**	5.35	1.360	0.932	0.822	0.783
RECO 9	5.38	1.396	0.952	0.800	0.773	PEDA 9	5.47	1.325	0.935	0.785	0.754
COMP 1	5.32	1.427	0.954	0.765	0.740	**ETHIC 1**	5.44	1.419	0.953	0.779	0.757
COMP 2	5.18	1.379	0.952	0.810	0.775	**ETHIC 2**	5.43	1.370	0.952	0.807	0.761
COMP 3	5.15	1.464	0.952	0.802	0.748	**ETHIC 3**	5.47	1.349	0.951	0.818	0.771
COMP 4	5.26	1.385	0.953	0.788	0.746	**ETHIC 4**	5.45	1.306	0.952	0.812	0.765
COMP 5	5.23	1.390	0.952	0.825	0.785	**ETHIC 5**	5.41	1.354	0.952	0.814	0.777
COMP 6	5.22	1.397	0.952	0.805	0.756	**ETHIC 6**	5.50	1.342	0.952	0.791	0.732
COMP 7	5.33	1.396	0.952	0.819	0.784	**ETHIC 7**	5.47	1.360	0.951	0.822	0.766
COMP 8	5.26	1.384	0.952	0.807	0.764	**ETHIC 8**	5.45	1.359	0.952	0.798	0.765
COMP 9	5.28	1.407	0.952	0.816	0.770	**ETHIC 9**	5.42	1.361	0.952	0.803	0.764
COMP 10	5.41	1.325	0.953	0.778	0.766	**ETHIC 10**	5.49	1.387	0.952	0.801	0.742
COMP 11	5.40	1.364	0.952	0.812	0.792	**ETHIC 11**	5.47	1.330	0.952	0.798	0.746
COMP 12	5.39	1.391	0.952	0.811	0.797	**ETHIC 12**	5.57	1.342	0.952	0.785	0.737

3.1.4 Phase 4: Construct validity

In our assessment of our measurement model, all the factors had high correlations that were above 0.8, as shown in *Table 4*. The constructs presented varying degrees of fit. AI recognition showed a satisfactory fit, with chi-square = 144, df = 27, $p < 0.001$, RMSEA = 0.064, and SRMR = 0.021, along with good fit indices, including CFI = 0.981, GFI = 0.996, and AGFI = 0.992. AI fundamental comprehension constructs also indicated good model fits, with chi-square = 203, df = 54, $p < 0.001$, RMSEA = 0.051, and SRMR = 0.017, along with good fit indices, including CFI = 0.985, GFI = 0.995, and AGFI = 0.991. AI pedagogy showed a satisfactory fit, with a chi-square = 65, df =14, $p < 0.001$, RMSEA = 0.059, SRMR = 0.014, and good fit indices, including CFI = 0.990, GFI = 0.998, and AGFI = 0.996. AI ethical use showed a satisfactory fit, with a chi-square =199, df = 54, $p < 0.001$, RMSEA = 0.051, SRMR = 0.017, and good fit indices including CFI = 0.985, GFI = 0.995, and AGFI = 0.992.

Table 4: Descriptive statistics and Pearson correlations among factors

	Mean	SD	Aware	Know	Apply	Ethic
RECO	5.66	0.993	-			
COMP	5.58	1.011	0.858	-		
PEDA	5.62	0.986	0.820	0.866	-	
ETHIC	5.70	0.969	0.840	0.827	0.838	-

Table 4 presents convergent and divergent validity assessed using CFA with the measurement model, and CA and composite reliability (CR) tests were performed to assess reliability. CA measured the internal consistency among items, as seen in Table 5, and CR was used to describe the extent to which a train of items could represent potential constructs. The CR values ranged from 0.956 to 0.931, the factor loading ranged from 0.924 to 0.955, and, finally, the AVE values for the variables ranged from 0.616 to 0.658. DeVellis (2012); Fornell and Larcker (1981) suggested that, where AVE is above 0.50 and CR is above 0.70, the convergent validity of the construct is satisfactory. The values of Cronbach's alpha for these findings for the four constructs were AI Recognition (RECO) = 0.928, AI Fundamental Comprehension (COMP) = 0.956, AI Pedagogy (PEDA) = 0.931, and AI Ethical Use (ETHIC) = 0.956, respectively. Although each of the four constructs exhibited a reliability of more than 0.70, the instrument itself had a value above 0.80, indicating that the instrument was more reliable than the separate constructs.

Table 5: Results of the measurement model

Latent	Observed	Mean	SD	b(SE)	β	z	p	R^2	α	CR	AVE
RECO	RECO 1	5.87	1.204	0.000	0.747			0.558	0.920		
	RECO 2	5.58	1.219	0.041	0.775	25.900	< .001	0.600	0.918		
	RECO 3	5.78	1.194	0.040	0.772	25.800	< .001	0.596	0.918		
	RECO 4	5.56	1.265	0.042	0.796	26.700	< .001	0.633	0.917		
	RECO 5	5.63	1.197	0.040	0.808	27.200	< .001	0.654	0.916		
	RECO 6	5.60	1.226	0.041	0.795	26.700	< .001	0.632	0.917		
	RECO 7	5.62	1.232	0.041	0.795	26.700	< .001	0.632	0.918		
	RECO 8	5.65	1.218	0.040	0.787	26.400	< .001	0.619	0.918		
COMP	COMP 1	5.61	1.269	0.000	0.764			0.584	0.954		
	COMP 2	5.43	1.233	0.036	0.810	28.500	< .001	0.656	0.952		
	COMP 3	5.50	1.302	0.038	0.803	28.100	< .001	0.644	0.952		
	COMP 4	5.56	1.216	0.036	0.788	27.500	< .001	0.622	0.953		
	COMP 5	5.51	1.245	0.036	0.825	29.100	< .001	0.681	0.952		
	COMP 6	5.53	1.219	0.036	0.806	28.300	< .001	0.649	0.952		
	COMP 7	5.63	1.251	0.037	0.819	28.800	< .001	0.671	0.952		
	COMP 8	5.55	1.226	0.036	0.807	28.300	< .001	0.652	0.952		
	COMP 9	5.59	1.235	0.036	0.816	28.700	< .001	0.665	0.952		
	COMP 10	5.67	1.170	0.035	0.778	27.100	< .001	0.606	0.953		
	COMP 11	5.68	1.193	0.035	0.812	28.500	< .001	0.659	0.952		
	COMP 12	5.69	1.217	0.036	0.810	28.500	< .001	0.656	0.952		
PEDA	PEDA 2	5.57	1.127	0.000	0.790			0.624	0.922		
	PEDA 3	5.61	1.157	0.036	0.815	29.700	< .001	0.664	0.920		
	PEDA 4	5.65	1.177	0.036	0.811	29.600	< .001	0.658	0.920		
	PEDA 5	5.64	1.199	0.037	0.835	30.700	< .001	0.697	0.918		
	PEDA 6	5.63	1.164	0.036	0.795	28.800	< .001	0.632	0.922		
	PEDA 7	5.63	1.193	0.037	0.808	29.400	< .001	0.652	0.920		
	PEDA 8	5.60	1.193	0.037	0.821	30.000	< .001	0.674	0.919		
ETHIC	ETHIC 1	5.71	1.260	0.000	0.778			0.606	0.953		
	ETHIC 2	5.65	1.195	0.034	0.807	29.000	< .001	0.652	0.952		
	ETHIC 3	5.70	1.170	0.033	0.818	29.500	< .001	0.670	0.951		
	ETHIC 4	5.67	1.128	0.032	0.812	29.200	< .001	0.659	0.952		
	ETHIC 5	5.63	1.207	0.034	0.814	29.300	< .001	0.662	0.952		
	ETHIC 6	5.71	1.170	0.033	0.792	28.300	< .001	0.627	0.952		
	ETHIC 7	5.69	1.188	0.034	0.822	29.700	< .001	0.675	0.951		
	ETHIC 8	5.70	1.191	0.034	0.798	28.600	< .001	0.637	0.952		
	ETHIC 9	5.69	1.186	0.034	0.803	28.800	< .001	0.645	0.952		
	ETHIC 10	5.71	1.205	0.034	0.802	28.800	< .001	0.643	0.952		

Latent	Observed	Mean	SD	b(SE)	β	z	p	R^2	α	CR	AVE
	ETHIC 11	5.71	1.140	0.033	0.798	28.600	< .001	0.636	0.952		
	ETHIC 12	5.83	1.126	0.032	0.785	28.000	< .001	0.616	0.952		
AI Literacy	RECO	5.66	0.993	0.000	0.949			0.900	0.928	0.928	0.616
	COMP	5.58	1.011	0.046	0.955	23.900	< .001	0.912	0.956	0.956	0.646
	PEDA	5.62	0.986	0.041	0.952	24.500	< .001	0.906	0.931	0.931	0.658
	ETHIC	5.70	0.969	0.045	0.924	23.700	< .001	0.853	0.956	0.956	0.644

First, the overall model fit was the theoretical model that was used for AI literacy was acceptable for the fit indicators assessed using multiple fit criteria: seven indices were used, including chi-square/degrees of freedom (df), GFI, AGFI, CFI, and root mean square residual. SEM analysis showed that the goodness of fit statistics of the theoretical framework in Table 6 represented good fit (chi-square = 1,610, df = 698, $p < 0.001$, $\chi2$ /df = 2.30, GFI = 0.974, AGFI = 0.969, CFI = 0.974, RMSEA = 0.035, SRMR = 0.022).

Table 6: Model fit statistics

	Results	Fit Criteria	Result	Reference
$\chi2$	1,610*	p < 0.001	Acceptable	(Hair, et al., 2018)
$\chi2$ /df	2.30	2-5	Acceptable	(Hooper, Coughlan and Mullen, 2007)
RMSEA	0.035	≤ .05	Acceptable	(MacCallum, et al., 1996)
SRMR	0.022	≤ .05	Acceptable	(Hair, et al., 2018)
Comparative Fit Index (CFI)	0.974	≥ .90	Acceptable	(Fan, Thompson and Wang, 1999)
Goodness of Fit Index (GFI)	0.974	≥ .90	Acceptable	(Tabachnick and Fidell, 2013)
Adjusted Goodness of Fit Index (AGFI)	0.969	≥ .90	Acceptable	(Hair, et al., 2018)

The effect was obtained in the research constructs, and the results were as follows: AI recognition (β = 0.949), AI fundamental comprehension (β = 0.955), AI pedagogy (β = 0.952), and AI ethical use (β = 0.924) significantly positively to AI Literacy, as shown in *Figure 1*.

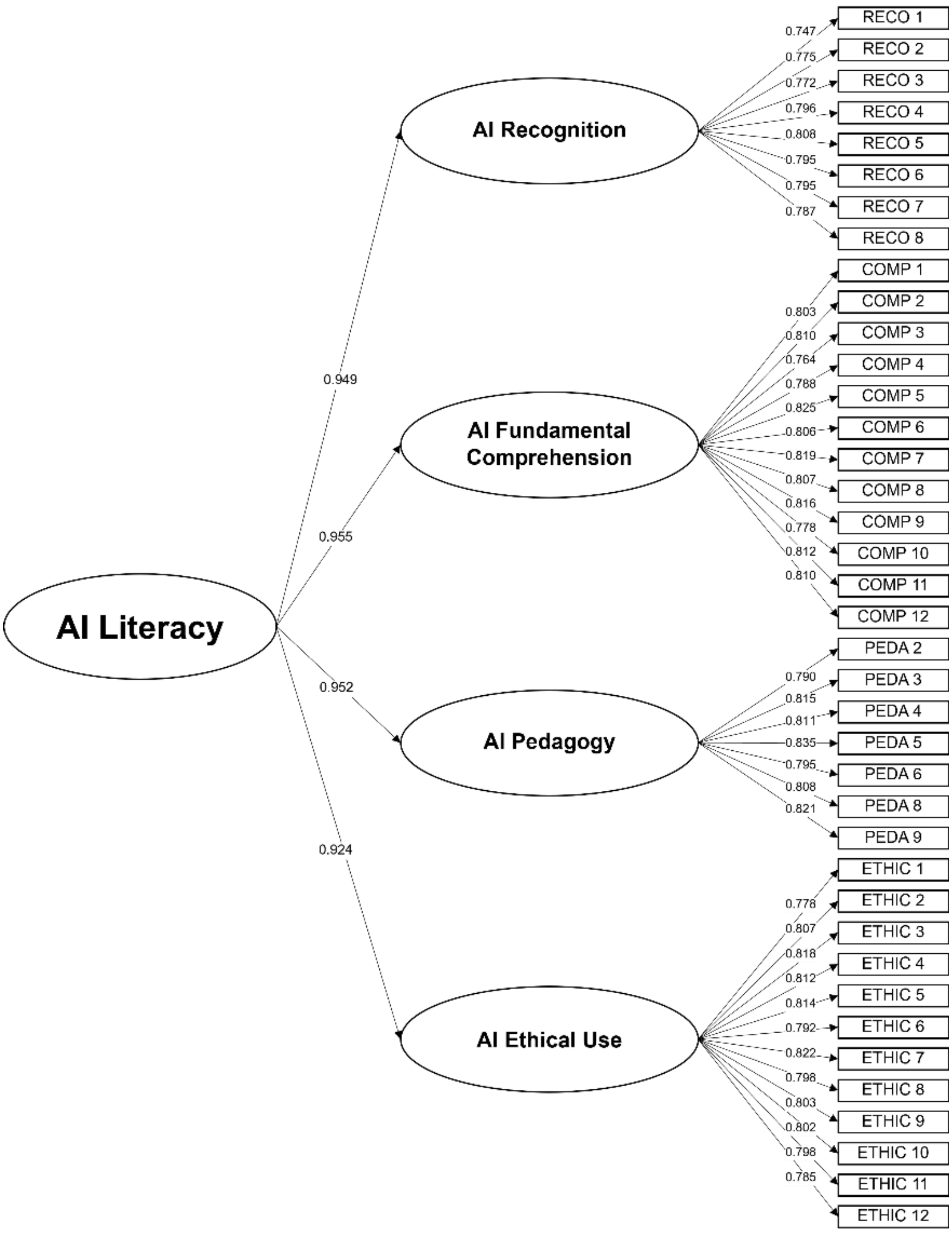

Figure 1: Result of the Confirmatory factor Analysis model

4. Discussion

This study examined AI literacy factors within the context of the teaching profession to develop a measurement instrument for use as a learning progression and self-assessment tool for AI literacy in pre-service teachers and teacher development. This AI literacy in this study includes AI recognition, fundamental AI comprehension, AI pedagogy, and ethical AI use, while other AI literacy scales have generally addressed broader AI literacy or digital skills. The AI literacy factors explicitly integrate pedagogical knowledge and ethical dimensions essential for pre-service teachers and curriculum design for enhancing AI literacy in courses or training (Celik, 2023a, 2023b; Khlaisang and Koraneekij, 2019; UNESCO, 2024; Wang, Rau and Yuan, 2022; Wilson, Scalise and Gochyyev, 2015). The results establish the reliability and validity of the AI literacy scale for both pre-service and in-service teachers. The findings showed that the significant results of the theoretical model comprised four characteristic constructs for the most appropriate conceptualization for AI literacy for teaching and learning. The author would like to present the discussions with the research questions as follows:

RQ1: What constructs and factors of an AI literacy scale for pre-service teachers?

The EFA value for RQ1 revealed a four-factor structure of AI literacy for pre-service teachers: AI recognition, AI fundamental comprehension, AI pedagogy, and AI ethical use, which collectively explained 73.786% of the variance in the data. KMO had an exceptionally high value (0.993), and Bartlett's test of sphericity indicated significant differences ($p < 0.0001$), confirming that the data were suitable for factor analysis. Thus, the scale captures four constructs of AI literacy among pre-service teachers. Each factor represents a different aspect of the ways that pre-service teachers understand and engage with AI. 1) AI recognition and 2) AI fundamental comprehension closely corresponds to the core knowledge and awareness components of AI literacy that have been presented in prior research. During factor analysis, three items were excluded due to overlapping conceptual constructs. The items initially designed to assess AI recognition and AI pedagogy were found to overlap significantly with items on AI ethical use, AI fundamental comprehension, and AI ethical use indicating a need for clearer differentiation in future studies.

This alignment is evident in the comparison of our findings to existing AI literacy frameworks, which commonly include awareness of AI systems and the ability to understand or evaluate AI functionalities (Laupichler, et al., 2023; Wang, Rau and Yuan, 2022). In our findings, AI recognition reflects the teacher's awareness of AI in educational tools and teaching and learning (e.g., recognizing AI applications and their use in educational context), while AI fundamental comprehension reflects a fundamental understanding of AI principles and concepts (e.g., how machine learning works at a basic level). AI pedagogy is a distinct domain that is uniquely important for educators. This factor includes the knowledge and skills that are required to integrate AI into teaching practice and to instruct others concerning AI. From this, it is clear that pre-service teachers recognize that being AI literate goes beyond knowing what AI is or how it works to knowing how to teach with and about AI. These findings are related to existing frameworks of educational technology. It resonates with the concept of TPACK adapted for AI, according to which teachers must blend AI knowledge with pedagogy that can effectively facilitate learning (Kim, et al., 2022). Thus, AI ethical use, indicating that ethical considerations form a key pillar of AI literacy for pre-service teachers, captures an understanding of responsible and principled uses for AI, including questions of fairness, privacy, bias, and social impact in educational settings. This indicates that pre-service teachers are aware of adopting AI in the classroom comes is accompanied by the duty to take moral and safety implications into account.

RQ2: Is the AI literacy scale for pre-service teachers reliable and valid?

CFA was used to address RQ2, producing straightforward evidence that the identified AI literacy constructs are reliably and effectively measured with the developed scale. The factor analyses indicated that the values for AVE and CR values met the thresholds for convergent and construct validity in the measurement model. The reliability for each factor is supported by the high internal consistency, indicated by Cronbach's alpha values well above 0.80. Moreover, the fit statistics of the research model show a good fit: chi-square = 1,610, df = 698, $p < 0.001$, $\chi 2/df = 2.30$, GFI = 0.974, AGFI = 0.969, CFI = 0.974, RMSEA = 0.035, and SRMR = 0.022.

The results of the analyses produce one of the most striking findings in this study, namely, the positive significance shown by all AI literacy constructs as tools as the measurement and learning progress to curriculum or course that integrated AI for education for teacher development. The findings show that teacher preparation programs should adopt a well-rounded, comprehensive approach in incorporating AI into the curriculum, course, or workshop. Instead of treating AI applications as a single skill, learning programs should include several dimensions: raising awareness of AI technologies and their presence, building a basic comprehensive of AI principles, training teachers in the pedagogical application of AI in classrooms, and fostering a strong sense of ethics and responsibility in AI use. Moreover, in designing ethical learning concerning AI, the findings show that blended ethical knowledge, as part of the substantive design of instructional design for AI literacy learning, plays an essential role in the effective utilization of AI (Chan, 2023). To illustrate the result practices from each construct, AI recognition might involve pre-service teachers critically identifying and thinking of AI-generated content and AI-driven tools and used to enhance student engagement, such as adaptive feedback for speech recognition applications. AI fundamental comprehension could manifest as teachers clearly explain to students how recommendation pattern recognition by machine operation and awareness of AI overuse. AI pedagogy might be seen in lessons integrating AI-driven assessments to personalize feedback or using AI-generated content as learning multimedia. Finally, AI ethical use could include teachers facilitating classroom discussions about privacy concerns and critically stimulating students about AI awareness in bias and creative thinking. Furthermore, the validated factor structure provides a framework for the development of AI for education interventions. For instance, if assessment using this scale shows that pre-service teachers, on average, have high ethical awareness but weaker pedagogical skills with AI, educators could design specific learning modules to enhance pedagogical strategies for the use of AI. Likewise, if the AI recognition rate is low, this could indicate a need to expose teachers to a broader range of examples and cases of AI applications in education. Hence, the scale can diagnose specific strengths and weaknesses, allowing for tailored instructional responses in teacher training. Likewise, Luo et al. (2024) designed AI literacy learning activities that they suggest can be supported with scaffolding tasks that enabled cognitively challenging and emotionally engaging feedback as well as enabling distributed cognition.

5. Conclusions

This study introduced and validated a four-factor model to measure AI literacy among pre-service teachers, providing a theoretically grounded and empirically supported framework for understanding teachers' readiness to integrate AI in education. The developed instrument enables instructional designers, teacher educators, and researchers to systematically assess and enhance AI literacy in teacher preparation programs. Beyond Thailand, the model offers a basis for cross-cultural comparisons and curriculum design that promotes equitable AI competence among future educators. Nevertheless, this study was limited to pre-service teachers in selected institutions, and future research should validate the instrument across broader educational levels and cultural contexts. By moving from conceptual discussions of AI literacy to a validated, evidence-based scale, this research contributes to advancing both theory and practice in AI-integrated teacher education.

5.1 Limitations and Recommendations

The results of this research provide opportunities for researcher to study AI literacy in education or relevant domains for future studies, such as in quantifying baseline AI literacy levels in teacher cohorts, comparing subgroups (e.g., comparing science and technology with humanities and language pre-service teachers), developing comprehensive instructional models for teaching AI literacy for the redesign of courses or curricula in institutions of higher education, and evaluating the impact of new training programs or curricular changes on each aspect of AI literacy. The uses of or scale are not limited to Thailand or to pre-service teachers; it can be adapted and validated for use in other teacher training contexts or with in-service teachers to explore how the construct may vary or hold constant elsewhere.

This study has certain limitations that temper the interpretation of the results. First, the research focused on a single demographic group, which could limit the generalizability of the findings. Then, the data that were collected drew on a cross-sectional design. This means that our results provide a snapshot of AI literacy to participants but do not capture how such competencies could develop or change with additional training or over the course of a teacher's career. Despite these limitations, the design of the study design and our cautious, descriptive interpretation of the scale can ensure that our conclusions are credible and applicable within the stated context.

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AI Ethics statement: The authors declare that they have used AI tools, Grammarly and Quillbot, to enhance the spelling and readability of this manuscript.

Ethics Approval: This paper involved human participants. Ethical permission was obtained from Chulalongkorn University Research Ethics Committee Multi-Institutional Group, set 2: Social Sciences, Humanities, and Fine Arts (reference number 429/67). Written consent was obtained from all participants for both participation and publication (maintaining anonymity). While conducting the research, the researchers followed privacy, data protection, and confidentiality policies. Therefore, all research participants' identities and data remain unidentifiable and will be deleted immediately after the research is completed. All participants consented to the data for research purposes.

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Appendix

These revised components and items of AI literacy for pre-service teachers in the following table were translated from Thai to English.

Items
AI Recognition (8 items):
1. I believe that using AI in services or products enhances my study and works more efficiently.
2. I think the current AI stimulates learners to adapt their methods of learning various subjects.
3. I believe that AI technology will become a part of future teaching and learning management.
4. I can provide reasons for the current use of AI in education.
5. I can clarify the reasons and necessity for integrating AI as a tool in teaching and learning management.
6. I can explain the benefits of AI that should be considered for their impact on teaching and learning management.
7. I can state the limitations and conditions of the use of various forms of AI.
8. I thoroughly check the results or information developed with AI before publishing or utilizing them.
AI Fundamental Comprehension (12 items):
1. I can explain the basic functioning of AI (e.g., social media and e-commerce platforms) in digital services and applications.
2. I can describe the processing work of Gen-AI from the information students read or listen to generated by Gen-AI processing.
3. I can specify the working characteristics of each type of AI (e.g., text-based, image-based, video-based).
4. I can point out the differences between the content generated by AI and the content created by humans.
5. I can classify the information I have read or heard according to each AI working type.
6. I can identify guidelines for selecting AI usage according to AI capability levels (e.g., specialized Gen-AI and multimodal Gen-AI).
7. I can explain why I chose particular AI services or tools as the assistance for designing a course's learning and teaching assistants.
8. I can identify observation points to distinguish the content parts resulting from AI usage.
9. I can clearly explain the reasons to confirm that the perceived content comes from AI.
10. I scrutinize the appropriateness before using AI in the learning design.
11. I can share knowledge about AI applications that can be used in educational contexts.
12. I explain the benefits and limitations of using AI to support usage and learning management.

Items
AI Pedagogy (7 items):
1. I can design learning activities including AI as a teaching aid.
2. I can organize and evaluate learning activities that use AI to promote learners' knowledge and skills.
3. I can demonstrate the steps of using AI to students, teachers, and fellow students.
4. I can show how to use AI to support learners' learning in my subjects.
5. I demonstrate AI usage while incorporating cautions, usage options, and all possible outcomes from its use.
6. I can design an AI usage agreement framework for learners in my course.
7. I can explain the reasons for setting AI usage boundaries to the learners.
AI Ethical Use (12 items):
1. I consider the ethical aspects of AI when deciding to use information that it has processed.
2. I am aware of the information processed by AI may infringe copyright.
3. I thoroughly account for the use of AI-generated information to ensure that it aligns with the institution's rules and agreements.
4. I filter and check data characteristics before inputting them into the AI for processing to ensure that personal and institutional data are secure.
5. I recognize that AI usage data in AI services will be used under the provider's conditions.
6. I am aware of the consequences of unethical AI usage and intellectual property violations.
7. I use AI considering the educational institution's regulations, requirements, or AI usage frameworks.
8. I inform stakeholders in professional teaching practices when using AI-generated data to design learning, lesson plans, learning activities, or portfolios.
9. I guide, supervise, and monitor learners' and others' AI usage to ensure compliance with rules, frameworks, and usage conditions.
10. I consider the necessity of using AI before doing so.
11. I try to think and search for answers thoroughly to solve problems or find information before using AI to help address those issues.
12. I use AI critically, applying my skills and independent thinking.

AI-Supported Learning in Online Discussion Forums: A Scoping Review

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Abstract: As the popularity and accessibility of artificial intelligence (AI) in learning continue to rise, online education has increasingly incorporated AI. It is imperative to investigate how AI in the scholarly community supports the learning of autonomous students. This scoping review investigated articles that employed AI in discussion forums. The objective of this study is to develop a summary that denotes the effective integration of AI in discussion forums, thereby characterizing the overall learning experience. In accordance with the search, appraisal, synthesis, and analysis (SALSA) framework, the preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram was employed to design the article screening and selection process. Scopus was utilized for the literature search, resulting in the identification of twelve articles that met the predetermined inclusion and exclusion criteria. The extracted articles covered the following six applications: intelligent tutoring systems, AI-assisted apps, chatbots, automatic formative assessment, AI teaching assistants, and AI-assisted lifelong learning assistants. Three types of man-machine partnerships related to the activities are discussed: student-AI partnerships, student-AI-student partnerships, and student-AI-teacher partnerships, the latter being the most commonly observed. The generated content was frequently processed through teacher adjustments and checks. Components of community of inquiry theory were adapted as indicators. Cognitive presence was observed to be more predominant than social presence, with a particular emphasis on individual learning achievements. Three distinct perspectives regarding the role of AI in learning were identified. The first perspective posited that AI functioned as a virtual teacher, supplementing the teaching functions of human teachers and delivering information to students. In the second perspective, AI facilitated students in collecting information by enabling interactions with messages or peers. In the third perspective, the significance of the automatic evaluation function, which assessed learning activities and provided feedback to enhance the system while simultaneously implementing immediate changes in the learning process, was acknowledged. Regarding the role of communication, teachers clearly intended for students to acquire knowledge through it. Despite the focus on assisting individual learners, each article encompassed references from a wide range of fields and exhibited substantial diversity overall. Consequently, the domain of discussion forums with AI was depicted through the complex interplay between technology, pedagogy, and the learning environment. This context is known as entangled pedagogies, which emphasize understanding the interconnections among these elements and their reciprocal influences. In summary, AI was predominantly utilized in the form of chatbots and GenAI in discussion forums. Emerging AI roles included virtual teachers, peer/message matching, and automated evaluation. Aggregated information was presented in a manner that supported student learning. AI also served as a conduit between students and teachers.

Keywords: Artificial intelligence, Community of inquiry, Discussion board, Discussion forum, PRISMA, SALSA framework

1. Introduction

1.1 AI-Supported Discussion Forums

The practical use of remote education in response to the global pandemic has resulted in a significant increase in interest in autonomous learning (Kukulska-Hulme et al., 2022). In contrast to traditional teacher-centered instruction, online autonomous learning courses prioritize self-directed learning (Lasfeto, 2020). Furthermore, learners are required to independently design learning processes for organizing self-regulated learning (Saks and Leijen, 2014). Within this context, students must recognize that they do not merely serve as passive recipients of instruction; instead, they actively engage in the learning process (Yoshida, 2022).

Regarding learning assistance, students require support in developing efficient study habits and techniques that will enable them to regulate their own learning (Murray, 2014). Innovative online services and tools can enhance learners' autonomy and empower them to take greater control of their learning experiences. These tools include

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websites and mobile applications specifically designed to facilitate scheduling, planning, time management, and reflection (Giannini, 2023). Learning Management Systems (LMSs) have been utilized in instructional settings for over two decades (Hassan et al., 2020).

Discussion forums within LMSs facilitate communication among users, providing teachers with the opportunity to manage protocols and respond to student inquiries while allowing students to communicate with their peers (Onyema et al., 2019). Discussion forums serve as a tool for fostering an online community (Ducate and Lomicka, 2024). In the discussion forums, students can communicate through even superficial or low-level discussions, which involve activities such as summarizing information or expressing agreement or disagreement with their peers (Sakeef et al., 2025). The application of collaborative online learning methodologies has been significantly enhanced through the use of discussion forums (Kalmar et al., 2022; Lu and Smiles, 2022). Discussion forums represent an optimal setting for the implementation of AI, which is a tool that enhances student learning (Spence et al., 2024). As AI becomes increasingly prevalent, cases for its application in online learning environments are expanding (Wang and Song, 2024). AI enhances these communications by mediating interactions between players as virtual tutors or virtual peers to support learners and introducing novel options for learning activities, such as Generative AI (GenAI) or translation services (Ackermann et al., 2025). The integration of GenAI in education is occurring at an unprecedented pace, outstripping the time required for curriculum validation and updates (Giannini, 2023). Additionally, the implementation of AI has the potential to assist teachers in managing a substantial volume of inquiries and overseeing lesson protocol management among diverse and heterogeneous participant groups (Leondes, 2010; Chang et al., 2023). This technological advancement presents a spectrum of opportunities and challenges within the field of education (Jose and Jose, 2024).

1.2 Community of Inquiry Framework

The online learning communication has the potential to facilitate the integration of individual learning, thereby fostering a sense of belonging within a community (Peacock et al., 2020). Recent studies have reported on the collaborative learning processes that have emerged within a Community of Inquiry (CoI) across various types of higher-order thinking (Garrison, 2007). The experiences within online communities encompass three interrelated components of CoI: social presence (SP), cognitive presence (CP), and teaching presence (TP) (Rolim et al., 2019; Guo et al., 2021). The CoI framework for online learning serves as a theoretical model within discussion forum (DeNoyelles and Mannheimer Zydney, 2014).

- SP in the discussion forums is essential for establishing effective practices that foster an environment conducive to community building and the development of shared understanding and trust, where students feel connected and supported in their learning. Generally, a higher frequency of posts is positively correlated with enhanced social presence.
- CP is intricately linked to the processes of knowledge construction and problem-solving. It encompasses the capacity to create, construct, and confirm meaning through ongoing reflection and discourse.
- TP aims to achieve learning outcomes that are personally meaningful and educationally valuable to students through effective design and facilitation. It addresses the problems of teachers face due to limited time and the overwhelming demands of facilitating students.

CP elucidates the mechanisms through which students acquire knowledge, whereas SP pertains to learners' ability to connect socially and emotionally with learning materials and environments (Green, Wyllie and Jackson, 2014).

In light of these elements, which highlight the application of AI in facilitating learning within educational frameworks, a comprehensive investigation was undertaken to understand the evolving role of AI. Furthermore, this study illustrates the role and function of AI. The objective of this study is to develop a summary that denotes the effective integration of AI in discussion forums, thereby characterizing the overall learning experience. The findings will elucidate how AI supports learners' academic interactions in online discussion forums and will contribute to providing knowledge materials that can be beneficial for future course designers' planning and educators' instruction.

1.3 Methodological Framework

This study employed a scoping review methodology to synthesize current literature in a transparent manner. A scoping review is a method of literature review utilized for knowledge synthesis that adheres to a systematic approach to delineate evidence on a specific topic. Its primary objective is to comprehensively map the existing literature, thereby identifying the principal concepts within a research area, including relevant theories, sources, key issues, and knowledge gaps. (Tricco, et al., 2018). The scoping review approach is advantageous when a body of literature has not yet undergone a comprehensive review (Munn et al., 2018). The protocol of the search, appraisal, synthesis, and analysis (SALSA) framework was utilized, as it provides a systematic process for conducting reviews that ensures methodological rigor (Table 1) (Grant and Booth, 2009).

Table 1: SALSA framework

Phase	Outcome	Methods
Search	Search strategy Search articles	Searching strings Search databases and article identification
Appraisal	Selecting articles	Defining inclusion and exclusion criteria
Synthesis	Extracting data Categorizing the data	Defining extraction fields Categorization of fields
Analysis	Data analysis Results	Quantitative categories, description, and narrative analysis Data analysis, identification of gaps, and comparison of results

1.4 Research Questions

The present study investigates published articles that utilize AI to support student learning within online discussion forums. Articles that involve records of learning behaviors and the effects of AI are selected and analyzed. The following three research questions were formulated:

RQ1 *What is the role of AI in facilitating student learning within discussion forums?*

RQ2 *In what ways do AI-powered tools support learners in online discussion forums?*

RQ3 *What are the trends in learning in the discussion forum when AI services are utilized?*

2. Method

In accordance with the SALSA framework, the preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram was employed to illustrate the article screening and selection process (Figure 1) (Page et al., 2021). The compliance of all extracted articles was examined and confirmed for each separate item of the PRISMA-ScR checklist (Prisma Executive, 2024.). The findings of the review are conveyed through descriptive summaries or data categorization, rather than through quantitative summaries or meta-analysis.

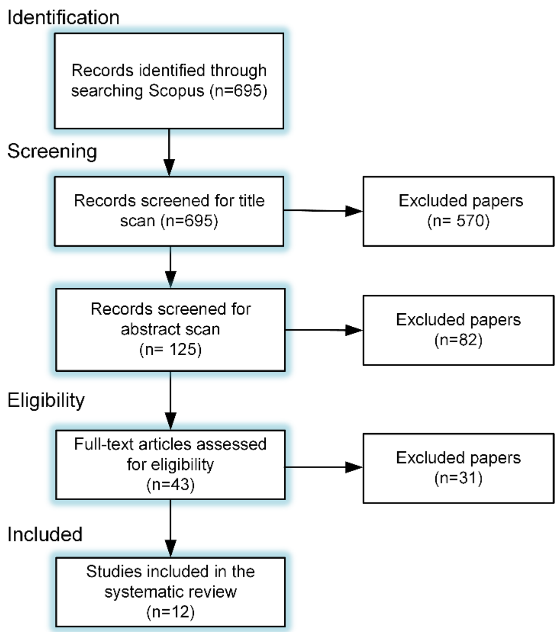

Figure 1: Flow diagram of literature search and study selection

2.1 Search

This phase entailed the identification of pertinent sources of information. The search query utilized variations of the following terms, applied to the title, abstract, and keywords: ("AI" OR ("artificial" AND "intelligence")) AND (("discussion" AND "forum") OR ("discussion" AND "board")). The search parameters were confined to articles published in English. Articles were extracted from Scopus on June 2, 2025, resulting in the identification of a total of 695 articles.

2.2 Appraisal

2.2.1 Study screening and selection

The selection of articles concentrated on studies that investigated practical online learning within discussion forums to elucidate the effects of AI. The established inclusion and exclusion criteria for the articles are delineated in Table 2. Following the application of the screening criteria to the titles, the number of articles was reduced to 125. Subsequently, the abstracts underwent a screening process, leading to the exclusion of 82 articles. The remaining 43 articles were assessed for eligibility through a comprehensive review of the full text and coding utilizing Atlas.ti version 9. Studies that collected relational data from post-interviews or post-questionnaires were excluded, while articles that specifically examined the practical communities themselves were extracted. Research studies conducted on AI trials that fall outside the realm of educational management have been excluded, as the findings of this study are specifically intended for use by educators tasked with implementation.

Table 2: Inclusion and exclusion criteria

Inclusion Criteria	• Empirical, primary research • AI featured by machine learning, deep learning, or natural language processing applications • AI-powered learning is concrete and focused • Use of AI service by students or connections from AI system to students • Existence of forum communication between participants • Conversational agents or chatbots are considered as participants (e.g. virtual teacher, tutor, assistant or peer)
Exclusion Criteria	• Not in English • Reviews, principles, or overviews of AI-based education: no practice is conducted • No real data on student learning with AI in the discussion forum • No information, feedback, or assistance provided to learners by AI • Data mining of forum messages: extracting targets for purposes other than providing a learning service • Measuring AI function takes precedence over learning assistance • Studies designed to deny the use of AI in self-directed learning

2.3 Synthesis

2.3.1 Data extraction

A data extraction schema for online discussion forums was proposed (Yu et al., 2024), and the present study selected two categories: study outline and study design (Table 3). The data fields in the data extraction schema were designed to align with the research objectives and questions of this study. The schema incorporated the field-weighted citation impact (FWCI), a time- and field-normalized citation metric provided by Scopus, which is less biased than traditional citation counts (Yu et al., 2020). These data fields are arranged to contribute to a deeper understanding of the unique characteristics of students and the role of AI in providing support.

Table 3: Data extraction schema

Category	Data field
Study Outline	Author, Publication year, FWCI, Used AI system, Outline of AI Function, Types of AI, Course Title, Content of Discussion, Participants
Study Design	Author, Publication year, Used Pedagogy, Emerged AI Effect, Challenging Part, AI effects on Students' Communication, AI Function on Student-Teacher Communication, Presences of CoI, Appeared New Learning Mode

In the SALSA process, two reviewers independently conducted the screening. The retrieved results were subjected to a preliminary screening and subsequent removal process using EndNote 21. Any discrepancies were addressed through discussion, consultation of supplementary materials (e.g., AI system manuals), and clarification. The inter-rater reliability between the reviewers was measured at 88.8% at the title and abstract level and 96.2% at the full-text level.

2.4 Analysis

The analysis phase involved evaluating the utilization of AI and extracting meaningful information and effects. The key components of the twelve articles were organized according to the data extraction schema and tabulated based on the year of publication (Table 4-5 in Appendix 1-2). The subsequent step involved processing work to clarify the relationship between AI services and the implemented education.

3. Results

3.1 Study Outline

The extracted articles indicate that the reports in conference proceedings (n=9) significantly exceed those of journal articles (n=2) and a book chapter (n=1). This finding suggests an increased demand for the immediate reporting of results. Table 4 in Appendix 1 presents five pivotal views.

Firstly, two strategies for the utilization of AI emerged. The first strategy involved the implementation of market AI services within discussion forums (Irish et al., 2022; Lin et al., 2024; Sinha et al., 2024; Huo et al., 2024; Jureynolds, 2024). The second strategy comprised research trials that integrated publicly available AI repositories into the discussion forums (Kim and Shaw, 2009; Zylich et al., 2020; Wang et al., 2022; Chang et al., 2023; Liu et al., 2024). These attempt settings were frequently revised, resulting in ambiguous reporting of student numbers and quantitative data on learning activity records (Zylich et al., 2020; Teo and Tan, 2023; Sinha et al., 2024; Huo et al., 2024).

Secondly, the variety of AI types deployed in society was unevenly used in the discussion forums. Chatbots were extensively utilized to engage with students, and AI functioned as virtual tutors with their AI status clearly denoted (Zylich et al., 2020; Wang et al., 2021; Liu et al., 2024; Lin et al., 2024; Sinha et al., 2024; Huo et al., 2024; Jureynolds, 2024). In contrast, the types of "metaverse" and "multimodal" were conspicuously absent, indicating a lack of introduction of AI technologies in design, identification, authentication, and gamification. The student code of conduct was emphasized, influencing the development stall for gamification and edutainment in the metaverse. Conversely, students placed a higher value on the content of the information provided and exhibited minimal concern regarding the identity of the sender (Irish et al., 2022).

Thirdly, the influence of the student code of conduct is notably observable in the integration of generative AI tools, such as ChatGPT, into learning activities. Due to the pervasive recognition of their usefulness and necessity, measures have been implemented to mitigate issues such as the unauthorized use of GenAI outputs and concerns regarding the hallucination of GenAI-generated documents by incorporating usage measures into discussion forums (Lin et al., 2024). The aggregation of substantial data through interactions with GenAI raises ethical considerations (Yu, 2024). For instance, a case was documented in the lessons for a coding program, where the purpose of AI-generated messages was to offer guidance rather than to provide direct solutions. In this instance, AI responses to student inquiries are generated using prompts developed by teacher (Liu et al., 2024). In other situations, the scope of machine learning is constrained (Huo et al., 2024), and the format of questions is specified (Lin et al., 2024). The content of GenAI necessitated adjustments and checks by teachers, ranging from small tweaks to wholesale regeneration, to make it suitable for the learning context for which it was intended (Kukulska-Hulme et al., 2024).

Fourthly, a notable application of AI in this context includes the incorporation of AI into online systems with large-scale participant engagement, such as Massive Open Online Courses (MOOCs). These systems employ AI to address students' questions and provide course protocols, thereby ensuring that student behavior is proactively managed rather than overlooked (Zylich et al., 2020; Liu et al., 2024; Lin et al., 2024; Sinha et al., 2024; Huo et al., 2024).

Finally, there are AI services that facilitate and support learning communication. These include a system that recommends communication partners based on the homophily evident in students' profiles (Wang et al., 2022) and a system that recommends a student based on the relevance of their posted messages (Kim and Shaw, 2009; Jureynolds, 2024).

As illustrated in Table 4, course offerings are predominantly concentrated in the domains of computer science and language training. This trend appears to reflect the adoption of social markets in translation and programming. Consequently, the educational domain presented in the articles seems misaligned with contemporary educational trends.

3.2 Study Design

Table 5 in Appendix 2 presents the data fields included in the study design.

The count of components of the CoI framework, as identified in the extracted articles, revealed the following: CP in 11 articles, SP in 6 articles, and TP in 12 articles. Students were provided with tailored learning experiences, thereby facilitating the attainment of higher-order thinking skills. In the discussion forums, CP was observed to be more predominant than SP, with a particular emphasis on communication for individual learning achievements (Chang et al., 2023; Lin et al., 2024; Sinha et al., 2024; Huo et al., 2024). The preceding finding that students are perceived as a group of individuals who collaboratively participate in intentional critical discourse and reflection to construct personal meaning and establish mutual understanding in CoI (Sevnarayan and Vaughan, 2024) was explicated.

Regarding man-machine partnership, layers were proposed based on interactions of people and groups within social and cultural environments (Campa, 2016; Teo and Tan, 2023). Three types of partnerships related to the activities in the discussion forums are the subject of this study.

First, individual student-AI partnerships (Teo and Tan, 2023; Chang et al., 2023; Lin et al., 2024) were established. Students received AI-generated reports on their contributions and advice for assignments with structural manner. Furthermore, the students were prompted to follow prepared patterns in their learning activities. The articles delved into the reasons why students generate ideas within specific confines and identified whether these patterns align with effective learning methodologies. Two out of three articles (Chang et al., 2023; Lin et al., 2024) did not involve SP, while all articles involved CP, in which teachers aimed to enhance students' knowledge acquisition using AI.

Next is the student-AI-student partnership (Irish et al., 2022; Wang et al., 2022; Jureynolds, 2024). The AI's role in this partnership was to navigate the discussion data and assist students in expanding their ideas through communication over time. Furthermore, the AI provided advice to introduce students' idea-building patterns and reflect on their learning processes. All studies of this partnership involved SP and CP, in which teachers clearly intended for students to acquire knowledge through communication.

Finally, there is the student-AI-teacher partnership (Kim and Shaw, 2009; Zylich et al., 2020; Wang et al., 2021; Liu et al., 2024; Lin et al., 2024; Huo et al., 2024). The AI addressed the shortage of teacher assistance, especially in large-scale courses. A potential solution to facilitate the establishment of high-level communication with virtual teachers was presented. Five of the six articles involved CP, and four of the six articles involved SP, in which teachers aimed to assist in developing students' competencies through scholarly communication. However, students felt that the advice and answers provided by the AI were inferior to those provided by teachers or tutors (Zylich et al., 2020; Wang et al., 2022; Lin et al., 2024; Huo et al., 2024).

Regarding the pedagogical theory outlined in Table 5, there is a lack of incorporation of contemporary theories. Conversely, the studies were designed to indicate the fundamental components expected to enhance the efficacy of online learning systems through the implementation of AI. Subsequently, a qualitative content analysis was conducted to discern analogous objectives and challenges in the collected literature and to ascertain the educational trends implicated in these studies. The selected 12 articles contained a total of 458 references. The mean reference age was 9.09 years ($\sigma = 10.67$), and given the novel nature of this domain, the cited literature is somewhat dated. The highest FWCI was observed (103.94) in the article with a short mean reference age (Liu et al., 2024) of 1.85 years. The results involved the collection and counting of these terms, which were then compiled into a Sankey diagram (Figure 2).

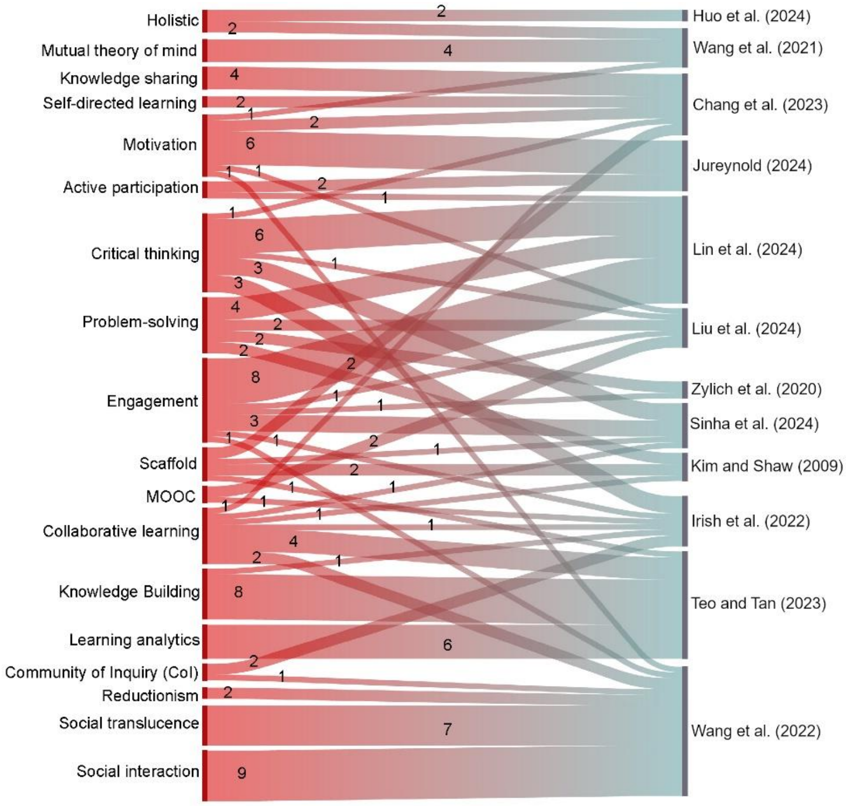

Figure 2: Sankey diagram of key terms of educational statements in articles

Given the wide range of man-machine partnerships employed, the educational terms extracted encompassed a broad array of topics, with minimal overlap among the emerging terms. A comprehensive analysis of the articles indicated that each article included a unique educational term. Nevertheless, instructional designs that incorporate active learning strategies—such as knowledge sharing, active participation, problem-solving, engagement, collaborative learning, and Communities of Inquiry (CoI)— have demonstrated consistent effects that enhance cognitive engagement. (Sakeef et al., 2025).

4. Discussion

4.1 RQ1 What is the Role of AI in Facilitating Student Learning Within Discussion Forums?

Broadly, three distinct perspectives regarding the role of AI in learning were identified. The first perspective posited that AI functioned as a virtual teacher, supplementing the teaching functions of human teachers and delivering information to students (Zylich et al., 2020; Wang et al., 2021; Liu et al., 2024; Lin et al., 2024; Sinha et al., 2024; Huo et al., 2024). In the second perspective, AI facilitated students in collecting information by enabling interactions with messages or peers (Kim and Shaw, 2009; Irish et al., 2022; Wang et al., 2022; Teo and Tan, 2023; Jureynolds, 2024). Additionally, in the third perspective, the significance of the automatic evaluation function (Chang et al., 2023), which assessed learning activities and provided feedback to enhance the system while simultaneously implementing immediate changes in the learning process, was acknowledged.

The extracted articles in this study clearly demonstrate that AI is utilized to promote conventional activities within discussion forums, such as knowledge acquisition and communication facilitation. The most sophisticated function is the information aggregation and notification system offered by AI. Fundamentally, the role of AI is to facilitate learners' access to external storage records. This role as a transducer is an extension of AI that serves to bridge the connection between the learner and the vast resources available in cyberspace. Conversely, this reveals the potential for the expansion of the learning environment in current discussion forums through the introduction of AI. Notably, the incorporation of generative AI (GenAI) created an environment that allowed students to access information beyond what was included in the course materials. Indeed, three of the articles selected for this study (Teo and Tan, 2023; Lin et al., 2024; Jureynolds, 2024) contained connections with individuals who had societal contexts outside classroom settings.

Regarding the provision of information by AI, the argument of its dual nature was noted, recognizing it as both a potential asset and a significant concern. In this context, the necessity for prior AI training has been emphasized, alongside a concurrent advocacy for prioritizing human expertise over excessive dependence on AI (Jose and Jose, 2024). Specifically, the researchers articulated that the benefits presented by AI outweigh the apprehensions and associated risks (Sinha et al., 2024).

4.2 RQ2 In What Ways do AI-Powered Tools Support Learners in Online Discussion Forums?

The AI technologies within discussion forums employed primarily consisted of GenAI (Liu et al., 2024; Lin et al., 2024; Sinha et al., 2024; Huo et al., 2024) and chatbots (Wang et al., 2021; Chang et al., 2023; Liu et al., 2024; Lin et al., 2024; Sinha et al., 2024; Huo et al., 2024; Jureynolds, 2024). While the existing review reports concerning online education and artificial intelligence published to date indicate that there are limited instances of the application of GenAI (Golrang and Sharma, 2025), the findings of this study will provide an opportunity to discuss GenAI in greater depth. The rationale behind the exclusive utilization of multimodal technology only in Teo and Tan (2023) can be attributed to the specific nature of the issues addressed in other discussion forums, which pertained solely to the domain of written communication. Although there is a general consensus in the overall articles that learning is a complex endeavor requiring information and support from teachers, there remains a paucity of initiatives that engage learners in activities outside an online course environment. Furthermore, the statuses of AI, peers, and teachers within the discussion forums were emphasized.

Holmes and Tuomi (2022) identified a taxonomy of twenty-two different applications of AI in education, ranging from student-focused to teacher-focused AI. The extracted articles in this study covered the following six applications: intelligent tutoring systems (Liu et al., 2024; Huo et al., 2024), AI-assisted apps (Jureynolds, 2024), chatbots (Ibid.), automatic formative assessment (Teo and Tan, 2023; Chang et al., 2023), AI teaching assistants (Wang et al., 2021; Wang et al., 2022; Liu et al., 2024), and AI-assisted lifelong learning assistants (Zylich et al., 2020; Wang et al., 2021; Liu et al., 2024; Lin et al., 2024; Sinha et al., 2024; Huo et al., 2024). The AI-assisted lifelong learning assistant showed a notable trend (n=6) and was the only item that ranked in the speculative stage of application in the taxonomy, confirming its cutting-edge nature in the domain.

AI revealed hidden patterns and prompted students to ask new questions while AI learned from students' inputs. Students could benefit from AI insights. In Zylich et al. (2020), students were advised the timing of posting a follow-up message. In Irish et al. (2022), AI introduced a relevant message before posting.

In an environment of information overload, AI aggregated vast amounts of data in milliseconds by tracking trends, compiling literature, or summarizing social sentiment, which could identify patterns invisible to the human eye. However, aggregated data was raw material; student curators needed to shape it into drafts worth posting. Students had to inject value, empathy, and purpose into machine outputs.

4.3 RQ3 What are the Trends in Learning in the Discussion Forum When AI Services are Utilized?

The diverse roles of AI were demonstrated in RQ1, and various applications utilizing AI were identified in RQ2. The domain of discussion forums with AI highlighted the complex interplay between technology, pedagogy, and the learning environment. This context is referred to as entangled pedagogies, which emphasize understanding the interconnections among these elements and their reciprocal influences (Fawns, 2022). The implementation of GenAI tools, such as ChatGPT, exemplifies the intricate relationship between technology and pedagogy, thereby necessitating ethical considerations and critical evaluation. The adoption of entangled pedagogies encourages teachers to reflect on the purposes and contexts of learning, as well as on how these are influenced by the intricate relationship among learning spaces, pedagogy, and technology (Wilde and White, 2025).

Moreover, a notable aspect of the integration of AI into online discussion forums was that many reports appeared to prioritize increasing support for difficulties faced by autonomous learners rather than focusing on quality control of student outcomes. In the extracted articles, the order of priority for the placement of supporters was as follows: virtual tutor > recommending a peer as a mentor > tutor > instructor. This could be considered an order of decreasing precision in instruction. However, since teachers needed to confront challenges with technology, there were limited opportunities to address the internal structure of the learners. This trend was likely attributable to the nascent stage of AI implementation in the discussion forums, as evidenced by the findings of RQ2, which demonstrated focused technologies and a concomitant focus on that application. Indeed, the effectiveness of the course was not examined from the perspective of any established educational theory. Additionally, there were articles with extremely limited use of education-related terminology (Zylich et al., 2020; Huo et al., 2024). Although all these AI approaches seemed new, they were not grounded in a proactive understanding of pedagogy.

While a greater number of extracted terms pertained to relationships among students (n = 8) than to individual learning (n = 6) in Figure 2, the content analysis revealed a higher frequency of related sentences in individual learning (t = 61) compared to relationships among students (t = 58). Nevertheless, both autonomous students and interactions among students were reconfirmed as mechanisms for facilitating learning development.

Additionally, the learners in some studies were not unified (e.g., Zylich et al., 2020; Teo and Tan, 2023; Liu et al., 2024; Sinha et al., 2024; Huo et al., 2024; Jureynolds, 2024). The course enrollment for these courses was designed to cater to the needs of learners from various backgrounds. A substantial proportion of the articles were primarily case studies, characterized by ambiguous cohorts and a lack of clarity regarding the scope of application of the findings. Consequently, the subjects and issues of learning were not the focus of the research.

To comprehend the intricate learning landscape of AI, the analysis of discussion forum content is crucial as it offers valuable insights into student engagement, learning outcomes, and the overall effectiveness of online learning environments (Nadeesha, Weerasinghe and Abeyweera, 2025). Furthermore, it is essential to adopt a holistic view that considers the entangled elements (Fawns, 2022). To achieve a comprehensive understanding of learner behavior, a holistic method—social network analysis for exploring structural connections—has been used (Yoshida and Theeraroungchaisri, 2024). However, there are currently no reports on the application of AI in education within this context.

5. Conclusion and Future Research

In discussion forums, AI was predominantly utilized in the form of chatbots and GenAI. Emerging AI roles included virtual teachers, peer/message matching, and automated evaluation. Aggregated information was presented in a manner that supported student learning. AI also served as a conduit between students and teachers. The articles encompassed references from a wide range of fields and exhibited a diversity of perspectives. As all CoI components in the articles focused on assisting individual learners, the domain was explicated by applying entangled pedagogies that led to an understanding of the interconnections among diverse roles and various applications of AI. The findings of this scoping review will serve to inform educators utilizing AI in online educational contexts regarding practical considerations and challenges. While the advent of AI has demonstrated the potential to expand the discussion forum environment into a broader cyberspace, there are no reports that provide a detailed analysis of the scholarly communication that has emerged from the discussion forum, and future research is anticipated. The utilization of AI into society and business raises the need for rapid solutions. The education sector is recognized as lagging in the social application and dissemination of AI technologies, highlighting the need for a dialogue to reach a consensus on the prerequisites for introducing AI into educational environments (Kukulska-Hulme et al., 2020). When students are allowed to use GenAI freely in their learning, a challenge arises in determining whether it is possible to create settings that "raise the bar" for learning objectives in educational theories (Sinha et al., 2024).

AI Statement: The authors declare that they have not used generative or assisted artificial intelligence tools at any stage of the paper's conception and revision. All content presented results exclusively from the authors' autonomous investigation, which guarantees originality, integrity, and compliance with ethical and scientific principles.

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Appendix 1

Table 4: Study Outline

No	Author(year)	Indexes (FWCI/Quartile/Education)	Used AI system	Outline of AI function	Types of AI				Course title	Content of discussion	Participants
					Metaverse	Multimodal	GenAI	Chatbot			
1	Kim and Shaw (2009)	2.04 N/A N	TF-IDF and LSA	The PedaBot tool recommended related messages from the past in the relation to the current one. The MentorMatch tool recommended a peer as a mentor.	-	-	-	-	Operating Systems (for PedaBot)	Informal discussion including Q&A	114 students
2	Zylich et al. (2020)	1.57 Q3 N	DrQA, BERT, recurrent neural network	The AI program answered students' questions and predicted the timing of follow-up posts.	-	-	-	-	An introductory physics course.	Logistical Q&A	2,004 posts, N/A
3	Wang et al. (2021)	8.42 N/A N	N/A	It is a Q&A conversational agent and a virtual teaching assistant. The system was evaluated based on its anthropomorphism, intelligence, and likability.	-	-	-	Y	Human-computer interaction in online master of science courses	Jill Watson, an ML-based conversational Q&A agent, responded to students' questions about class logistics.	376 students
4	Irish et al. (2022)	0.91 N/A Y	PARQR tool, Information Retrieval Models, Universal Sentence Encoder	A post recommendation system helped students find relevant messages when writing new posts. The impact of this intervention on forum interactions and performance was evaluated.	-	-	-	-	Artificial Intelligence	General discussion	68 students

No	Author(year)	Indexes (FWCI/Quartile/Education)	Used AI system	Outline of AI function	Types of AI				Course title	Content of discussion	Participants
					Metaverse	Multimodal	GenAI	Chatbot			
5	Wang et al. (2022)	2.71 Q1 N	SAMI (inc. Named Entity Recognition), AI-MC (inc. NLP, Recommendation Algorithms)	Introduced SAMI in discussion forums to help students build social connections. Identified that AI-mediated social interaction fulfills the requirements of the socio-technical gap and social translucence.	-	-	-	-	3 classes of online Master of Science in Computer Science	Students: self-introduction, class-related discussions, Q&A. Instructors: announcements and Q&A. SAMI and instructor: can appoint students into private groups.	26 students
6	Teo and Tan (2023)	3.85 Book Chapter Y	N/A, function of corpus analysis	Scaffolds were placed as templates for posting opinions. The developed links were displayed as a network graph. Messages posted were also linked with terms found in texts and related web lesson records. AI leverages existing records to reconfigure and calibrate, thereby enhancing collective idea improvement. Learning analytics: report cards are to be provided.	-	Y	-	-	N/A, a literature class	Poetry study and appreciation	15-year-old students, N/A
7	Chang et al. (2023)	0.98 N/A Y	BERT-based AI model, and Chatbot; Pypal	An automated post-rating system and feedback by chatbot.	-	-	-	Y	Python Programming & Introduction to AI	To share learning experiences and insights	5,100 posts, 44 students
8	Liu et al. (2024)	103.94 N/A Y	CS50.ai, CS50 Duck	Emulating a competent teacher using GenAI. Ensuring access to GenAI is provided in a controlled manner.	-	-	Y	Y	Introductory course in computer science	Asking curricular matters and administrative matters. Using AI generated hints. Coding.	15 prompts/participant. more than 50,000 participants
9	Lin et al. (2024)	4.23 Q1 Y	ChatGPT, Canvas	ChatGPT was accessed using a designated prompt, and the collected information and remarks were posted on the discussion board.	-	-	Y	Y	2 sections of the same graduate-level online course	Students utilized ChatGPT to generate reports, then added their own reflections on the generated information and posted them in the discussion forum.	27 adult students
10	Sinha et al. (2024)	N/A Q3 Y	BoilerTAI, ChatGPT	The AI system prepared answers to queries on forums. TAs used it, following an approval	-	-	Y	Y	4 courses of computer science	Logistical Q&A	About 800

No	Author(year)	Indexes (FWCI/Quartile/Education)	Used AI system	Outline of AI function	Types of AI				Course title	Content of discussion	Participants
					Metaverse	Multimodal	GenAI	Chatbot			
				workflow to post the answers. It integrates collaboration between human expertise and AI to enhance the learning and teaching experience.							
11	Huo et al. (2024)	N/A N/A Y	GenAI, Chatbots with LLMs, Prompt Perfect, dair.ai, Llama 2	A chatbot with LLM was introduced to answer student questions and provide feedback that is interpretable and visually represented. GenAI was used as an online tutor to offer immediate feedback on coding and debugging.	-	-	Y	Y	Programming 2	Logistical Q&A, including exam, and assignments. Management.	About 1,110 students
12	Jureynolds (2024)	N/A Q3 N	N/A HiNative, the article did not specify details of AI system beyond	Connecting with native speakers in a commercial-based discussion forum for learning foreign languages. Communication templates are provided to ask, and native speakers are available to double-check students' answers or provide examples.	-	-	-	Y	Mandarin, not specified	Q&A regarding language learning	56 students

Note. Indexes include three things: FWCI score (top), quartile in Scopus (middle), and whether or not it is indexed in the education category (bottom), BERT = Bidirectional Encoder Representations from Transformers, GenAI = Generative AI , TF-IDF = Term Frequency–Inverse Document Frequency, LSA = Latent Semantic Analysis, PyPal = Python learning Pal, LLM = Large language model, CS50 = An online computer science course offered by Harvard University, HiNative = An online service that helps you learn foreign languages, N/A = Not disclosed in the publications, "-" = N/A, NLP = Natural Language Processing

Appendix 2

Table 5: Study Design

No	Author(year)	Used Pedagogy	Emerged AI effect	Challenging part	AI effects on students' communication	AI function on Student-teacher communication	TP	SP	CP	Appeared New learning mode
1	Kim and Shaw (2009)	Collaborative learning	PedaBot retrieved moderately relevant messages. The number of messages per thread increased with PedaBot, especially for females. Students found PedaBot's features relevant and useful. MentorMatch results showed that 52% of responding students opened the mentor menu. Of those who noticed the links, 69%	Student discussions should focus on problem-solving rather than on task requests and commitments.	These tools are designed to promote student interactions.	N/A	Y	Y	Y	N

No	Author(year)	Used Pedagogy	Emerged AI effect	Challenging part	AI effects on students' communication	AI function on Student-teacher communication	TP	SP	CP	Appeared New learning mode
			reportedly clicked through to a discussion.							
2	Zylich et al. (2020)	Importance of TA in self-regulated learning	AI provides a virtual TA who interacts with many students at the same time. AI is not yet performing at the same level as humans when it comes to answering questions. The developed system performed better than other systems.	Difficulty conducting research using information from different parts of the document.	Delay a post to maintain a useful discussion among students.	Virtual TA	Y	Y	Y	N
3	Wang et al. (2021)	Mutual Theory of Mind	Students' perception of AI agents changed a lot over time. The students' perception of the AI agent was revealed through the use of complex language, readability, emotion, diversity, and adaptability.	The system could not be transferable to private dyadic interaction.	Student perception and interaction with JW might be interfered with by other students' interactions.	Virtual TA, Verbosity negatively associates with student perception of JW. Readability, sentiment, diversity, and adaptability were positively associated with anthropomorphism, intelligence, and likeability.	Y	N	N	N
4	Irish et al. (2022)	N/A	Students were successfully guided to a suitable ongoing thread, where they wrote follow-up comments and replies. The average number of initial posts in the discussion forum dropped by 55%. Passive learners did better than active learners. The decrease in initial posts did not discourage the students from participating in the forum.	To identify logistical questions typically contributes less than posts that demonstrate a deeper critical thinking.	The system led to fewer posts.	Decreased 8.35 instructor responses per instructor per assignment.	Y	Y	Y	N
5	Wang et al. (2022)	AI-mediated social interaction	Illustrated difficulties in remote social interactions. Identified ethical and social challenges such as user agency and privacy. Helped students build social connections. Found that deep social connections were uncommon yet desired among learners. SAMI augmented social translucence by improving the visibility of social signals and increasing students' feelings of accountability. SAMI automatically recommended social matches, eliminating the need for students to	Lack of visibility. SAMI needs to be more human-like. There is a lack of spontaneity and randomness compared to interactions in person. SAMI took away students' agency in choosing groups to join.	Supported the creation of social interactions that extend beyond the learning environment. 8/26 students reported building friendships through the course.	N/A	Y	Y	Y	Y

No	Author(year)	Used Pedagogy	Emerged AI effect	Challenging part	AI effects on students' communication	AI function on Student-teacher communication	TP	SP	CP	Appeared New learning mode
			proactively seek out opportunities to expand their social connections. However, SAMI did not bridge the social-technical gap.							
6	Teo and Tan (2023)	Knowledge Building	The student-machine partnership was key to actively engaging with and making sense of analytics. The report card helped students understand their classmates' strong points and made them think of their own arguments and ways to strengthen their points and ideas. The report card also informed progress in active discussions and encouraged sharing more ideas.	A danger of over-relying and over-generalizing sets of indicators or instructions put into AI.	Students were shown LA visuals to help them build on their peers' ideas and understand how their ideas are adopted by their friends.	Teachers used learning analytics to help students develop a habit of mind. AI encourage acceptance and support.	Y	Y	Y	Y
7	Chang et al. (2023)	Interdisciplinary knowledge sharing	Improving post quality, reducing plagiarism, and enhancing comprehension.	Students have a negative view of the system's accuracy. They are curious about the criteria for post ratings and hope to indicate how to improve post quality.	N/A	AI is seen as a feature, not a teacher	Y	N	Y	N
8	Liu et al. (2024)	Pedagogical guardrails	Provided students with high-quality online educational support. Students praised the AI for being very helpful (47%), very effective (35%), and very confident (23%). Provided students with an alternative way to use Gen AI.	Establish an AI tool that automates design grading.	N/A	Complementing human instruction by AI. All responses are subject to endorsement, amendment, or deletion by staff. Designating a prompt that makes the AI act as a teaching assistant.	Y	-	Y	Y
9	Lin et al. (2024)	Kolb's Experiential Learning Theory	Twice the number of times contributed to the discussion board when ChatGPT was involved. Students reported that discussion forums with ChatGPT helped them develop generic skills and abilities. It made the online discussion engaging and motivated effective learning.	AI-generated info is very long and all very similar.	A student felt more engaged when they did not rely on it for every discussion post.	Assist in how to use the discussion system.	Y	N	Y	Y

No	Author(year)	Used Pedagogy	Emerged AI effect	Challenging part	AI effects on students' communication	AI function on Student-teacher communication	TP	SP	CP	Appeared New learning mode
10	Sinha et al. (2024)	Vygotsky's sociocultural theory	No significant difference in student reception exists between the responses from AI-TAs and those from instructors. GenAI can effectively meet educational needs when managed well.	Faced limitations from a smaller TA sample size and the fact that responses were infrequent.	N/A	The system was designed to augment the instructional capabilities of course staff, serving as an auxiliary function to facilitate educational dialogue between students and instructors.	Y	N	Y	N
11	Huo et al. (2024)	Tutoring	Demonstrated an apparent improvement in student performance after using the LLM to help them code. Most students praised LLM tool for its helpfulness, effectiveness, and reliability. Simpler programming questions on code structure, logic, or syntax could be addressed by the LLM. 23.4% of questions on the discussion board are unanswered. 62.2% of questions are resolved. In 11/14 questions, students voted for better answers provided by staff than by chatbots.	Possibilities for ethical considerations around student privacy, social responsibility, and research integrity exist. The current LLM still requires additional development to provide suitable personalized online assistance.	N/A	Teachers still offered more accurate and preferred answers than the LLM. The students, first and foremost, value accuracy in answers.	Y	N	Y	N
12	Jureynolds (2024)	N/A	93% strongly agreed that HiNative helped them learn Mandarin. 75% agreed that HiNative enabled students to use Mandarin fluently.	N/A	HiNative accommodated collaborative learning among online users.	N/A	Y	Y	Y	N

Note. TA = Teaching Assistant, JW = Jill Watson, LLM = Large language model, N/A = Not disclosed in the publications, "-" = N/A

Interactive Edu-Video App for Teaching Electricity and Electronics Principles to Bachelor of Science in Industrial Technology (BSIT) Students

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Abstract: Teaching complex electrical and electronic principles to Bachelor of Science in Industrial Technology (BSIT) students presents a significant pedagogical challenge due to the abstract nature of the concepts. Traditional static methods often fail to provide the visualization required for technical mastery. This study aimed to bridge this gap by designing, developing, and evaluating an "Interactive Edu-Video App" for the course Electricity & Electronics Principles at North Eastern Mindanao State University, Philippines. The study utilized a Research and Development (R&D) approach grounded in the ADDIE model, combined with a quasi-experimental design (non-equivalent control group). The participants included 76 BSIT students and 16 experts (instructors and industry practitioners). Data were analyzed using weighted means for validity and t-tests for learning effectiveness. The development phase produced a mobile application integrating interactive hotspots and quizzes based on Cognitive Load Theory. Expert validation rated the app as "Very Satisfactory" (M=3.61) in terms of accessibility and engagement. Experimental results revealed that while baseline knowledge was comparable (p=0.146), the experimental group using the app achieved significantly higher posttest scores (M=25.45) compared to the control group (M=17.39), with a significant learning gain (t=18.781, p<0.001). The findings confirm that interactive video is not merely a supplementary tool but a superior pedagogical strategy for technical education. The study contributes a validated, scalable mobile learning model that enhances conceptual mastery in TVET, offering a practical solution for resource-constrained industrial technology programs.

Keywords: TVET, Interactive video, ADDIE model, Electrical technology, Mobile learning, Instructional design

1. Introduction

The rapid evolution of Industry 4.0 demands that students in electrical technology possess not only theoretical knowledge but also robust practical competencies to navigate a technology-driven world (Bekhoeva, Ramazanova and Bekoeva, 2022, Ma, 2024). Consequently, Technical-Vocational Education and Training (TVET) institutions are under pressure to revise curricula to include advanced concepts such as the Internet of Things (IoT) and intelligent manufacturing (Verdejo Espinosa et al., 2023). However, teaching foundational subjects like Electricity and Electronics Principles remains a significant pedagogical hurdle. Concepts such as voltage, current, and resistance are invisible and abstract, making them difficult for Bachelor of Science in Industrial Technology (BSIT) students to conceptualize through traditional lectures alone (Al-Ali, 2021, Ibanga, Dawasa and Yaro, 2023).

A critical gap exists in the delivery of these technical subjects. While the COVID-19 pandemic accelerated the adoption of e-learning, many resources used in TVET remains "static"—consisting largely of PDFs or passive video lectures that do not fulfill the varied learning requirements of technical students (Dotsenko, 2022, Utari and Mukhaiyar, 2020). Passive observation often leads to disengagement and fails to bridge the gap between theory and practice. Unlike general education, technical education requires active visualization and manipulation of variables. Although interactive multimedia has shown promise in other fields, there is a scarcity of validated, interactive mobile applications specifically designed for the BSIT electricity curriculum in the Philippine context.

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To address this gap, this study aimed to design, develop, and evaluate an Interactive Edu-Video App for BSIT students at North Eastern Mindanao State University (NEMSU). Grounded in the ADDIE instructional design model, the study sought to: (1) develop a mobile learning tool that integrates interactive elements (quizzes, hotspots) to reduce cognitive load; (2) validate the app's acceptability through expert review; and (3) determine its effectiveness in improving learning outcomes compared to conventional static materials.

2. Literature Review

Challenges in Technical Education

Teaching electricity poses unique challenges due to the abstract nature of the phenomena. Misconceptions regarding circuit behaviors are common because students cannot "see" the electron flow (Burde, Weatherby and Wilhelm, 2022, Moodley and Gaigher, 2017). Traditional methods often rely on rote memorization of calculations, which hinders the development of the deep conceptual understanding required for industry troubleshooting (Fan et al., 2023, Kang and Liang, 2024). Furthermore, resource constraints in developing countries often result in limited laboratory access, making digital simulation and visualization critical for bridging the theory-practice gap (Hermawati, 2022).

The Role of Interactive Video in TVET

While video is a staple in e-learning, passive video consumption often fails to sustain the cognitive engagement necessary for complex learning (Buentello-Montoya and Montes-Montejo, 2022). In contrast, interactive video—which requires user inputs such as answering embedded questions or navigating branching scenarios—transforms the learner from an observer to a participant (Dahlan et al., 2023). Empirical studies in STEM education indicate that interactivity improves retention by forcing the learner to actively process information (Peisen and Jr., 2023). However, most existing studies focus on general engineering; there is a need for specific applications within the vocational and industrial technology sector (Hasanuddin, Asgar and Jayadi, 2023).

Theoretical Framework: Designing for Cognitive Efficiency

The design of the Interactive Edu-Video App is theoretically grounded in Mayer's Cognitive Theory of Multimedia Learning (CTML) and Sweller's Cognitive Load Theory (CLT). CTML asserts that learning is optimized when visual and auditory channels are processed simultaneously but not overwhelmed (Mayer, 2021). The app applies Mayer's Signaling Principle (highlighting key circuit parts) and Segmenting Principle (breaking complex laws into short, user-controlled clips) to manage processing capacity. CLT emphasizes minimizing extraneous cognitive load (distractions) to maximize germane load (schema construction) (Noetel et al., 2021, Sweller, Ayres and Kalyuga, 2011). By embedding quizzes directly into the video timeline, the app aligns with the interactivity effect, ensuring that students test their understanding before moving to more complex concepts. This theoretical alignment distinguishes the proposed app from standard repository-based e-learning tools.

3. Methods

3.1 Research Design

This study employed a Developmental-Quasi-Experimental research design. The developmental phase followed the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model to systematically construct the Interactive Edu-Video App. The evaluation phase utilized a non-equivalent control group pretest-posttest design to measure the app's effectiveness. This dual approach allowed for both the creation of a validated instructional tool and the empirical testing of its impact on student learning outcomes.

3.2 Research Setting and Participants

The study was conducted at North Eastern Mindanao State University (NEMSU) - Cantilan Campus. The participants were selected using purposive sampling (Table 1).

- **Validators (N=16):** Comprised of 6 Teacher Experts (Instructors/RMEs) and 10 Student Experts (NCII holders) who assessed the app's usability and content.
- **Experimental Subjects (N=76):** First year BSIT students enrolled in *ELC 111 - Electricity and Electronics Principles*. They were divided into the Experimental Group (n=38) which used the interactive app, and the Control Group (n=38) which used traditional static materials.

Table 1: Research Participants

	Category	Number of Respondents
Validators (N=16)	Teacher Experts (Instructors, Professors, RME)	6
	Student Experts (OJT, NCII Holders)	10
Experimental Subjects (N=76)	BSIT Learners - Section ELC 1Q	25
	BSIT Learners - Section ELC 1R	24
	BSIT Learners - Section ELC 1L	27
	TOTAL	92

3.3 Research Instruments

- Validation Questionnaire: Adapted from Rice and Ortiz (2021), assessing four dimensions: Accessibility, Active Engagement, Advocacy for Inclusion, and Accountability. It used a 5-point Likert scale.
- Learning Achievement Test: A 50-item multiple-choice test covering ELC 111 competencies. This instrument underwent pilot testing and item analysis to ensure validity and reliability before being used as the pretest and posttest.

3.4 Data Collection Procedure

- Phase 1 (Development): A needs analysis was conducted via interviews to identify learning gaps. Based on these findings, the app was designed using storyboards and developed using LUMI software.
- Phase 2 (Validation): The beta version was evaluated by the expert panel using the Validation Questionnaire. Feedback was incorporated into the final build.
- Phase 3 (Experiment): Both groups took the pretest. The Experimental Group utilized the Interactive Edu-Video App for a 6-week intervention period, while the Control Group utilized standard PDF modules and static video lectures. Both groups took the posttest immediately after the intervention.

3.5 Data Analysis

Quantitative data were analyzed using SPSS. Weighted Means were used to interpret expert validation ratings. For the experimental phase, Independent Samples t-tests were used to check for baseline equivalence (pretest), and Paired Samples t-tests and Independent t-tests were used to determine significant differences in learning gains (posttest). Significance was set at $p < 0.05$.

4. Results

4.1 System Development Results (ADDIE Output)

The application of the ADDIE model yielded a fully functional interactive mobile learning tool tailored to BSIT students.

4.1.1 Analysis phase output

The thematic analysis of student interviews revealed critical gaps in existing materials. As shown in Table 2, students expressed a strong "Need for Interactive Content" and "Desire for Instant Feedback" to combat the passivity of traditional lectures.

Table 2: Thematic Analysis of Student Needs Assessment Interview Responses

CODE	THEME	ILLUSTRATIVE QUOTES
Lack of Engagement with Existing Videos	Need for Interactive Content	"The videos are okay, but they become dull pretty fast." "I often lose concentration after a short time." "It's just passive watching without any involvement."
Difficulty Grasping Concepts	Enhanced Learning through Interaction	"Sometimes, I don't fully grasp the material being shown." "I wish there was a way to ask questions or practice alongside the video."

CODE	THEME	ILLUSTRATIVE QUOTES
Preference for Hands-On Activities	Active Participation	"I learn better by doing, not just watching." "Practical exercises help me understand the material more clearly."
Desire for Instant Feedback	Interactive Feedback Features	"It would be helpful if the video could tell me whether I'm doing something correctly as I follow along." "I want immediate confirmation if I'm on the right track."
Need for Customizable Learning Speed	Self-Paced Learning	"Sometimes the videos move too quickly, and I can't keep up." "I'd like to be able to pause and try things at my own speed."
Struggling to Retain Information	Better Retention through Interaction	"I tend to forget a lot of what I watch afterward." "If I could interact with the content, I think I would remember it more effectively."

4.1.2 *Design phase output*

Guided by the analysis, the app's architecture was structured to reduce cognitive load. The content flow (Figure 1) and visual storyboards (Figure 2) prioritized "segmenting" complex electrical laws into manageable interactive chunks.

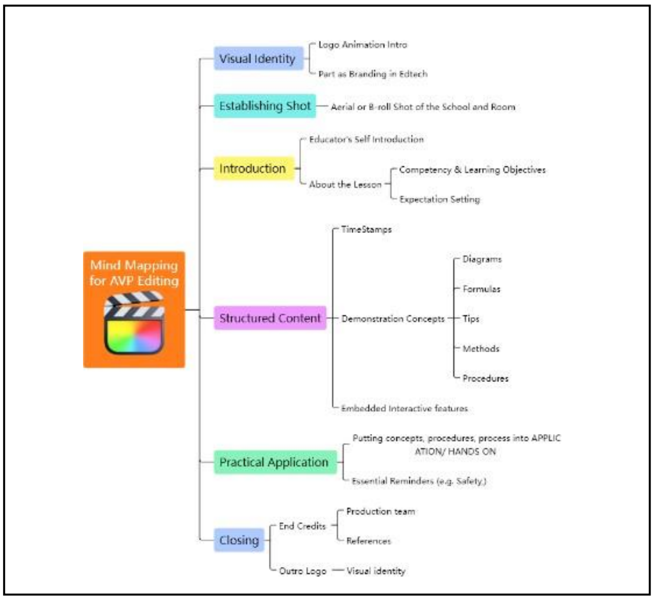

Figure 1: Mind map of Edu-video Lesson

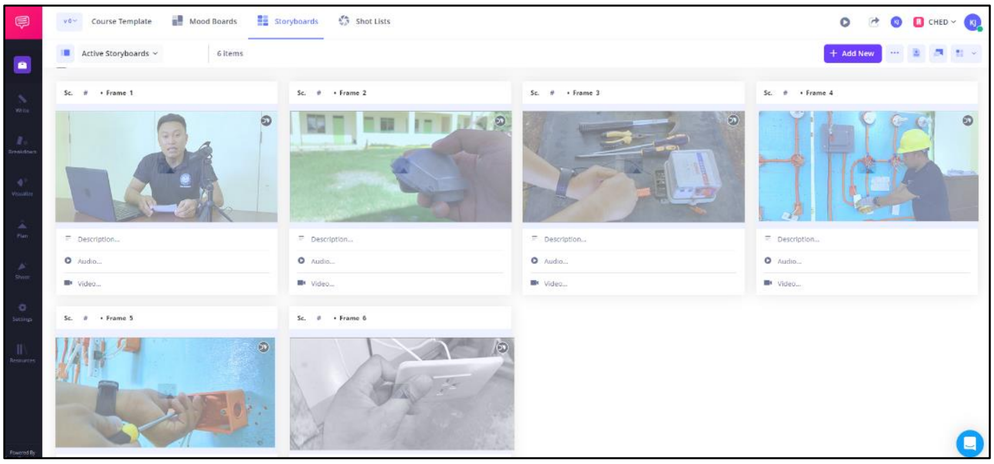

Figure 2: Storyboard for Edu-Video Lesson

4.1.3 Development phase output

The final output was the "Interactive Edu-Video App" (APK format) (Figure 4&5). Unlike static videos, this app integrated "hotspots" and "pop-up quizzes" using LUMI software (Figure 3). This allows students to engage with the video timeline directly, transforming passive watching into active problem-solving.

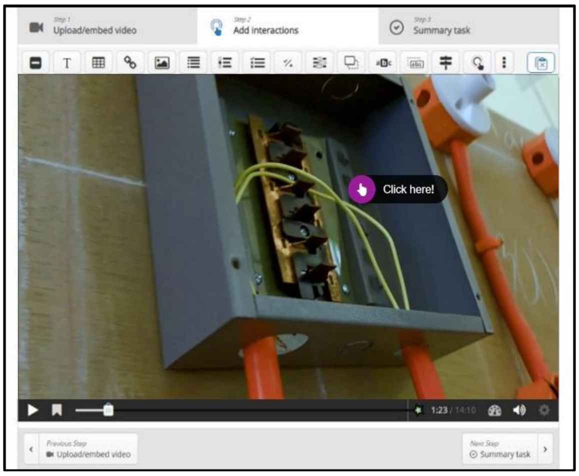

Figure 3: Interactive features using LUMI

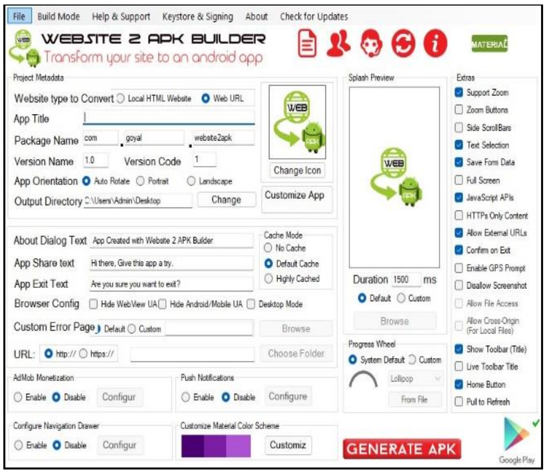

Figure 4: Converting HTML5 to APK

Figure 5: Application Development Results

4.2 Expert Validation Results

The Interactive Edu-Video App underwent validation by both teacher experts and student experts using an adapted instrument assessing Accessibility (ACC), Active Engagement (AE), Advocacy for Inclusion (AI), and Accountability (AC) (Rice and Ortiz, 2021).

4.2.1 Teacher expert validation

As summarized in Table 3, teacher experts provided high ratings across all dimensions. Each indicator's average weighted mean fell into the 'Very Satisfactory' category. Accessibility received an average score of 3.50, Active Engagement 3.58, Advocacy for Inclusion 3.57, and Accountability 3.58. Specific items receiving particularly high ratings included the app offering feedback (AE item 7: 4.00) and being viewable on various devices (ACC item 3: 3.67). Areas noted for potential enhancement included the availability of materials in multiple formats (ACC item 2: 3.00) and transparency regarding affiliations/sources (AC item 2: 3.17).

Table 3: Teacher Experts' Validation Ratings (N=6)

Indicator	Code	Average Weighted Mean	Verbal Description
ACCESSIBILITY	ACC	3.50	Very Satisfactory
ACTIVE ENGAGEMENT	AE	3.58	Very Satisfactory
ADVOCACY FOR INCLUSION	AI	3.57	Very Satisfactory
ACCOUNTABILITY	AC	3.58	Very Satisfactory

Scale interpretation: 3.25-4.00 - Very Satisfactory; 2.25-3.24 – Satisfactory; 1.25-2.24 – Unsatisfactory; 1.24 and below - Poor

4.2.2 Student expert validation

Student experts also rated the app very positively, with all indicators achieving an overall 'Very Satisfactory' description, as shown in Table 4. Accessibility received an average score of 3.62, Active Engagement 3.68, Advocacy for Inclusion 3.67, and Accountability 3.64. Notably, high ratings were given for device compatibility (ACC item 3: 4.00) and the provision of feedback (AE item 7: 4.00). Similar to teacher feedback, areas with relatively lower (though still satisfactory) scores included availability in multiple formats (ACC item 2: 3.20) and revealing affiliations/sources (AC item 2: 3.30).

Table 4: Student Experts' Validation Ratings (N=10)

Indicator	Code	Average Weighted Mean	Verbal Description
ACCESSIBILITY	ACC	3.62	Very Satisfactory
ACTIVE ENGAGEMENT	AE	3.68	Very Satisfactory
ADVOCACY FOR INCLUSION	AI	3.67	Very Satisfactory
ACCOUNTABILITY	AC	3.64	Very Satisfactory

Scale interpretation: 3.25-4.00 - Very Satisfactory; 2.25-3.24 – Satisfactory; 1.25-2.24 – Unsatisfactory; 1.24 and below - Poor

4.3 Effectiveness Evaluation Results

The effectiveness of the Interactive Edu-Video App was evaluated using a quasi-experimental design involving BSIT ELC 1 students (N=38 per group, Control and Experimental) enrolled in the Electricity and Electronic Principles course. Pretest and posttest scores were analyzed.

4.3.1 Learning performance (pretest and posttest scores)

Mean scores and standard deviations are summarized in Table 5, covering both the initial (pretest) and final (posttest) assessments for each group. For the control group, average scores increased slightly between the initial assessment (M=15.18) and the concluding one (M=17.39). Using the Interactive Edu-Video App, the experimental group exhibited a substantially larger increase, from a pretest mean of 14.42 to a posttest mean of 25.45. Score dispersion among the experimental participants decreased notably from the initial to the final test.

Table 5: Pretest and Posttest Performance of Control and Experimental Groups (N=38 each)

Group	Test	Mean	Std. Deviation
Control	Pretest	15.18	2.481
	Posttest	17.39	2.074
Experimental	Pretest	14.42	2.035
	Posttest	25.45	1.639

4.3.2 *Statistical comparisons (T-tests)*

Statistical tests were conducted to evaluate whether the observed variations were statistically significant (Table 6). An independent samples t-test confirmed no statistically substantial difference between the control and experimental groups' pretest scores ($p = 0.146$), indicating comparable baseline knowledge. Paired samples t-tests revealed statistically substantial improvements from the pretest to the post-test within both groups: the control group ($p < 0.001$) and, more significantly, the experimental group ($p < 0.001$). Crucially, an independent samples t-test comparing the posttest scores showed a highly statistically substantial difference between the groups ($p < 0.001$), with the experimental group achieving significantly higher scores than the control group after the intervention period.

Table 6: T-test Results for Pretest and Posttest Comparisons

Comparison	t-statistic	p-value	Decision	Interpretation (Statistical)
Paired T-test: Control Group (Pretest vs Posttest)	5.041	< 0.001	Reject H_0	Significant difference within the control group
Paired T-test: Experimental Group (Pre vs Post)	22.864	< 0.001	Reject H_0	Significant differences within the experimental group
Independent T-test: Pretest (Control vs Exp.)	1.466	0.146	Fail to Reject H_0	No significant difference between the groups' pretest
Independent T-test: Posttest (Control vs Exp.)	18.781	< 0.001	Reject H_0	A significant difference between groups' posttest

5. Discussion

5.1 Development and Validity of the App

The study successfully developed an Interactive Edu-Video App that meets the specific needs of BSIT students. The "Very Satisfactory" ratings from both teachers (M=3.56) and students (M=3.65) confirm that the app is not only technically functional but pedagogically sound. High ratings in Active Engagement validate the design decision to move away from passive MP4 videos. By integrating LUMI software features like hotspots and branching scenarios, the app transformed the viewing experience. This aligns with Mayer's Cognitive Theory of Multimedia Learning, specifically the Signaling Principle, as the interactive elements guided students' attention to critical circuit behaviors that are often missed in static diagrams (Mayer, 2021).

5.2 Effectiveness in Enhancing Learning Outcomes

The most significant finding is the substantial learning gain observed in the experimental group ($t=18.781$, $p<0.001$). While both groups started with equivalent background knowledge, the group using the interactive app outperformed the control group by a wide margin (Posttest M: 25.45 vs. 17.39).

This superiority can be attributed to the reduction of Extraneous Cognitive Load (Sweller, Ayres and Kalyuga, 2011). In the control group, students had to mentally visualize electron flow while reading static text, a process that consumes high cognitive effort. In contrast, the app provided dynamic visualization and immediate feedback through embedded quizzes. This "interactivity effect" prevented the passive "illusion of competence" often seen in video learning (Buentello-Montoya and Montes-Montejo, 2022). Furthermore, the app allowed for self-paced learning—students could replay complex segments (e.g., Ohm's Law calculations) until mastery was achieved, a flexibility not always possible in a rigid classroom lecture.

5.3 Implications for TVET

These findings have profound implications for technical education. They suggest that the difficulty students face in Electricity and Electronics is not necessarily due to the subject's complexity, but the delivery medium's limitations. For TVET institutions facing resource constraints, this study demonstrates that mobile learning applications can serve as effective, low-cost alternatives to expensive simulation hardware for foundational theoretical training.

6. Conclusion

This study confirms that integrating interactivity into educational video significantly enhances the learning outcomes of BSIT students in electrical technology. The Interactive Edu-Video App proved to be a superior pedagogical tool compared to traditional static materials, not merely because it is digital, but because it aligns with cognitive principles of engagement and load reduction. The study concludes that for abstract technical subjects, passive visualization is insufficient; active learner intervention within the content is required for deep conceptual mastery.

7. Recommendations

Based on these findings, the following recommendations are proposed:

1. Instructional Design: TVET educators should transition from repository-based e-learning (uploading PDFs/MP4s) to interactive multimedia design. Tools like LUMI or H5P should be standard in the development of technical modules.
2. Curriculum Integration: Institutions should formally integrate validated mobile apps into the Electricity and Electronics syllabus as supplementary review tools to bridge the gap between classroom theory and laboratory application.
3. Future Research: Future studies should address the limitations of this research by:

- Conducting longitudinal studies to determine if the knowledge retention persists over a full semester.
- Expanding the sample to include multiple TVET institutions to improve generalizability.
- Investigating the app's effectiveness on psychomotor skills (actual wiring tasks) in addition to cognitive knowledge.

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AI Statement: The authors acknowledge the use of specific AI-assisted technologies to support the preparation of this manuscript, adhering to ethical guidelines. Consensus AI was utilized to assist in the discovery of relevant literature during the review phase. Google AI Studio and Grammarly were used exclusively for language refinement, paraphrasing, and grammatical correction to enhance readability and flow. EndNote software was employed for reference management and formatting. The authors confirm that no AI tools were used for data generation, statistical analysis, or the scientific interpretation of results. All data processing (using SPSS), thematic analysis, and conclusions are the original work of the authors. The authors have critically reviewed all AI-assisted output and take full responsibility for the content of the work.

Ethical Statement: This study was conducted in strict adherence to the ethical protocols established by the Research and Development Office of North Eastern Mindanao State University. Ethical approval was granted under the institutional review oversight for social science research (Protocol/Ref: NEMSU-RDO-2025-04). Informed consent was obtained from all participants prior to data collection.

Conflict of Interest Statement: The authors declare that the research was not conducted in the presence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Medieval-Themed Video Games For History Teaching: A Systematic Review

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Abstract: In recent years, medieval-themed video games have emerged as increasingly relevant educational tools, for history teaching, recognised for their ability to foster historical understanding, digital literacy, and critical thinking across a variety of learning environments. This systematic review investigates how these games are incorporated into educational practice and interrogates the narratives they construct about the medieval past. These aims are grounded in prior research on game-based learning and on the cultural analysis of medievalist representations. Guided by the PRISMA protocol, fourteen peer-reviewed studies published in the last ten years were identified, selected, and analysed to provide a structured and critical overview of current research in this area. The findings reveal a strong predominance of commercial titles particularly strategy and role-playing games that reproduce Eurocentric, militarised, and masculinised representations of the Middle Ages. Nevertheless, several studies report innovative pedagogical strategies that embed these digital resources within intentional didactic frameworks, aligning them with curricular objectives and supporting immersive experiences, enquiry-based learning, and the development of disciplinary historical competences. Such practices highlight the capacity of video games to operate as complex cultural artefacts, rather than mere motivational tools. Despite this potential, significant shortcomings remain. These include a lack of sustained critical engagement with symbolic and ideological representations, the scarce incorporation of gender-sensitive or intersectional perspectives, and the limited connection between explicit educational aims and the cultural content of the games. Addressing these gaps requires stronger pedagogical models that connect the analysis of digital representations with the development of historical thinking, digital literacy, and critical reflection. Overall, this study underscores both the opportunities and limitations of medieval-themed video games as didactic resources. It stresses the importance of inclusive, reflexive, and gender-aware approaches that challenge dominant historical imaginaries and contribute to the formation of culturally literate, critical, and democratically engaged citizens.

Keywords: Educational video games, Middle Ages, Historical representations, Systematic review, Digital narrative

1. Introduction

In recent decades, digital culture has profoundly transformed social, educational, and communicative dynamics. In this context, video games have established themselves as one of the most influential cultural products due to their ability to faithfully reproduce realities and generate meaningful cognitive experiences (Raessens, 2006). As part of this transformation, their presence in the educational sphere has intensified, both in formal contexts and in non-formal and informal spaces. Video games are gradually being incorporated into more flexible learning environments, where active participation, exploration, and problem-solving are valued as ways of acquiring knowledge (Marín-Suelves et al., 2022). As their pedagogical potential is recognised, video games have begun to be incorporated for educational purposes focused on the development of cognitive, social and emotional skills (Cobo & Moravec, 2011). The medieval imaginary occupies a prominent place in the symbolic and aesthetic construction of contemporary Western culture and, most notably, in digital culture. Its roots lie in a historical and cultural process that began with Romanticism in the 19th century, when Europe turned its gaze to its national past to find the foundations of its identity. It is also a source of highly idealised aesthetic inspiration (Jiménez, 2009). In this context, cultural expressions such as the Gothic novel and the emergence of Pre-Raphaelite art contributed to the spread of the Arthurian cycle, a dark aesthetic associated with the period, as well as certain ethical values. Although rooted in the most puritanical Victorianism, they would eventually permeate the present day. This period and its creations laid the foundations for a medieval mythology reimagined by the contemporary eye and mind that has been widely disseminated through literature, film, and other cultural media, fitting within the framework of neomedievalism (Carrasco et al., 2024). From ancient books of chivalry to contemporary works such as The Lord of the Rings (J. R. R Tolkien), The Name of the Rose (U. Eco), The Pillars of the Earth (K. Follett) and The Cathedral of the Sea (I. Falconés), the Middle Ages have served as a privileged setting for stories of conflict, romance, spirituality, and heroism (Rodríguez, 2023). The leap of these

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representations to the big screen and especially their appropriation by the entertainment industry, as in the Disney classics, has contributed to the consolidation of this imaginary, present since childhood. This has been prioritised over other historical periods such as classical antiquity or the Renaissance. A pre-eminence that can be explained, in part, by the durability and enormous presence of medieval monuments and buildings throughout much of Europe, the survival of important literary works and the variety of written sources that have survived to the present day. Thanks to the survival of tangible references in the current European landscape, frequent setting elements such as castles, cathedrals, and even the ideal of chivalry are part of a visual and symbolic repertoire that is easily recognisable to the contemporary public. However, this modern appropriation of the Middle Ages and its insertion into mass consumption circuits is not without its problems. The idealisation of the period, often consumed uncritically, has contributed to the perpetuation and glorification of narrative and aesthetic clichés, such as the concept of the "Reconquista" and certain historical processes of colonization (understood as civilizing) that current historiography strives to nuance, revise, or even dismantle (Ríos 2021).

1.1 Video Games as Educational Resources

Beyond their integration into different training contexts, the pedagogical value of video games lies in the dynamics and possibilities they offer for learning. Their structure combines objectives, rules, feedback, and narratives that encourage autonomous exploration, experimentation, and knowledge construction (Prats & Marín, 2021). Due to their characteristics, video games are particularly useful in activities that encourage discovery learning and problem-solving, as they promote decision-making, free exploration and hypothesis building (González-Fernández & Jiménez-Pérez, 2023). Far from being a complementary resource, video games can form part of complex educational proposals aimed at developing key skills, such as digital literacy, critical thinking, and self-regulation in digital environments (Prats & Marín, 2021). In fact, studies in history education confirm that video games can effectively improve those skills and foster specific historical thinking competences such as understanding chronology, primary sources and evaluating causality (McCall, 2023). These benefits are enhanced when their use responds to intentional didactic planning, aligned with specific objectives and mediated by critical pedagogical reflection (Prats Fernández & Marín Suelves, 2022). From this perspective, video games act as an immersive environment that allows players to experience and resolve conflicts within an almost realistic fiction. Their use in the classroom, in addition to facilitating cognitive learning, can activate emotional and relational dimensions with the aim of creating meaningful learning for students (López Gómez et al., 2023). Therefore, their incorporation into education cannot be limited to technical or instrumental use but must be accompanied by a critical view that allows us to understand what narratives, values and cultural references video games mobilise in teaching-learning processes. In addition to considering their pedagogical possibilities, it is also important to consider what types of video games are used in educational contexts and how they are classified. Video games used for educational purposes can be broadly divided into two types: educational video games or serious games and commercial video games. The former are designed with an explicit pedagogical intention and tend to focus on specific content or skills, although they sometimes have limitations in terms of narrative or gaming experience (Pérez-García, 2014; Olivas Ripoll, 2022). Commercial video games, on the other hand, originally designed for entertainment, offer immersive environments, complex dynamics and more elaborate plots that can promote meaningful learning if used with appropriate mediation (Griffiths, 2002; Gros, 2000; Alfageme & Sánchez, 2002). These titles can contribute to the development of skills such as creativity, decision-making, strategic thinking, and digital literacy, as well as allowing for critical analysis of the values, stereotypes, and representations they convey (Linares, 2019; Muros, Aragón & Bustos, 2013; Olivas Ripoll, 2022). Therefore, it is not only important which video game is chosen, but also how it is integrated into the teaching-learning process.

1.2 Video Games as Spaces for the Representation of the Middle Ages

Video games are cultural products capable of representing, reinterpreting, and narrating the past through the specific codes of the digital medium. Through interactive mechanics, immersive environments, and visual narratives, they construct experiences that mediate the understanding of the past, activating emotions, roles, and conflicts in the first person (Chapman, 2016). Much like cinema or graphic novels, they convey the past as a symbolic construction anchored in historical events (Escandell, 2023). In historically themed titles—particularly those set in the Middle Ages—there is a marked tendency to reproduce conventional imaginaries shaped by Eurocentrism, martial epicness, and the masculinisation of action (González-Fernández & Jiménez-Pérez, 2023). Castles, crusades, knights, and clerics form a readily recognisable visual representation which, while referencing real historical elements, is often constructed through simplifications and stereotypes widely disseminated by popular culture. These representations, far from being neutral, contribute to the reproduction of symbolic hierarchies and biased visions of the past, thereby influencing how players interpret and relate to history (Ramos

Soriano & del Pozo Bernaldo de Quirós, 2022). From an educational standpoint, this cultural dimension of video games represents a key didactic opportunity. Analysing how history is constructed within digital environments enables students to develop critical competences, question dominant narratives, and understand history as an interpretative process (López Gómez et al., 2023). In this regard, the video game is not merely a tool for "learning history" but a space in which to learn how to read history in its multiple narrative, visual, and symbolic layers (Uricchio, 2005). These narratives of the Middle Ages, in addition to reproducing epic stereotypes, establish a symbolic framework through which the understanding of the past is configured. As Chapman (2016) points out, historical video games do not offer neutral reconstructions but rather designed narratives that appeal to the player on both emotional and ideological levels. These symbolic constructions, while they may reinforce traditional or Eurocentric views, also open opportunities for critical analysis and historiographical debate in the classroom. Incorporating video games as objects of study enables the training of students capable of identifying stereotypes, dismantling myths, and understanding history as a social and cultural construction in constant reinterpretation (González-Fernández & Jiménez-Pérez, 2023; López Gómez et al., 2023).

In addition, recent scholarship on neomedievalism has emphasised the gendered nature of many contemporary reinterpretations of the Middle Ages, particularly the recurrent marginalisation or idealisation of female figures. For this reason, the present review also examines how women and gender roles are portrayed within the medieval-themed video games included in the selected studies. Incorporating this dimension into the analytical framework connects representational patterns with the development of critical historical skills and supports a more nuanced understanding of how digital narratives shape learners' interpretations of the past (Yeager, 2025).

Although research has examined game-based learning and medievalist representations, few studies explore how medieval-themed video games contribute to historical learning, how they construct narratives about the Middle Ages, or how gendered portrayals appear in these contexts. These gaps justify a systematic review that maps current pedagogical uses and representational patterns.

Based on this, the review addresses the following research questions:

(RQ1) What types of medieval-themed video games are used in educational contexts and at which levels?

(RQ2) What pedagogical approaches and methods guide their educational application?

(RQ3) How is the medieval past represented in the games examined in the included studies?

(RQ4) How are women and gender roles represented in these studies?

(RQ5) How is the medieval setting used pedagogically, and what opportunities and limitations are identified?

In light of these theoretical considerations and the growing interest in the educational use of video games, it is pertinent to systematically examine how this subject is being addressed in scientific research. The objective of this study is to identify, through a systematic literature review, the pedagogical approaches linked to the use of video games with medieval settings. The types of games employed, the educational levels in which they are implemented, and the ways in which the medieval past is represented in these digital environments. The aim is to offer a structured and critical perspective that enhances our understanding of the educational potential of such resources.

2. Methodology

In order to examine the current state of research on medieval video games in education, a systematic literature review was conducted. The process was carried out following the guidelines of the PRISMA protocol (Page et al., 2021), which is recognised for ensuring transparency, thoroughness, and quality in review studies (Moher et al., 2009). The four stages undertaken are detailed below.

Stage 1. Formulation of the research question and creation of the search equation to retrieve results

The guiding question of this study is: How has the use of medieval-themed video games in history education been addressed in the scientific literature? This question adopts an exploratory approach aimed at identifying trends, analytical frameworks, and gaps in the academic production on the subject. Although the PICO model was originally developed for clinical research, its structure can be effectively adapted to educational studies, particularly systematic reviews. In this case, the elements are translated as follows: the population (P) refers to the contexts in which video games are incorporated for educational purposes, particularly within history education (I) refers to the use of titles with medieval settings; the comparison (C) may involve different types of games (commercial, educational, or hybrid) or different educational contexts (formal or non-formal); and the outcome (O) is linked to pedagogical objectives, cultural representations, or learning outcomes. This formulation helps to clearly delimit the object of analysis and to underpin the methodological strategy adopted. Based on the formulation of the research question, a search equation was created to be applied in Stage 2. The equation is as follows: ("medieval" OR "Middle Ages") AND ("video game*" OR "digital game*" OR "educational game*") AND ("education" OR "teaching" OR "learning")

Stage 2. Locating and identifying studies

The literature search was conducted across four academic databases: ERIC, Scopus, Web of Science (WoS), and Dialnet. These four databases were selected because they offer complementary and comprehensive coverage of research in education, digital game studies, and the humanities: ERIC as the primary source for educational scholarship; Scopus and Web of Science for their wide multidisciplinary indexing of peer-reviewed research; and Dialnet to ensure the inclusion of relevant studies produced in Spanish-speaking contexts. To ensure thoroughness and consistency throughout the process, a common search equation was applied in all databases. This equation, constructed using Boolean operators and English-language terms, combines three key components: the historical period (medieval or Middle Ages), the type of resource (video game, digital game, educational game), and the educational context (education, teaching, learning). The results of the search process are summarised in Table 1.

Table 1: Application of the search equation across different databases

Databases used	Search equation applied	Results obtained
ERIC	("medieval" OR "Middle Ages") AND ("video game*" OR "digital game*" OR "educational game*") AND ("education" OR "teaching" OR "learning")	9
Scopus	("medieval" OR "Middle Ages") AND ("video game*" OR "digital game*" OR "educational game*") AND ("education" OR "teaching" OR "learning")	26
WOS	("medieval" OR "Middle Ages") AND ("video game*" OR "digital game*" OR "educational game*") AND ("education" OR "teaching" OR "learning")	21
Dialnet	("medieval" OR "Middle Ages") AND ("video game*" OR "digital game*" OR "educational game*") AND ("education" OR "teaching" OR "learning")	7

A total of 63 potentially relevant publications were identified. All records were exported and incorporated into the Rayyan QCRI platform for collaborative management and screening. Duplicates were detected and matches eliminated. The result was 54 documents.

Stage 3. Selection and eligibility of studies

To ensure the relevance and quality of the selected studies, clear inclusion and exclusion criteria were applied, as detailed in the table (Table 2) below:

Table 2: Inclusion and exclusion criteria applied

Inclusion criteria	**Exclusion criteria**
Studies analysing video games with an explicit medieval theme	Studies on video games unrelated to the medieval period
Articles addressing the use of video games in educational contexts (formal or informal)	Studies focused solely on entertainment, with no explicit pedagogical aims
Studies published within the last 10 years (2014–2024)	Publications prior to 2014
Empirical, theoretical, or review studies focused on digital video games	Research focused exclusively on board games or analogue games

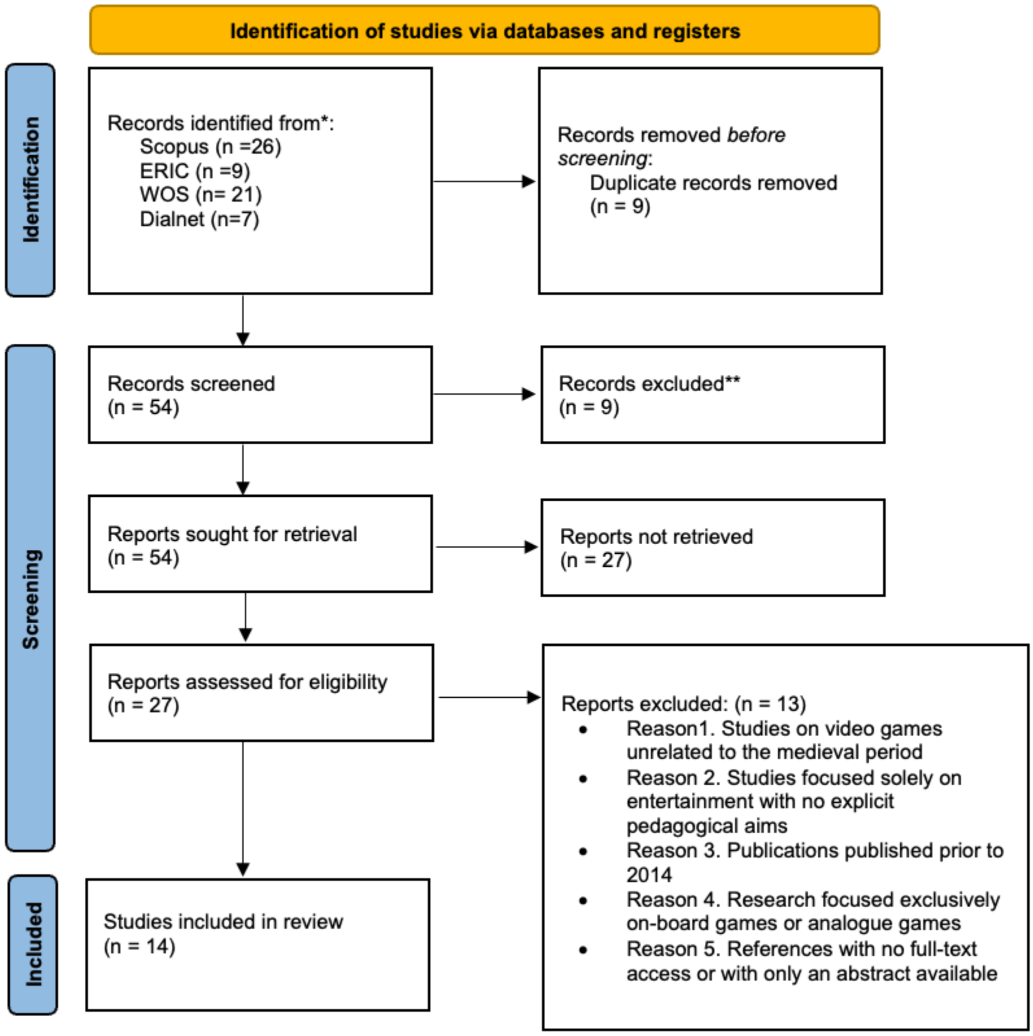
Inclusion criteria	Exclusion criteria
Full-text availability	References with no full-text access or only an abstract available

Stage 4. Data extraction and analysis

During the review process, 63 records were identified through searches in the selected databases. After removing duplicates, 54 documents remained and were subjected to an initial screening using the previously defined inclusion and exclusion criteria (see Table 2). Based on the reading of titles and abstracts, 27 studies were excluded for not meeting the thematic or methodological requirements. The remaining 27 articles were assessed in full-text format. Of these, 13 were excluded due to lack of full-text accessibility, absence of educational analysis, or insufficient connection to the medieval theme. Ultimately, 14 studies were included in the final systematic review. These are detailed in Table 3, and the full process is illustrated in Figure 1, which presents the PRISMA flow diagram.

Table 3: Studies included in the review

Study	Reference
Study 1	Negro Cortés et al. (2017)
Study 2	Bokolas & Panagouli (2019)
Study 3	Sukhov (2021)
Study 4	Houghton (2023)
Study 5	Gabellone et al. (2017)
Study 6	Insulander et al. (2016)
Study 7	Gutiérrez Castillo & Molina García (2022)
Study 8	Pramono et al. (2021)
Study 9	Hiriart (2019)
Study 10	Campillo (2022)
Study 11	Mugueta et al. (2015)
Study 12	Pérez Lajarín & Rodríguez (2018)
Study 13	Alsina Riera (2021)
Study 14	Escandell Montiel (2017)



Note. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. Declaración PRISMA 2020: una guía actualizada para la publicación de revisiones sistemáticas. Rev Esp Cardiol [Internet]. 2021 Sep;74(9):790–9. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0300893221002748

Figure 1: PRISMA diagram

To extract key information from the selected articles, a detailed protocol was employed to systematise and organise the data into specific categories. This protocol included the categories and elements outlined in Table 4:

Table 4: Data extraction protocol

Category	**Elements**
Basic identification	• Article title • Year of publication • Authors • Country of study

Category	Elements
Methodological aspects	• Type of study • Study objectives • Type of video game • Educational context of application • Methodology used • Instruments and techniques
Thematic aspects	• Types of representations: realistic / fictionalised / stereotypical / fantastical • Medieval elements: chivalry, religion, architecture, social roles, etc. • Thematic focus: violence? battles? treasure hunting? etc. • Female representation and participation • Level of historical accuracy: high / medium / low (as stated by the author or by own assessment)
Key findings	• Pedagogical use of the medieval setting: is it used as historical content or merely as background? • Pedagogical critique • Key findings

Rayyan QCRI was used for the initial analysis, enabling the detection of duplicates, the review of titles and abstracts, and the selection of articles for full-text reading. Data extraction followed the previously established protocol. A database was created containing the defined variables. Quantitative analysis was conducted using Jamovi, while qualitative analysis was carried out with ATLAS.TI. Beyond describing frequencies, the analysis followed a mixed descriptive and interpretative approach. Quantitative data were used to map trends in game types, educational levels, and implementation formats, whereas the qualitative coding schemes were informed by scholarship in history didactics and neomedievalism.

3. Results

The review comprised 14 studies published between 2015 and 2023. A higher concentration was observed in 2017 and 2021, with three articles published in each of those years. The years 2019 and 2022 each contributed two studies, while 2015, 2016, 2018, and 2023 recorded only one study each. These data indicate a steady interest in medieval-themed video games in education, although the intensity has varied across the years, as shown in Figure 2.

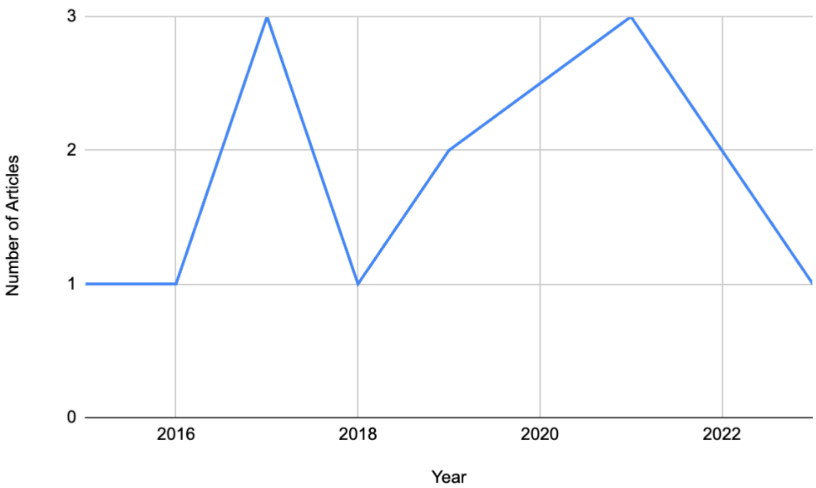


Figure 2: Distribution of studies by year of publication

The studies, represented in Figure 3, originate from various countries, with a stronger concentration in Europe. Spain accounts for the highest number of publications (n = 6), followed by the United Kingdom (n = 2). In addition, individual contributions were identified from Greece (n = 1), Russia (n = 1), Italy (n = 1), and Sweden (n = 1). There were also international collaborations between Spain and Argentina (n = 1) and between Germany and Indonesia (n = 1), reflecting a growing and cross-regional interest in the educational use of medieval-themed video games.

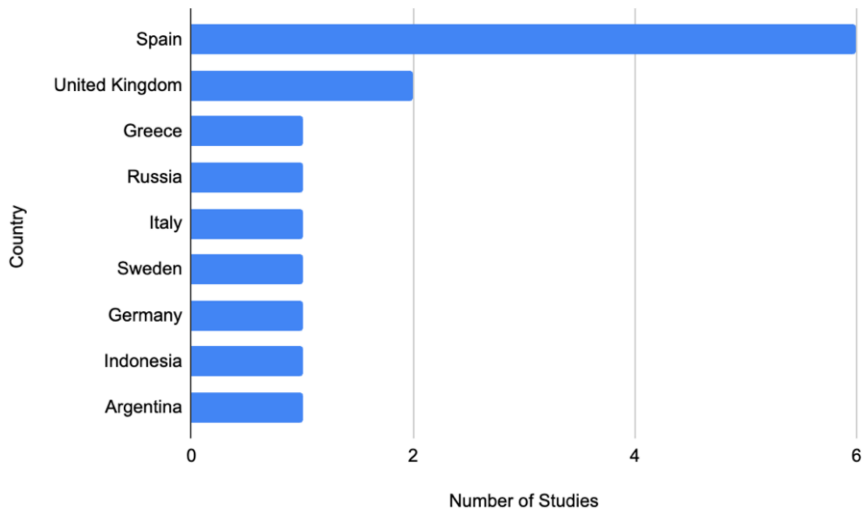


Figure 3: Countries of origin of the included studies

Three main methodological approaches were identified: theoretical and critical (n = 7), empirical (n = 4), and applied or linked to action research (n = 3). The first group addresses conceptual, pedagogical, or cultural issues related to the use of medieval-themed video games. Empirical studies include surveys, comparisons of learning experiences, or usability analyses, whereas applied studies focus on the design, validation, or implementation of educational proposals. As summarised in Table 5, the aims of these studies vary considerably. Some focus on the evaluation of specific games in real educational contexts (n = 2), while others explore their use in school programmes without focusing on a particular game (n = 3). Notably, several studies offer a critical analysis of historical representations in video games (n = 5), revealing how narratives of the Middle Ages are constructed. A smaller number of studies are dedicated to the development of digital educational resources (n = 2), the analysis of specific classroom cases (n = 1), or pedagogical reflection from a theoretical standpoint (n = 1).

Table 5: Research aims of the included studies

Objective category	Description	*f*	Studies
Evaluation of specific video games	Analyses the educational impact of specific titles in real teaching contexts.	2	Negro-Cortés et al. (2017); Mugueta et al. (2017)
Exploration of use or design in school settings	Investigates how medieval video games are integrated into programmes or educational practices without focusing on a single title.	3	Bokolas & Panagouli (2019); Sukhov (2021); Hiriart (2019)
Critical analysis of historical representations	Examines how video games construct narratives about the Middle Ages and their educational implications.	5	Houghton (2023); Campillo (2022); Pérez & Rodríguez (2018); Alsina (2021); Escandell (2017)
Development and validation of digital resources	Presents the creation and implementation of educational games or tools.	2	Gabellone et al. (2017); Pramono et al. (2021)
Case study analysis in the classroom	Focuses on specific educational settings to examine the use of video games for learning.	1	Insulander et al. (2016)
Theoretical review or pedagogical reflection	Offers a general methodological perspective on the educational use of video games.	1	Gutiérrez & Molina (2022)

3.1 Educational Level of Application

The reviewed studies are primarily situated in higher education (n = 6), where video games are integrated into degree programmes related to History, Heritage, Visual Culture, and Digital Media. This concentration at the university level reflects a trend towards their use as tools for critical analysis, cultural exploration, and didactic support in advanced academic contexts. Secondary education also features prominently (n = 5), particularly in subjects such as History, with approaches focused on historical representation and narrative. In the case of primary education (n = 3), although studies are fewer, they offer relevant experiences that integrate video games into school projects with clear pedagogical intent. Non-formal education contexts were also identified (n = 3), such as cultural dissemination activities or heritage-related initiatives, as well as informal self-learning environments (n = 2), reinforcing the potential of video games as educational tools beyond institutional settings. Museums (n = 2) stand out as mediating spaces, where educational video games are used to communicate historical content to younger audiences. In contrast, teacher training is addressed in only one study (n = 1), revealing an area of development that is still in its early stages. Titles such as Age of Empires II and Assassin's Creed appear across several formal levels, whereas others like Hanse 1380 or the Yrsum Game are linked to non-formal or museum settings. This distribution suggests a significant relationship between the type of video game and the educational context in which it is applied. As both variables are categorical, a chi-square test was conducted to assess their association. The analysis ($\chi^2 = 7.70$; $p = 0.0212$) reveals that commercial games are used predominantly in formal educational contexts, while educational and hybrid games tend to be employed in non-formal settings.

3.2 Types of Video Games Used and Characteristics

The analysis reveals a wide range of video games used for educational purposes related to the medieval period, including both commercial titles and those specifically designed for educational contexts. As detailed in Table 6, the games have been individually classified according to their type, pedagogical purpose, and mode of use. Most identified games are commercial (n = 5), such as Crusader Kings II, Age of Empires II, Medieval: Total War, Assassin's Creed, and Kingdom Come: Deliverance. Although not originally designed for educational purposes, they have been incorporated into formal educational contexts due to their historical accuracy, strategic depth, or narrative value. These titles enable the exploration of content such as political and social organisation, warfare dynamics, feudalism, and the Crusades through a critical lens. Three games were developed with explicit educational intent (n = 3), including Hanse 1380, El Camino del Cid, and the Yrsum Game. Designed for teaching or heritage dissemination purposes, these games are used in schools, museums, or as part of extracurricular activities, addressing medieval history from analytical, comparative, or experiential perspectives. The hybrid category (n = 3) includes titles such as Maldita Castilla, Tzar: El Cid and the Reconquista, and Civilization, which, although not originally pedagogical, have been adapted for cultural, narrative, or historical analysis. Finally, one case of a modified game (n = 1), Total War: Medieval II, stands out. It was adapted in collaboration with historians to enhance its historical accuracy, highlighting processes of co-creation between designers, educators, and subject-matter experts.

Table 6: Types of video games and description of use

Video game	Type of game	Description
Crusader Kings II	Commercial	Grand strategy game set in the Middle Ages. Used in higher education to explore complex historical processes through political dynamics and dynastic succession.
Age of Empires II: Definitive Edition	Commercial	Real-time strategy. Employed to illustrate feudalism, the Crusades, and medieval military structures through tactical simulations.
Assassin's Creed	Commercial	Open-world action-adventure game. Its historical narrative and medieval urban settings are used to foster critical analysis of history and heritage in secondary and higher education.
Medieval: Total War	Commercial	Turn-based and real-time tactical strategy game. Used for its strategic portrayal of medieval warfare and depiction of political and religious structures of the time.

Video game	Type of game	Description
Maldita Castilla	Hybrid	Platformer inspired by Castilian medieval mythology. Its educational use lies in the cultural and symbolic analysis of legends and medieval Spanish iconography.
Kingdom Come: Deliverance	Commercial	Historical role-playing game with high fidelity to 15th-century daily life and social structures. Used in higher education to study material culture and historical simulation.
El Camino del Cid	Educational	Mobile serious game designed to promote knowledge of the Cid's heritage and history through quizzes, geolocation, and educational scavenger hunts.
Yrsum Game	Educational	Non-commercial educational game focused on Anglo-Saxon life. Designed to teach medieval social and daily structures through an analytical and immersive approach. (Prototype documented by Gabellone et al., 2016).
Hanse 1380	Educational	Developed for heritage spaces, this game simulates Hanseatic League maritime trade in the 14th century with didactic and cultural dissemination purposes.
Tzar: El Cid and the Reconquista	Hybrid	Strategy game based on territorial conflicts among Iberian kingdoms. Used in classrooms to address military history and key historical figures of medieval Spain.
Civilization	Hybrid	Although generalist in scope, it is used in education for its simulation of civilisational evolution, including the medieval period, with emphasis on diplomacy, religion, and territorial expansion.
Total War: Medieval II (modded)	Modified commercial	Strategy game adapted with historians' input to enhance historical accuracy. Used to teach medieval military history, architecture, and political systems.

3.3 Pedagogical Approaches, Methodologies, and Techniques in the Educational Use of Video Games

The data reveal a wide range of pedagogical approaches in the use of video games for history education. Among them, game-based learning (n = 6) and gamification (n = 4) stand out, employed both to structure didactic proposals and to enhance student motivation. References to the edutainment approach (n = 3) were also identified, in which the video game serves as an entertaining resource with formative potential. Several studies apply theoretical frameworks derived from ludology and narratology (n = 4), particularly in analysing the ludic and narrative structure of games. A significant number of studies promote critical or historical thinking (n = 5), focusing on how video games construct discourses about the past. Experiences related to heritage education (n = 3) and experiential learning (n = 3) also appear, particularly in museum contexts and digital reconstructions. Some approaches adopt a constructivist and critical perspective (n = 2), especially in the use of digital media to encourage historical reflection. From a methodological perspective, qualitative approaches (n = 6) and case studies (n = 4) are predominant, followed by design-based research (n = 3) and action research (n = 2), particularly in school contexts. These approaches allow for situated exploration of how students interact with video games and how these influence their learning processes. Regarding techniques and instruments, structured questionnaires (n = 5) are common, used to assess prior knowledge, perceptions, or acquired learning. Interviews and focus groups (n = 3), usability testing with prototypes (n = 3), and direct classroom observation (n = 4), including the analysis of student-generated materials, were also employed. In addition, many studies apply textual, visual, or narrative analysis techniques (n = 5), focusing on game structure and historical representations. Several works also rely on literature reviews or theoretical analysis of educational experiences (n = 3).

3.4 Typologies of Historical and Aesthetic Representation in the Video Games Analysed

The video games examined in the reviewed studies display a wide range of aesthetic styles and approaches to representing the Middle Ages, ranging from rigorous reconstructions to symbolic or fantastical settings. From the analysis of the texts, four major typologies were identified:

- Realistic aesthetics (n = 5): These representations are grounded in archaeological, documentary, or scholarly sources to recreate detailed aspects of the period such as spaces, architecture, clothing, material culture, and social hierarchies. This approach is found in games like Kingdom Come: Deliverance, Hanse 1380, or educational prototypes developed in collaboration with museums.
- Fictionalised aesthetics with historical basis (n = 4): These combine plausible medieval elements with narrative or commercial liberties. While recognisable historical settings are reconstructed, they are often simplified or modified for entertainment or accessibility. Games such as Age of Empires II, Assassin's Creed, and Crusader Kings II belong to this category.
- Stereotypical, epic, or parodic aesthetics (n = 3): These representations rely on popular clichés of the medieval imaginary castles, knights, crusades with strong symbolic emphasis. Such images, inherited from popular culture, are used without critical intent or historical fidelity, as seen in Maldita Castilla, Tzar: El Cid and the Reconquista, and El Camino del Cid.
- Symbolic or fantastical aesthetics (n = 1): These incorporate superficial medieval references without aiming for historical reconstruction. A notable example is Fortnite, which, although not a historical game, occasionally features medieval-themed skins, game modes, or settings such as swords, castles, or knights. Some studies use these elements critically or didactically, even though the game does not follow a historical logic. While medieval-themed video games frequently contain simplifications or biased portrayals of the past, their educational validity does not rely on their accuracy but on the pedagogical framing through which they are used. When integrated into guided activities, these distortions can become productive tools for developing critical historical thinking, prompting learners to question representations, contrast sources, and analyse how historical narratives are constructed in digital media.

3.5 Historical Elements Represented in the Video Games Analysed

Beyond narrative or gameplay, the titles studied stand out for integrating historical elements that allow for a visual and conceptual exploration of the Middle Ages from different perspectives. As summarized in Figure 4, the most frequent representations correspond to medieval architecture (n=7), with references to Romanesque and Gothic styles, defensive structures, religious structures, and domestic spaces. Religion (n=6) and social roles or estates (n=6) are also constant, with particular attention paid to Christianity, feudal stratification, and the organization of social life. War conflicts (n=5), focusing on local wars, crusades, and historical military campaigns, occupy a prominent place, as do certain aspects of daily life (n=4), such as food, hygiene, and rural work. Other elements that appear to a lesser extent include medieval trade and economics (n=4), specific historical figures (n=3), and political organization (n=2), especially in simulations and strategy games. This distribution suggests a predominance of traditional approaches, centred on the masculine, military, and religious structures of the past, leaving other themes such as culture, art, women, and non-institutionalized forms of education in the background.

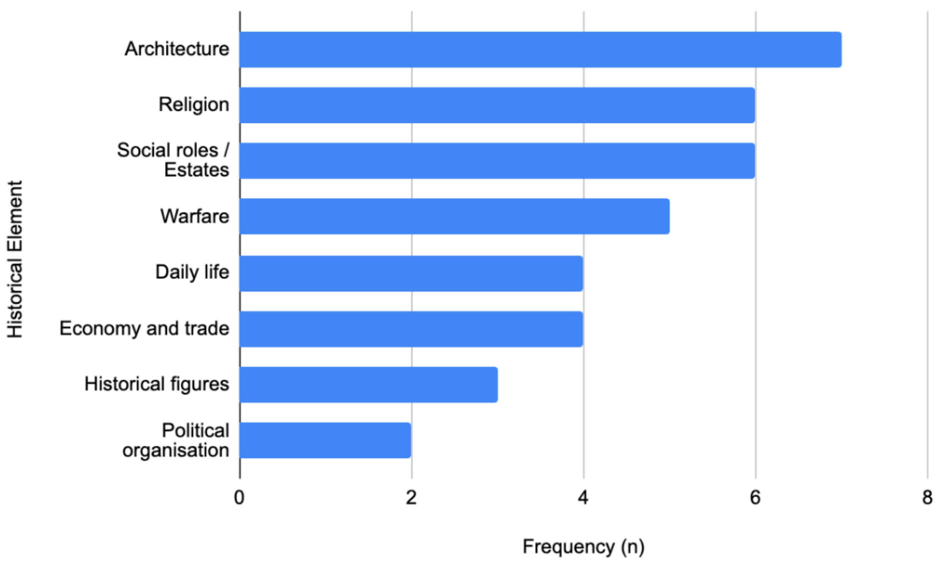


Figure 4: Representation of historical content in the educational video games analysed

3.6 Dominant Themes in the Video Games Analysed

Beyond gameplay mechanics, the review reveals a clear thematic trend towards strategic and military domains. Titles such as Age of Empires II and Crusader Kings II place battle, territorial conquest, and military expansion at the heart of both narrative and gameplay (n = 5). In these cases, violence is not presented as glorification, but as a means of understanding historical dynamics of power, defence, and territorial organisation typical of the medieval period. Another significant theme is the construction and management of medieval spaces (n = 3), where players design fortifications, manage resources, and develop towns. This facilitates the structural analysis of medieval space and supports content related to architecture and engineering. Some games adopt an archaeological or museographic orientation (n = 2), focusing on the precise reconstruction of historical environments based on documented sources. Less common are games centred on everyday medieval life (n= 2), exploring agriculture, trade, professions, or family organisation. References to transport and navigation technologies (n = 1), particularly in 14th-century maritime contexts, also appear. The accumulation of treasures and resources (n = 2) functions as a reward mechanic in some titles, reflecting conventional commercial game logic that does not always align with critical educational aims. Lastly, while violence features as a gameplay mechanic in several games (n = 3), some studies highlight its pedagogical potential, encouraging reflection on historical causes rather than reproducing spectacle.

3.7 Female Representation and Participation in the Video Games

The review reveals a limited and often superficial presence of female characters in the medieval-themed video games analysed. In most cases, gender issues are not directly addressed (n = 5), nor is attention given to the representation of women within the narrative or gameplay dynamics. This omission contributes to an incomplete vision of the Middle Ages, ignoring the historical roles of women across social, religious, and political contexts. Only one study explicitly references a female historical figure—Joan of Arc—though without a gender-sensitive analysis. Another study mentions female characters in family contexts but lacks a critical exploration of their roles or symbolic representation. Some articles warn of gender stereotypes in commercial games, where women appear hypersexualised, wearing revealing clothing, with normative bodies, and confined to secondary or decorative functions. These portrayals reinforce traditional dynamics of invisibilisation or objectification, even in contexts where a more equitable historical reconstruction would be possible.

3.8 Pedagogical Uses of the Medieval Period in Educational Video Games

The reviewed studies show a predominant tendency to use the medieval period as central historical content within educational proposals (n = 6). In such cases, the Middle Ages are explicitly addressed as a thematic axis to work on topics like feudalism, the Crusades, daily life, or territorial expansion through simulations, storytelling, or digital reconstructions. Some studies (n = 3) take an applied or contextual approach, linking the medieval theme to broader topics such as heritage history, social structures, or visual culture. In fewer cases, the historical content is combined with playful or aesthetic elements (n = 2) or used solely for narrative or atmospheric purposes without deep educational intent (n = 4).

From a critical perspective, several studies stress the need for didactic planning and teacher mediation (n = 3), highlighting that the use of video games alone does not guarantee meaningful learning. There is also concern about the risk of superficial or uncritical interpretations (n = 3), especially when realistic aesthetics create an illusion of historical objectivity. Some works mention the lack of appropriate assessment strategies for multimodal environments (n = 2) and the reproduction of Eurocentric or heroic narratives (n = 2). Nevertheless, several studies emphasise the educational potential of video games for historical analysis, critical thinking, and cultural appropriation of the past (n = 4), provided they are embedded in structured, reflective pedagogical frameworks.

4. Discussion and Conclusions

The findings of this systematic review suggest that, although the educational use of medieval-themed video games has gained increasing interest, its implementation in formal learning contexts remains sporadic and fragmented. The reviewed studies reflect a diversity of approaches and educational levels yet reveal a lack of methodological systematisation and explicit curricular integration. This limitation restricts the potential of video games as learning spaces beyond their motivational or entertainment value (Prats & Marín, 2021; Marín-Suelves et al., 2022). In terms of representation, the selected games tend to reproduce a Eurocentric, male-dominated, and violence-centred vision of the Middle Ages. While this phenomenon has been noted in prior studies as a structural feature of the digital entertainment industry (Chapman, 2016; Escandell, 2023), few educational initiatives critically engage with these narratives. Most of the reviewed experiences accept such discourses as aesthetic background, without fostering reflection on their symbolic or political dimensions. These patterns align with established critiques in neomedievalism and historical game studies, which consistently highlight the dominance of Eurocentric and masculinised narratives (Chapman, 2016; Escandell, 2023). Another significant issue is the scarce inclusion of gender perspectives. Games used in educational contexts often maintain traditional patterns that overlook women or assign them secondary roles, and the studies rarely question this or propose alternative classroom readings. This absence limits the potential of video games to promote democratic values—though it may also represent an opportunity to do so through critical engagement. This scarcity mirrors findings in feminist analyses of neomedievalism, which identify a persistent marginalisation or idealisation of women in contemporary medievalist media.

Moreover, although video games are recognised for sparking interest in history and enabling experiential learning, only a few studies embed them within structured didactic sequences aimed at developing historical thinking. Dimensions such as multiperspectivity, source analysis, and historiographical debate are rarely addressed, reinforcing a superficial use of digital media. This echoes concerns raised in History Didactics, where the integration of digital media frequently remains disconnected from the explicit development of historical thinking skills (López Gómez et al., 2023; González-Fernández & Jiménez-Pérez, 2023)

This limitation highlights the need to develop robust pedagogical models, grounded in learning theory and aligned with specific competences, as advocated by Prats & Marín (2021) and López Gómez et al. (2023). The framework proposed responds directly to these gaps. Rather than reproducing categories already present in the literature, it emerges from an interpretative synthesis of the recurring limitations identified across the studies—namely the lack of curricular structuring, the absence of critical engagement with representations, and the insufficient incorporation of gender-aware perspectives. Figure 5 synthesises this proposal through a visual framework that articulates eight key dimensions for the critical educational application of medieval-themed video games. Each segment of the diagram includes two levels: a key element for the critical selection of the game, and a practical recommendation for its didactic integration.

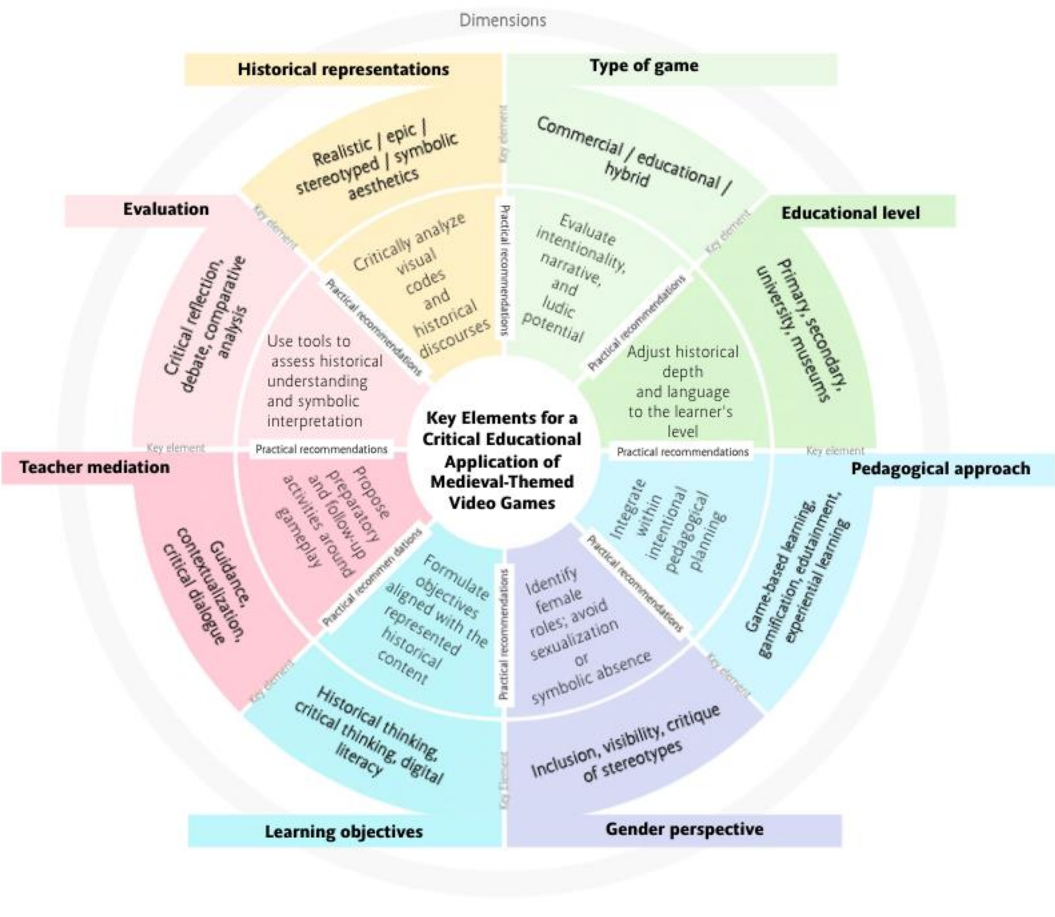


Figure 5: Key elements for the critical educational application of medieval-themed video games

This review offers a panoramic overview of the current state of research on the use of medieval-themed video games in education, enabling the identification of key trends, gaps, and areas for further development. Across the studies, there is a clear need to design pedagogical proposals that move beyond the superficial or merely motivational use of these resources. This requires a critical reading of the historical narratives conveyed by video games. Equally important is the incorporation of inclusive and gender-sensitive perspectives, which can help to challenge dominant discourses about the past and open spaces for new forms of historical representation and reflection. Advancing in these directions would support the consolidation of video games as a truly educational tool, aimed at fostering a critical and culturally aware citizenship.

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Ethics Statement: This research is a systematic literature review and did not involve human participants, animals, or the collection of sensitive data. Therefore, ethics approval was not required.

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Improving Critical Thinking Skills through a Flipped Project-Based Learning Model Integrated with Mockup Media and Augmented Reality

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Abstract: The rapid advancement of the Industrial Revolution 4.0 demands that vocational high school graduates possess not only technical expertise but also higher-order thinking skills, particularly critical thinking. However, many learning practices in vocational education remain limited to procedural instruction with minimal emphasis on cognitive development. This study aimed to evaluate the effectiveness of the Flipped Project-Based Learning (FPjBL) model integrated with mockup and Augmented Reality (AR) media in enhancing vocational students' critical thinking skills compared to conventional learning approaches. This study uses a quantitative approach with a quasi-experimental design, namely pretest-posttest control group design. The research sample was grade X and XI students from six state vocational high schools in the Solo Raya area, consisting of 216 students divided into experimental and control groups. The experimental group used the FPjBL model with mockup and AR media, while the control group used conventional learning. Data were collected through critical thinking ability tests and learning motivation questionnaires. Data analysis used ANCOVA and multiple linear regression. The results showed that the experimental group experienced a significant increase in critical thinking skills compared to the control group ($F(1,213) = 104.192$, $p < .001$, partial $\eta^2 = .329$). The analysis and explanation indicators showed the greatest increase. Linear regression shows that learning motivation, media perception, and student activity significantly affect critical thinking skills ($R^2 = .613$). These results confirm that integrating Integration Media Mockup and Augmented Reality with FPjBL effectively strengthens students' critical thinking and can be adopted in vocational education curricula to better prepare learners for the complex challenges of Industry 4.0.

Keywords: Critical thinking, Flipped project-based learning, Mockup media, Augmented reality, Vocational High School, Industrial revolution 4.0

1. Introduction

The use of Industry 4.0 technologies in factories and manufacturing sectors has generated a demand for new competencies among employees. Learning Factories 4.0 at vocational schools can enhance technical competences pertinent to specific disciplines, yet may not substantially augment multidisciplinary skills that are genuinely applicable in the industry (Roll and Ifenthaler, 2021). With the advancement of the period, platforms for digital learning processes, such as e-learning, are deemed capable of enhancing the 21st-century skills of students in vocational schools (Budiarto et al., 2024). Furthermore, the primary technical competencies for Industry 4.0 encompass data analysis, process optimization, and device maintenance, which are deemed to be attained through the effective implementation of e-learning (Ismail and Hassan, 2019).

The urgency of mastering 21st-century skills for Vocational High School (SMK) students is more significant within the current global educational context, particularly in light of the challenges and opportunities presented by the Fourth Industrial Revolution. UNESCO and several field studies indicate that these skills encompass creativity, critical thinking, collaboration, and communication, which are essential for preparing students to navigate the dynamics of change in the workforce. According to Gündüz (2023), these skills are closely related to lifelong learning and help students develop critical and collaborative thinking skills during their learning process. A study emphasized that in this highly competitive era, vocational education should focus on scientific literacy as a transferable outcome, which enables students to use scientific knowledge meaningfully and solve problems relevant to their lives (Jaedun et al., 2022)

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Subsequent study indicates that secondary school-aged children can attain elevated levels of 21st-century skills, suggesting that education at this stage requires further optimization to enhance the cultivation of these skills (Kocaman, 2022). Consequently, vocational education must be executed proficiently using new pedagogical approaches, including project-based learning and STEAM integration, to provide students with the requisite skills for competitiveness in the labor market (Zayyinah et al., 2022). Moreover, studies indicate that acquiring communication skills via English literacy activities enhances students' active participation and expression of ideas, exemplifying the implementation of 4C skills (creativity, critical thinking, collaboration, communication) within the educational framework (Ratama, Padmadewi and Artini, 2021; Jaedun et al., 2022). Furthermore, understanding digital skills is crucial, as research indicates that the amalgamation of STEM and digital literacy enhances students' competencies in 21st-century skills (Rizaldi, Nurhayati and Fatimah, 2020; Sá et al., 2021). Consequently, it is imperative for all stakeholders in education to dedicate themselves to developing pertinent curricula and pedagogical approaches, enabling students to realize their utmost potential in confronting future difficulties.

Despite the growing recognition of these needs, many vocational learning practices remain focused on procedural knowledge and fragmented skill acquisition, with limited emphasis on higher-order thinking such as critical and analytical reasoning. This gap underscores the need for innovative pedagogical designs that integrate contextual learning, active inquiry, and technological engagement. Accordingly, this study does not focus solely on the technological impact of Augmented Reality (AR), but rather on how its integration within the Flipped Project-Based Learning (FPjBL) model can foster students' critical thinking skills in vocational education settings.

Deep learning and critical thinking are becoming progressively significant in vocational education within the construction sector. Deep learning can be improved via educator training and the provision of innovative teaching resources, while critical thinking is vital for future career contexts (Romero-Tena, Lopez-Lozano and Gutierrez, 2020;Ratama, Padmadewi and Artini, 2021). Deep learning applications in construction encompass automatic progress monitoring, safety notifications, and equipment management (Park et al., 2020; Sollied Madsen, Thorvaldsen and Sollied, 2021). E-learning systems can improve 21st-century competencies, including critical thinking, among vocational students (Budiarto et al., 2024). Despite the introduction of numerous advances in vocational education, practical learning in civil engineering courses, particularly regarding concrete buildings, continues to encounter some substantial hurdles. Current curricula frequently fail to effectively connect theoretical concepts with practical application in the field. This affects the inadequate mastery of advanced cognitive abilities, including critical and analytical thinking, which are essential for contemporary and future civil engineering endeavors (Romero-Díaz de la Guardia et al., 2024).

Although deep learning technology in construction has been employed to automate progress monitoring, safety alerts, and equipment management (Elghaish et al., 2021; Mansoor et al., 2022), its utilization in vocational school learning remains constrained. Conversely, e-learning platforms have demonstrated potential in enhancing 21st-century abilities, including critical thinking (Budiarto et al., 2024), nonetheless, issues such as restricted datasets and the lack of technology interpretability persist as substantial obstacles (You et al., 2023). A study by Peng and Fang (2024) shown no significant link between deep learning and enhanced critical thinking skills, highlighting the necessity for a more contextual and experiential learning strategy. Consequently, creative pedagogical approaches are required that not only enhance the acquisition of technical skills in concrete reinforcing structures but also promote the cultivation of critical thinking abilities through authentic and significant learning experiences.

Vocational education, particularly at the Vocational High School (SMK) level, plays a pivotal role in cultivating exceptional and competitive human resources in the context of the Industrial Revolution 4.0. SMK graduates must not only excel in technical competencies within their respective fields but also possess critical thinking, collaboration, creativity, and communication skills, which are essential 21st-century skills necessary in a dynamic, technology-driven work environment (Budiarto et al., 2024; Gündüz, 2023). In civil engineering vocations, proficiency in concrete structural reinforcement necessitates not only procedural expertise but also analytical capabilities for contextual problem-solving in construction. Consequently, a novel pedagogical strategy is required that can concurrently integrate technical skills and advanced cognitive processes.

Implementing the mockup media into the Flipped Project Based Learning model seeks to fill a novel gap in research pertaining to critical thinking skills of SMK students and vocational education pedagogy. The purpose of this study is to determine the effectiveness of the Flipped Project Based Learning paradigm using mockup media with regards to students' critical thinking skills on the topic of concrete structures taught in grade 11. This study tries to measure the perceptions of learners and motivation quantifiably in order to evaluate catalytic impacts on the learners' critical thinking skills. Although Industry 4.0 has driven the need for 21st-century competencies, many vocational programs particularly in civil engineering, still fail to link theory with authentic practice, resulting in weak critical thinking and problem-solving skills. Previous studies show that deep learning and e-learning approaches alone are insufficient to foster higher-order thinking. Therefore, this study addresses that gap by implementing a Flipped Project-Based Learning model integrated with mockup and augmented reality media to enhance students' critical thinking in vocational education. Based on these objectives, the formulated study question is: (1) How Flipped Project Based Learning model with mockup media differs from conventional learning in terms of critical thinking skills? How do the learners' perceptions of motivation impact the critical thinking abilities after this approach?

2. Literature Review

2.1 Critical Thinking and Deep Learning in Vocational Education

Critical thinking and deep learning are essential components of vocational education, particularly as the employment landscape demands high levels of adaptability and competence. The educational paradigm shift for Industry 4.0 highlights the crucial role of critical thinking, encompassing the ability to analyze, evaluate, and synthesize information in practical scenarios. Hamdani et al. emphasize that addressing contemporary challenges requires a shift from specific skills to broader competencies that foster critical thinking, enabling students to navigate labor market transitions (Hamdani and Suherman, 2021). Critical thinking serves as the foundation for deep learning, emphasizing in-depth understanding over memorization. Sudirta et al. state that enhancing student autonomy and creativity is crucial in vocational environments (Sudirta et al., 2022).

The integration of information and communication technology (ICT) plays a crucial role in developing critical thinking capacity and deep learning. Kang and Zhang (2022) note that combining vocational education with modern pedagogical techniques can foster students' critical thinking skills while preparing them for real-world applications. The application of innovative teaching methodologies has been shown to create more immersive learning experiences (Hu and Xue-yu, 2022). The link between critical thinking and deep learning is evident in the need to solve complex problems as a crucial skill for the 21st century according to Mutohhari et al. (2021)who emphasize that contemporary job demands require a combination of critical thinking and creative problem-solving. The ability to combine theoretical understanding with practical application ensures vocational students are active participants in their learning, illustrating the cyclical relationship between critical thinking and deep learning.

Deep learning is characterized by achieving eight student engagement with the content and requires learners to make connections between concepts and applications. Surface learning, on the other hand, usually entails a more simplistic approach wherein students focus primarily on memorization of content, engage with the material at the lowest level, and as a result, develop inadequate understanding and skills relevant to their field of work (Mishra, Reddy and Pathak, 2021). Deep learning in education emphasizes meaningful knowledge construction, integration of concepts, and the ability to apply understanding in novel contexts (Prianto, Qomariyah and Firman, 2022; Entwistle, 2023). In vocational education, this process encourages learners to move beyond procedural execution toward reflective and analytical reasoning.

Studies show that learners utilizing deep learning techniques in a vocational education setting outperform their peers academically and in terms of skills gained. There is also evidence that deep learning techniques positively impact student outcomes, indicating that incentives geared towards deep learning are critical for vocational achievement (Janiesch, Zschech and Heinrich, 2021; Lee et al., 2022). In addition, the emphasis placed on project-based learning (PjBL) as an educational approach in vocational institutions supports this evidence because it encourages active inquiry and places emphasis on the application of higher order thinking skills (Zhao, Wu and Li, 2023). This perspective suggests effective designed and delivered immersive learning experiences can bridge the gap between theory and practical application skills. The shift emphasizes how important cultivating knowledge is together with acquiring practical skills that are necessary for securing a job in today's competitive world (Smith and Seal, 2021).

In conclusion, the dichotomy between deep and surface learning holds significant implications for vocational education. These approaches not only enhance student engagement and competencies but also align vocational training with the evolving demands of the labor market (Bouw, Zitter and de Bruijn, 2021). Thus, fostering a culture of deep learning can lead to more effective educational outcomes and better prepare students for future challenges in their respective fields.

2.2 Flipped Classroom and PjBL in The Context of Vocational Schools

Implementation of the Flipped Classroom and Project-Based Learning (PjBL) models in vocational high schools (SMK) enhances students' practical skills within a responsive framework because of the deep content engagement and real-world application required of them. In the Flipped Classroom model, lectures are replaced with student-centered activities having the students access instructional materials online, which frees up class time for projects and cooperative work (Triyanto et al., 2024;Kausar, Maryono and Aristyagama, 2021). This model is useful in vocational education, where skill execution must be learned and practiced. Consequently, class time is spent on discourse, problem solving, and project work which are more suited to vocational education within its aims to develop relevant competencies not just through learning, but through thoughtful execution.

In addition, the combination of Flipped Classroom and PjBL in vocational high schools (SMK) effectively creates a lively class atmosphere that integrates theory with practice. This model enables active learning alongside peer interaction which is fundamental in vocational education and training. As Usmeldi and Amini (2022) note, this synergistic application of these models serves to increase student motivation and learning outcomes, enhancing their academic and vocational pathways.

Some scholars have stated that the application of these models can improve student motivation and learning outcomes tremendously, allowing students to navigate their academic and professional pathways successfully (Rahmawati et al., 2021;Efendi, Sumarmi and Utomo, 2020). The ability of these models to be applied in integrated STEM education makes them even more useful because they promote comprehens as well as critical thinking among students regarding the collaboration of different disciplines. Hence, to effectively equip students for the demands of their future careers, vocational institutions need to actively research and apply such innovative teaching strategies.

In this study, the flipped classroom approach was implemented by having students access digital instructional materials, including video lectures and augmented mockup simulations, before class meetings (Triyanto et al., 2024). This allowed students to gain preliminary understanding independently, so classroom sessions could focus on collaborative project execution, discussion, and problem-solving within the Project-Based Learning framework. This approach aligns with the interactive and practice-oriented nature of vocational education described by Usmeldi and Amini (2022) , but extends it further by integrating mockup-based Augmented Reality media. The novelty of this model lies in combining flipped learning, PjBL, and immersive AR environments to bridge the gap between theoretical knowledge and real-world construction practices, which was an integration that remains limited in current vocational education research.

2.3 Integration Media Mockup and Augmented Reality (IMM&AR) in Contextual Learning

The use of Media Mockups and Augmented Reality (IMM&AR) in the context of engineering learning in vocational schools (SMK) is very important in cultivating one's ability to reason and critically evaluate problems (HOTS) which are fundamental in modern education. This learning practice corresponds to the form of vocational education that requires strong hands-on learning (Sukatiman, Budiwan and Waluyo, 2023). With the initial interaction with IMM&AR, students use and defend their theories while going through an iterative design process, which encourages inquiry, evaluation, and critical reflection on results achieved.

An AR system projects computer-generated augmentations onto real objects, enabling real and virtual objects to function synchronously and provide a proper depth of perception for the user, through this real-time integration, AR environments allow learners to observe complex structures, spatial relationships, and procedural sequences in ways that are not achievable through static instructional media (Siriwardhana et al., 2021). Such perceptual enrichment supports clearer conceptualization, reduces cognitive load during visualization, and promotes more meaningful engagement with learning tasks particularly in vocational settings where understanding three-dimensional structures and technical details is essential.

Incorporating conventional teaching with CAD tools and video instruction has been found to improve the learning achievement of students in technical drawing; moreover, multimedia student-centered learning environments positively affect students' participation in the laboratory (Hendarwati, Nurlaela and Bachri, 2021). Simulation, problem-based learning, and constructivist multimedia methods are effective for teaching many advanced engineering concepts (Wati and Widiansyah, 2020; Jurayev, 2021). Additionally, as these authors report, advanced modeling and visualization platforms facilitate conceptual understanding and design evaluation in devising a product. These reasons emphasized the importance of enhanced media literacy instruction in algorithmic learning environments (Valtonen et al., 2019). In professional settings, this is particularly relevant, as students bridging divergent levels of prior knowledge engage in project-based learning, which features multifaceted challenges. IMM&AR technologies increase understanding of technologies and simultaneously foster evaluative and creative thinking, preparing students to address contemporary engineering challenges with greater confidence and ingenuity.

A significant body of research has identified Augmented Reality (AR) as an effective tool for enhancing teaching methodologies, while numerous studies have demonstrated the positive impact of Virtual Reality (VR) on the learning process by facilitating interaction with virtual and real objects, fostering learning through experimentation, participation, and interactivity, thereby increasing learner motivation and attention, and making learning more engaging and effective, especially when dealing with abstract concepts or complex phenomena (Elmqaddem, 2019). As can be seen that recent studies highlight that AR-based mockup environments enhance visualization and contextual understanding, bridging abstract concepts with real-world applications (Kassutto, Baston and Clancy, 2021; Kozov and Ivanova, 2023). Within the FPjBL framework, IMM&AR serves as an immersive medium that strengthens deep learning engagement by enabling students to manipulate, test, and reflect on virtual construction models—transforming abstract theoretical knowledge into experiential learning.

As noted along with IMM&AR, developing critical thinking skills via active learning techniques has recently been acknowledged as a fundamental component of effective vocational education. Citing Omelchenko, the author's assertion is supported that critical thinking strategies used in the context of media education technologies cultivated the foundational competencies indispensable for students to thrive in the contemporary workforce (Omelchenko, 2022). Evidence showing that interactions with mockups enable students to test their design hypotheses and evaluate the outcomes of their actions, thus exercising deeper reasoning and reflective judgment, which is part of the higher-order thinking synergy, also supports this (Sukatiman, Budiwan and Waluyo, 2023). Moreover, Flipped Project-Based Learning has been shown to foster participation and understanding within context, allowing students to engage with concepts theoretically. Such approaches are especially important in civil engineering education where the theory-practice divide tends to hinder the development of critical thinking skills (Kausar, Maryono and Aristyagama, 2021; Budiarto et al., 2024).

To conclude, the integration of Media Mockups and Augmented Reality (IMM&AR) as part of vocational engineering education shows that strategies designed to foster critical thinking are responsive and proactive to the concerns of the gap between teaching in classrooms and the needs of industries. This literature review focuses on the critical analysis of teaching strategies and appropriate instructional media in vocational education, especially in cultivating critical thinking and other 21st century competencies.

3. Theoretical Framework

The incorporation of Deep Learning alongside Flipped Learning, Project Based Learning (PjBL), and Constructivism gives rise to a practical pedagogical approach that improves practical learning skills in vocational high schools (SMK). These integrations are beneficial for vocational education because there is a need to provide students with both theory and practice as preparation for employing. Deep Learning, which is developed by Biggs, focuses on the understanding and application of information as opposed to rote memorization, which is more aligned with the requirements of vocational education that demands real-life problem solving (Rahayu, Sutikno and Indriyanti, 2023). (Sandal, 2023) states that Flipped Learning adds to this by allowing students to part outside the classroom which enhances classroom participation during lessons. This model supports knowledge implementation using simulations of actual and theoretical industrial environments which is ideal for vocational education. Utilizing Augmented Reality (IMM&AR), learning can be done before and after school hours, enabling students to complete tasks assigned by instructors at any time.

Furthermore, PjBL methodology excels within this integration because it promotes an environment in which students expertly work on projects that replicate real-life situations, improving their higher order thinking skills, creativity, and problem solving abilities (Xiong, 2024). Rahayu, Sutikno and Indriyanti (2023) claims that this model develops decision making and creativity capabilities, while strongly supporting the constructivist approach in which learners build understanding and meaning through real-world activities and reflection. The critical link with Constructivism is emphasized as learners apply their prior knowledge to acquire new skills, which increases engagement and motivation—factors particularly critical in vocational education where active participation is central to learning (Chang and Chen, 2022). As a result, students skillfully tackle multifaceted problems within their domains, preparing them for the realities

In wake of the current trends in the job market, the integration of specific teaching methodologies has become ever more essential as vocational institutions continue accommodating to educational paradigms. The development of collaborative, creative, and critical educational practices distinguishes learning in SMK toward successful career pathways, demonstrating the importance of practical educative work to the students' value system. Deep Learning in vocational high schools with Flipped Learning, PjBL, and constructivism enhances personal and professional growth for students through comprehensive vocational education.

4. Method

4.1 Types of Research and Research Design

This study adopts a quantitative approach with a quasi-experimental type design, specifically a pretest-posttest control group design (Cresswell et al., 2003; Abdullah, 2015). This was done to measure the critical thinking ability of students after the implementation of the Flip Learning Project Based Learning (FPjBL) model with Immersive Multimedia & Augmented Reality (IMM&AR) Media. The experimental group learned through FPjBL-IMM&AR while the control group learned through conventional teaching. The study focused on assessing the pedagogical impact of the FPjBL model, with IMM&AR functioning as a supporting medium rather than a stand-alone technological intervention. Students in the experimental group accessed augmented mockup simulations of a two-storey building prior to class and collaborated in small groups during project activities using structured worksheets (LKPD). Both groups covered identical content and were evaluated through pre- and post-tests on critical thinking performance.

4.2 Samples and Sampling Techniques

Participants were selected using purposive sampling, considering their relevance to the research objectives and accessibility in real classroom settings (Etikan, Musa & Alkassim, 2016; Cohen, Manion & Morrison, 2018). This technique ensures that the selected participants possess characteristics aligned with the competencies studied, particularly in building and construction programs (Mingers and Willcocks, 2017; Bostley and Peters, 2023). From this sample, a proportional split into two groups was made, one experimental group of 108 learners who were exposed to flipped project-based learning with mockup media in IMM&AR (Immersive Multimedia & Augmented Reality) alongside 108 in a control group with conventional instruction. All participants underwent identical pretest and posttest assessments.

4.3 Research Procedures

The research procedure commenced with the preparation of instructional materials and learning media. The instructor, assisted by student teachers (PPL), developed scaled prototype models representing multi-storey concrete reinforcement structures based on authentic industrial data. These prototypes were subsequently transformed into three-dimensional AutoCAD designs and embedded within an augmented application known as the Immersive Multimedia and Augmented Reality (IMM&AR) media. The IMM&AR platform enabled students to visualize and manipulate structural components through interactive simulations accessible via mobile devices, thereby supporting independent pre-class learning activities. In the experimental group, the Flipped Project-Based Learning (FPjBL) model was implemented through three stages: (1) a pre-class phase, where students accessed digital instructional videos and IMM&AR simulations to study core concepts independently; (2) an in-class phase, focusing on collaborative project execution, analysis, and discussion guided by the instructor; and (3) a reflection phase, where students evaluated design outcomes and articulated reasoning processes. The control group received the same instructional content and assessment procedures but without the use of IMM&AR media. Both groups were taught by the same instructor to maintain instructional consistency. This structured approach ensured procedural validity and effectively integrated theoretical understanding with authentic construction practices.

4.4 Data Collection Technique

Data collection was conducted through two primary methods: (1) assessment of critical thinking abilities via group work analysis involving reinforcement calculations, presentation of results, and structural drawings utilizing the AutoCAD application to evaluate intervention effectiveness, and (2) administration of closed questionnaires employing a Likert scale to gauge learning motivation and student perceptions of the implemented instructional approach (Fukuzawa, Boyd and Cahn, 2017;Yaki, 2022). The data collection technique consists of the following stages: familiarization with teachers and students, administration of pretests, execution of learning sessions across 4-5 meetings, administration of posttests, and completion of questionnaires by students in the experimental group. Data were gathered throughout two semesters in two vocational schools for grades 10 and 11.

4.5 Data Collection Instruments and Grids

The main instrument in this study was a critical thinking ability test designed to measure students' higher-order thinking skills in the context of concrete structure learning. This test was designed based on The Delphi Report framework by Facione, which includes five main indicators: analysis, inference, evaluation, explanation, and self-regulation. Each indicator is represented by two questions, so that there are a total of 10 essay questions based on construction project case studies. These questions are designed to test students' abilities in identifying technical problems, drawing logical conclusions from technical data, evaluating alternative solutions, explaining the reasons for decision making, and reflecting on their thinking processes. All questions were developed by considering the suitability of the vocational context, content validity, and the measurability of students' critical thinking competencies, as can be seen in table 1.

Table 1: Critical thinking test grid

Indicator	Description
Analysis	Identifying structural components in a project
Inference	Drawing conclusions from project technical data
Evaluation	Evaluating technical solutions in case studies
Explanation	Explaining the results of technical decisions taken
Self-Regulation	Reflecting on the problem-solving process

Adaptation from research Tang, Vezzani and Eriksson (2020) and Yaki (2022)

4.6 Instrument Validity and Reliability Test

All research instruments have undergone content validity testing which was consulted with three experts in the field of vocational education and learning evaluation. To maintain internal validity, the same procedures and criteria were applied across both experimental and control groups, while the testing environment, timing, and instructions were standardized to minimize bias and external interference. The results of the validity and reliability tests can be seen in table 2.

Table 2: Results of Statistical Validity Tests of the Critical Thinking Test

No	Critical Thinking Aspects	Number of Items	Validity Coefficient Range (r)	Validity Category
1	Analysis	2	0,61 – 0,74	High
2	Inference	2	0,65 – 0,71	High
3	Evaluation	2	0,52 – 0,68	Medium – High
4	Explanation	2	0,58 – 0,72	Medium – High
5	Self-Regulation	2	0,60 – 0,76	High

The results of the statistical validity test on the critical thinking ability test instrument show that all items across the five critical thinking indicators such as analysis, inference, evaluation, explanation, and self-regulation showed validity coefficients ranging from 0.52 to 0.76 ($p < 0.05$), indicating medium to high validity levels. Furthermore, the reliability analysis using Cronbach's Alpha yielded a coefficient of 0.82, demonstrating strong internal consistency and stability of the measurement instrument (Elshareif and Mohamed, 2021). These findings indicate that the critical thinking test instrument has good internal consistency and is suitable for use in research.

4.7 Data Analysis Techniques

The data in this study were analysed utilising SPSS statistical software version 26. The analytical procedure was conducted in two primary phases. An Analysis of Covariance (ANCOVA) was performed to evaluate the efficacy of the Flipped Project-Based Learning model, utilising the Integration of Mmockup Media and Augmented Reality (IMM&AR) to enhance students' critical thinking skills, while controlling for pretest scores as a covariate (Patten and Newhart, 2018). Additionally, a multiple linear regression analysis was performed to assess the degree to which motivation and student perspective in learning influenced critical thinking skills post-intervention (Collis, 2021). All analyses were performed at a significance threshold of α = 0.05, signifying that results are deemed statistically significant if the p-value is below 0.05.

5. Results

5.1 Descriptive Statistical Analysis

Based on the results of data collection from 216 respondents divided into experimental groups (n=108) and control groups (n=108), the following table 3 is descriptive statistics results.

Table 3: Descriptive Statistics of Pretest and Posttest Scores of Critical Thinking Ability

Group	N	Pretest			Posttest			N-Gain
		Mean	SD	Min-Max	Mean	SD	Min-Max	Mean
Experiment	108	58.42	8.76	42-75	78.63	7.14	65-92	0.49
Control	108	57.96	8.94	40-76	68.21	7.68	55-84	0.24

Table 3 indicates that the average pretest scores for the experimental group (M = 58.42, SD = 8.76) and the control group (M = 57.96, SD = 8.94) are comparable, exhibiting a negligible difference. Post-treatment, a notable disparity emerged in the average posttest scores, with the experimental group (M = 78.63, SD = 7.14) demonstrating superior performance compared to the control group (M = 68.21, SD = 7.68). The experimental group exhibited an N-Gain value of 0.49, categorising it as medium, whereas the control group recorded an N-Gain of 0.24, placing it in the low category as shown in table 4.

Table 4: Comparison of Scores Per Critical Thinking Ability Indicator

Indicator	Experimental Group		Control Group	
	Pretest (Mean)	Posttest (Mean)	Pretest (Mean)	Posttest (Mean)
Analysis	60.74	82.25	60.42	70.48
Inference	58.17	79.38	57.85	68.22
Evaluation	55.96	75.40	56.18	65.73
Explanation	59.84	80.94	58.26	69.45
Self-Regulation	57.39	75.18	57.09	67.17

Table 4 describes the comparison of scores per indicator of critical thinking skills. In the experimental group, the highest increase occurred in the Analysis indicator (21.51 points), followed by Explanation (21.10 points), while in the control group, the highest increase also occurred in the Analysis indicator (10.06 points). Overall, the experimental group that followed the Flipped Project-Based Learning model based on mockup media showed a greater increase in all indicators of critical thinking skills compared to the control group that followed conventional learning.

5.2 Significant Differences between Experimental and Control Groups

To test the effectiveness of the Flipped Project-Based Learning model based on mockup media, an analysis of covariance (ANCOVA) was conducted with the pretest score as a covariate. The results of the ANCOVA analysis are presented in the following table 5.

Table 5: Results of ANCOVA Test of Critical Thinking Ability

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.	Partial η²
Corrected Model	7845.263	2	3922.632	74.518	.000	.411
Intercept	5827.418	1	5827.418	110.721	.000	.342
Pretest	1624.841	1	1624.841	30.872	.000	.127
Group	5483.726	1	5483.726	104.192	.000	.329
Error	11225.159	213	52.700			
Total	1126473.000	216				
Corrected Total	19070.422	215				

The results of the ANCOVA analysis in Table 5 show that there is a significant difference in the critical thinking ability scores between the experimental group and the control group after controlling for the influence of the pretest score, $F(1, 213) = 104.192$, $p < .001$, with an effect size (partial η^2) of 0.329 which is included in the large category. This finding confirms that the Flipped Project-Based Learning model based on mockup media is significantly more effective in improving students' critical thinking skills compared to conventional learning.

Table 6 displays the adjusted estimated marginal means of posttest results, accounting for variables (pretest). The experimental group exhibited an adjusted mean of 78.42 (SE = 0.70), whereas the control group had an adjusted mean of 68.42 (SE = 0.70), resulting in a mean difference of 10.00 points. The 95% confidence intervals for the two groups do not intersect, so reinforcing the significance of the difference between them.

Table 6: Estimated Marginal Mean Posttest Scores After Covariate Adjustment

Group	N	Adjusted Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Experiment	108	78.42	0.70	77.04	79.80
Control	108	68.42	0.70	67.04	69.80

Subsequent analysis in Table 7 indicates that all metrics of critical thinking skills have considerably improved according to the ANCOVA test results ($p < .001$), with effect size values (partial η^2) ranging from 0.227 to 0.317, categorising them as large. The indicator exhibiting the greatest mean difference is Analysis (11.74 points), succeeded by Explanation (11.19 points), whereas the smallest difference is observed in Self-Regulation (8.01 points).

Table 7: ANCOVA Test Results Per Critical Thinking Ability Indicator

Indicator	F	Sig.	Partial η^2	Mean Difference
Analysis	98.473	.000	.317	11.74
Inference	87.215	.000	.291	10.45
Evaluation	67.891	.000	.242	9.38
Explanation	92.746	.000	.303	11.19
Self-Regulation	62.518	.000	.227	8.01

The findings demonstrate that the Flipped Project-Based Learning paradigm utilising mockup media is successful in enhancing all dimensions of critical thinking, particularly in analytical and explanatory skills. These findings substantiate the research aims and address the initial inquiry concerning the disparities in critical thinking skills between students engaged in the innovative learning model and those in traditional learning settings.

5.3 The Influence of Motivation, Media Perception, and Activeness on Critical Thinking

To identify factors that influence students' critical thinking skills in the experimental group, multiple linear regression analysis was conducted with learning motivation, perception of mockup media, and student activity as predictors, the result of the analysis summarized in table 8 and 9.

Table 8: Regression Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	.783	.613	.602	4.503

Table 9: Regression Coefficient Analysis

Variabel	B	Std. Error	Beta	t	Sig.
(Constant)	21.843	4.217		5.180	.000
Learning Motivation	.352	.088	.368	4.005	.000
Media Mockup Perception	.279	.076	.301	3.671	.000
Student Activeness	.264	.071	.287	3.718	.000

The regression model indicates that the three predictor factors collectively account for 61.3% of the variance in students' critical thinking ability scores ($R^2 = .613$). The ANOVA findings indicate a statistically significant model

(F(3, 104) = 54.687, p < .001), confirming the validity of the overall regression model. The regression coefficients indicate that learning motivation exerts the most significant influence (β = .368, p < .001), followed by the perception of simulated media (β = .301, p < .001), and student activity (β = .287, p < .001). All factors provide a favourable and significant influence on critical thinking capacity. The subsequent analysis is the effect size test, illustrated in Table 10.

Table 10: Summary of Effect Size Analysis

Analysis	Metric	Score	Interpretation
ANCOVA (Overall)	Partial η^2	.329	Big effect
Linear Regression	R^2	.613	Big effect
Analysis Indicator	Partial η^2	.317	Big effect
Inference Indicator	Partial η^2	.291	Big effect
Evaluation Indicator	Partial η^2	.242	Big effect
Explanation Indicator	Partial η^2	.303	Big effect
Self-Regulation Indicator	Partial η^2	.227	Big effect

The results of the effect size measurement show that the Flipped Project-Based Learning model based on mockup media has a major impact on improving students' critical thinking skills. The partial η^2 value for the overall critical thinking skills reached 0.329, which according to Cohen is included in the large effect category. All indicators also show effect sizes in the same category (partial $\eta^2 > 0.14$). In addition, the regression analysis shows that three predictor variables such as motivation, perception of media, and activeness simultaneously explain 61.3% of the variance in critical thinking scores ($R^2 = 0.613$), which is also quite large. These findings indicate that learning interventions are not only statistically effective but also practically meaningful in encouraging the development of high-level thinking skills of vocational high school students in the subject of concrete structures. Thus, this model is proven to be able to create a conducive learning environment for improving 21st century competencies.

6. Discussion

The substantial enhancement of critical thinking abilities in the experimental group validates the hypothesis of deep learning theory as articulated by Biggs, Students participating in the FPjBL paradigm with mockup media showed remarkable improvements in their abilities to analyze and synthesize complex technical problems as well as evaluate alternative solutions. Going by the findings of deep learning (Rahayu, Sutikno and Indriyanti, 2023;Xiong, 2024). further emphasized how learning enhancement motivates learners to be actively engaged in the learning process. Most importantly, this study's results showed that the highest gains were seen in Analysis (21.51 points) and Explanation (21.10 points) which demonstrates the students' ability to integrate intricate technical concepts instead of just superficial ones. These results indicate that the observed improvement in students' critical thinking is attributable not solely to the use of technology, but to the pedagogical integration of AR-based mockups within the FPjBL framework, which facilitated active engagement, reflection, and conceptual understanding.

This conclusion supports the findings of other studies that have noted a positive correlation between the application of the deep learning technique and the academic achievement of vocational students (Natarajan et al., 2022;Park et al., 2020). Suwarno, Wahidin and Nur (2020), as well pointed out that contextual learning helps prepare students in the construction industry from facing certain realities. The results from the ANCOVA test F (1, 213) = 104.192, p < .001, partial η^2 = .329 also confirm the effectiveness of the Flipped Project-Based Learning model in developing skills of higher order thinking. This model combines flipped learning and project-based learning to create a setting that encourages participation as well as the development of higher order thinking skills. This pattern of education is in agreement with research conducted by Jaedun et al. (2022) which emphasizes the role of inquiry-based learning towards the enhancement of critical and analytical skills in vocational institutions. In addition, the research conducted by Rahim et al. (2024) demonstrates that applied learning through Project-Based Learning (PjBL) not only improves technical skills, but also enhances soft skills which are highly valued in contemporary workplaces.

The regression analysis indicates that learning motivation (β = .368), perception on mockup media (β = .301), and student activeness (β = .287) have important contributions to the critical thinking skills with the R^2= .613 (high category). This result validates the active and context-based learning's roles in vocational schools as

Sukatiman, Budiwan and Waluyo (2023), remarked, “mockups assist students in visualizing technical concepts and promote iterative design and exploration, encouraging reflection.” Furthermore, these findings support constructivist theory which highlights reflection and authentic experience as the basis for understanding. (Chang and Chen 2022) highlighted the fact that a constructivist perspective in vocational education enables a learner to combine previous knowledge with fresh experiential learning in a practical challenge. Overall, these findings empirically confirm that the integration of deep learning theory, IMM&AR with the application of FPJBL, and the constructivist learning approach is effective in the context of vocational education. This approach not only significantly improves critical thinking skills, but also prepares students to face the complexity of the world of work in the era of the Industrial Revolution 4.0.

The results of this study align with several investigations that highlight the efficacy of project-based learning and interactive media in vocational education. The notable enhancement in critical thinking abilities, particularly in the Analysis and Explanation metrics, corroborates the findings of Pando Cerra et al. (2020) and Sukatiman; et al. (2020), which demonstrate that the application of CAD, video, and hybrid methodologies, facilitated by visual-interactive technology, can augment the engagement and comprehension of engineering students significantly. Numerous data corroborate that mockup and simulation media enhance the visualisation of technical concepts and promote reflective inquiry-based learning (Sukatiman, Budiwan and Waluyo, 2023; Wati and Widiansyah, 2020). These results align with the findings of Ruijuan, Srikhoa and Jantharajit (2023), which demonstrate that the deep learning technique in vocational education greatly enhances academic performance and the mastery of advanced cognitive skills. This study demonstrates that motivation variables, media perceptions, and student activity significantly contribute to critical thinking skills (R^2 = .613), indicating a high level of cognitive engagement among students during the learning process (Budiarto et al., 2024).

Additionally, these findings help address the gaps in previous studies (Park et al., 2020), that did not find any association between deep learning and critical thinking skills. Here, the achievement of deep learning implementation successfully worked hand-in-hand with project-based instructional design and contextual learning media like mockups that have been shown to promote student engagement and active reflection (Omelchenko, 2022; Chang and Chen, 2022). These findings reaffirm that the improvement in critical thinking was primarily driven by the pedagogical arrangement of the FPjBL model, in which IMM&AR served as a facilitative tool to support contextual learning and engagement rather than as an independent technological intervention. This reinforces the view that the effectiveness of technology in education depends largely on how it is pedagogically integrated within constructivist and project-based learning frameworks.

Based on the results of this study, it seems that the FPjBL model based on IMM&AR could be effectively implemented in Vocational High Schools (SMK) focused on Building Model Dasar and Konstruksi dan Perumahan Teknik (TKP) as well as in Civil Engineering vocational colleges. This approach enables the seamless integration of theoretical teaching and practical exercises while ensuring that students actively participate in the learning process. To tackle the challenges posed by Industry 4.0, which demands highly skilled and deep-thinking graduates, educators in vocational institutions need to adopt a project-based approach integrated with visual, structural, and functional aids like mockups (Sukatiman, Budiwan and Waluyo, 2023;Rahim et al., 2024). This methodology is deemed pertinent to the demands of the progressively intricate, dynamic, and technology-driven professional environment (McGunagle and Zizka, 2020).

This study has several advantages, including the use of a quasi-experimental design with a large sample, the integration of pedagogical approaches and field-based media in the context of civil engineering, and robust data analysis through ANCOVA and linear regression. However, this study also has limitations, such as the limited scope of one subject (concrete structures) in two vocational schools in Solo Raya, the short duration of the intervention (4–5 meetings) so that the discussion of structures was not fully discussed, and it has not included other variables such as collaboration and communication as part of 21st century skills. Further studies with longitudinal designs are recommended to evaluate long-term impacts, as well as exploring the integration of this model with the STEAM approach, digital fabrication, or Teaching factories to address the challenges of vocational education in the industrial era 4.0.

7. Conclusion and Suggestions

This study demonstrates that the Flipped Project-Based Learning model utilising mockup media (FPjBL-IMM&AR) is effective in enhancing the critical thinking skills of vocational high school students, with notable improvements particularly in the indicators of analysis and explanation. Regression results also revealed that learning motivation, media perception, and student engagement significantly contributed to critical thinking performance. These findings validate the importance of integrating deep learning methodologies, project-based learning, and contextual technologies within vocational education. The use of AR-based mockup media has been shown to enhance visualization, engagement, and reflective reasoning, allowing students to connect abstract construction concepts with real-world applications more effectively. However, the successful implementation of such technology-assisted learning depends on adequate digital infrastructure, teacher preparedness, and students' ability to use technology meaningfully. Therefore, balanced integration between pedagogy and technology remains crucial to sustain meaningful learning outcomes and the long-term development of critical thinking skills.

It is recommended that vocational educators adopt this model to promote active learning, engagement, and employability readiness among students. Policymakers should also support capacity building through teacher training and the development of immersive learning resources to ensure sustainable implementation of technology-enhanced instruction. While this study focuses on Augmented Reality integration, future research could extend this approach by incorporating Artificial Intelligence (AI) to enable adaptive feedback, personalized learning pathways, and real-time performance analytics in vocational learning environments.

AI Statement: AI tools were used in a limited and supervised manner. QuillBot supported language refinement, and Elicit assisted in identifying relevant literature. No AI tool contributed to original ideas, analysis, or interpretation. All content was reviewed and verified to ensure academic rigor and authorship integrity.

Ethics Statement: This study complied with ethical research standards. All participants received clear information about the study and provided written informed consent prior to participation. The protocol was approved by the Health Research Ethics Committee of Dr. Moewardi General Hospital, Surakarta, Indonesia (Approval No. 2.427/XI/HREC/2025), and the research adhered to the Declaration of Helsinki.

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Towards Smart and Socially Integrated Learning: A Systematic Review of LMS, Social Media and Artificial Intelligence Synergies

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Abstract: This systematic literature review investigates the synergistic role of Learning Management Systems (LMS), social media (SM) and artificial intelligence (AI) in enhancing student engagement, satisfaction, and academic success within smart online and blended learning environments. LMS platforms are highlighted as the backbone of digital pedagogy, offering increasingly personalized, interactive, and adaptive experiences. The paper examines 34 peer-reviewed articles sourced from Scopus and Web of Science that address the connection between LMS and SM in higher education. In addition, a separate search query was conducted for research question 3, resulting in 11 studies that focus specifically on the intersection of AI, LMS, and SM. Findings indicate that LMS tools such as discussion forums, automated assessment, learning analytics, and interactive content modules consistently support motivation, timely feedback, and improved academic outcomes. The integration of SM enhances these outcomes by introducing familiar, interactive and collaborative dynamics that foster peer engagement and community - building. Case studies- including platforms like Moodle-VKontakte, KnowMore, and my.eskwela - show how features like newsfeeds, chatbots, and analytics can transform static learning portals into autonomous learning ecosystems. Looking ahead, the review also identifies significant potential for emerging technologies - particularly AI - to elevate the effectiveness of LMS and SM integrations. Future learning environments may incorporate AI-driven personalization, predictive analytics for early intervention, and chatbot assistants that provide academic guidance or direct students to well-being resources in an empathetic, non-diagnostic manner, influencing their engagement and overall satisfaction with learning. Immersive virtual spaces such as metaverse-based classrooms also offer new avenues for simulation-based learning and collaborative engagement. Together, these developments signal a shift toward digital ecosystems that are adaptive, community-oriented, emotionally supportive, and grounded in evidence-based design principles. Overall, this review contributes a consolidated understanding of how LMS and SM can jointly advance the quality of digital education, supported by emerging technologies such as AI. By outlining both current practices and future opportunities, it offers a clear foundation for the development of next-generation learning systems that are more engaging, equitable, and responsive to the diverse needs of today's learners.

Keywords: Learning management systems, Social media, Artificial intelligence, e-Learning, Student satisfaction, Student engagement, Academic success

1. Introduction

One area of interest in higher education is the development of social tools integrated inside of Learning Management Systems (LMS), as these tools have the potential to increase student satisfaction, engagement, and even success. Social media (SM) is becoming a part of educational tools taking one step further by enabling more interactive and collaborative experiences between students and faculty.

Despite the adoption of LMS and SM individually in e-learning, there is limited research on their structured integration, particularly regarding their combined impact on student satisfaction and engagement. Moreover, the role of artificial intelligence (AI) in enhancing these integrated digital learning environments, especially in higher education, remains largely unexplored. These gaps highlight the need for a contemporary systematic review to provide an updated overview of the evidence as of 2025 and to examine how LMS, SM, and AI collectively influence student experience.

This systematic literature review (SLR) examines the multifaceted effects of integrating SM into LMS on student outcomes. SM can enhance education by fostering collaborative learning and social interaction, which are key to improving student engagement and performance. Research shows that SM promotes purposeful collaborative learning through active interaction, while ease of use and perceived usefulness have minimal impact. The Technology Acceptance Model and constructivist learning theories support the positive role of SM in education. By encouraging active, collaborative learning, SM improves both student satisfaction and academic performance. Likewise, specific SM platforms have been shown to enhance learning satisfaction and perceived academic achievement.

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The use of SM in asynchronous learning frameworks has been shown to enhance student participation and academic success. Students who engage in both face-to-face and online learning via SM demonstrate higher levels of engagement, motivation, and academic performance. Integrating SM into educational environments also supports goal orientation and persistence, contributing to improved grades and overall learning outcomes. This is particularly important given the research problem that many students in online learning environments experience low motivation and limited engagement, which can hinder their academic success.

Building on these benefits, AI can further amplify motivation, satisfaction, and engagement by personalizing learning content and interactions to individual needs, increasing relevance, enjoyment, and sustained involvement. Through interactive features such as chatbots and virtual assistants, AI can increase the sense of social presence and offer quick informational and entertainment-based rewards, both of which can strongly contribute to user satisfaction and continued engagement. AI-generated and AI-curated content supports hedonic motivation by creating enjoyable and culturally meaningful experiences that can encourage users to stay motivated and take action. Furthermore, AI can enable adaptive gamification by adjusting challenges, rewards, and feedback to individual users, which can further strengthen motivation and enhance overall engagement.

By conducting this SLR, we aim to address these gaps and provide a modern, comprehensive understanding of how LMS, SM, and AI integration can enhance student satisfaction, engagement, and academic success in higher education. Given the increasing role of LMS and SM in university education, this review seeks to answer the following research questions:

RQ1: In the evolving digital learning environment, how do Learning Management Systems influence student satisfaction, engagement, and academic success in higher education?

RQ2: In the context of technology-enhanced education, how does social media influence student satisfaction, engagement, and academic success in higher education?

RQ3: How is artificial intelligence integrated across Learning Management Systems and social media to shape student engagement and satisfaction in higher education?

2. Methodology

Following established SLR standards, the methodology consists of planning, conducting, and reporting phases, including a structured search strategy, clearly defined inclusion and exclusion criteria, and systematic quality assessment. Because of the nature of the topic and research goals, the SLR was designed and executed in two parts. The first part focused on studies addressing LMS and SM integration in higher education, aiming to establish the current state of knowledge and identify possible developments or shifts in findings up to 2025. The second part involved an additional, targeted search examining the role and impact of AI within LMS and SM supported learning environments, allowing the review to capture emerging evidence and gaps in knowledge on how AI influences motivation, engagement, and academic outcomes.

In the planning phase, the scope and criteria for both parts of the review were defined. For the first part, the review applied limits to peer-reviewed, English-language empirical studies published between 2021 and 2025 to capture the most recent evidence. Scopus and Web of Science were selected for their comprehensive coverage of educational technology research. For the second, AI-focused part of the review, Scopus and Web of Science were used as well, and no publication-year restriction was applied in the AI search because an initial scoping check indicated a relatively small number of relevant studies.

For Scopus, the following search string was used for the first and second research question:

(TITLE-ABS-KEY(e-learning) OR TITLE-ABS-KEY(online education) OR TITLE-ABS-KEY(distance learning)) AND (TITLE-ABS-KEY(lms) OR TITLE-ABS-KEY(learning management system)) AND (TITLE-ABS-KEY(social media) OR TITLE-ABS-KEY(social network)) AND PUBYEAR > 2020.

This search returned **1,857 articles**. To refine the results, additional filters were applied:

(TITLE-ABS-KEY(e-learning) OR TITLE-ABS-KEY(online education) OR TITLE-ABS-KEY(distance learning)) AND (TITLE-ABS-KEY(lms) OR TITLE-ABS-KEY(learning management system)) AND (TITLE-ABS-KEY(social media) OR TITLE-ABS-KEY(social network)) AND PUBYEAR > 2020 AND (LIMIT-TO (SUBJAREA, "COMP")) AND (LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")).

This refinement reduced the number of articles to **176**.

For Web of Science (WoS), the initial search query was:

TS=("e-learning" OR "online education" OR "distance learning") AND TS=("LMS" OR "learning management system") AND TS=("social media" OR "social network").

This search returned **73 articles**. Additional filters were applied:

TS=("e-learning" OR "online education" OR "distance learning") AND TS=("LMS" OR "learning management system") AND TS=("social media" OR "social network") AND PY=(2021-2025) AND DT=("ARTICLE" OR "PROCEEDINGS PAPER") NOT TS=("review" OR "systematic review") AND LA=(ENGLISH).

This refinement resulted in **17 articles**.

After retrieving the articles, a systematic screening process was performed in two stages: title and abstract screening, followed by full-text analysis. In **Scopus**, after reading the titles and abstracts, **55 articles** were selected for detailed reading. In **Web of Science**, duplicate studies were removed, and after screening, **8 articles** remained. For the full-text analysis, all selected articles were evaluated for methodological rigor, relevance and contribution to the research questions. Out of the **55 Scopus articles**, **18 were inaccessible**, leaving **37 for full review**. After detailed reading, **26 articles** were found to be relevant. In **WoS**, all **8 articles** were accessible and considered suitable for inclusion. Data extraction was performed using predefined categories, including study objectives, methodology, key findings, and relevance to the research questions. The extracted data was synthesized to identify recurring themes related to SM features and LMS.

The final dataset consisted of **34 articles (26 from Scopus and 8 from WoS)**, which were systematically analyzed to extract insights into the role of SM in LMS. The findings were categorized into key themes such as communication, collaboration, content delivery, engagement, and academic success. The results provide a comprehensive understanding of how SM functionalities can enhance LMS, offering valuable insights for future research and practical implementation in higher education. Table 1. presents the number of articles identified from the initial search across different scientific databases, along with the filtering process through additional criteria and qualitative analyses. Figure 1. illustrates the article selection process, detailing the number of articles identified, filtered, and analyzed from both Scopus and WoS databases.

Table 1: Summary of retrieved articles

Science database	Number of articles found	Number of articles after additional criteria	Number of articles after (initial) qualitative analysis of titles and abstracts	Number of articles after qualitative analysis of the entire text
WoS	73	17	8	8
Scopus	1857	176	55	26

For the third research question, the same query used in Scopus was also applied in Web of Science, however, it returned only a single article, which was already included among the Scopus results. Therefore, no additional unique records were obtained from WoS for this stage of the analysis.

The search query applied was:

(TITLE-ABS-KEY("artificial intelligence" OR "AI") AND TITLE-ABS-KEY("learning management system" OR LMS OR "online learning" OR "e-learning") AND TITLE-ABS-KEY("social media" OR "social network" OR "digital platform*") AND TITLE-ABS-KEY("higher education" OR university OR "college student*") AND TITLE-ABS-KEY("student satisfaction" OR "student engagement" OR "student experience")).*

This search identified 11 documents published between 2014 and 2025, with six studies appearing between 2023 and 2025 and the remaining five predating 2020. The limited number of retrieved studies is not indicative of a narrow search strategy but rather reflects the nascent nature of research simultaneously addressing AI, LMS, and SM within higher education learning contexts. The wide range and limited number of publications highlight that research at this intersection is still emerging and requires further investigation. All identified studies were analysed using the same screening and extraction criteria as in the previous phases, focusing on the methodological design, variables measured, and reported outcomes related to AI-driven integration of LMS and SM in higher education contexts.

Following the PRISMA logic (Page et al., 2021), the inclusion process and results were systematically documented to ensure replicability and transparency. The final dataset thus provides a comprehensive overview of current evidence and identifies significant research gaps - most notably the recent but underexplored intersection between AI, SM, and LMS in higher education. Figure 2. illustrates the article selection process, followng the PRISMA framework.

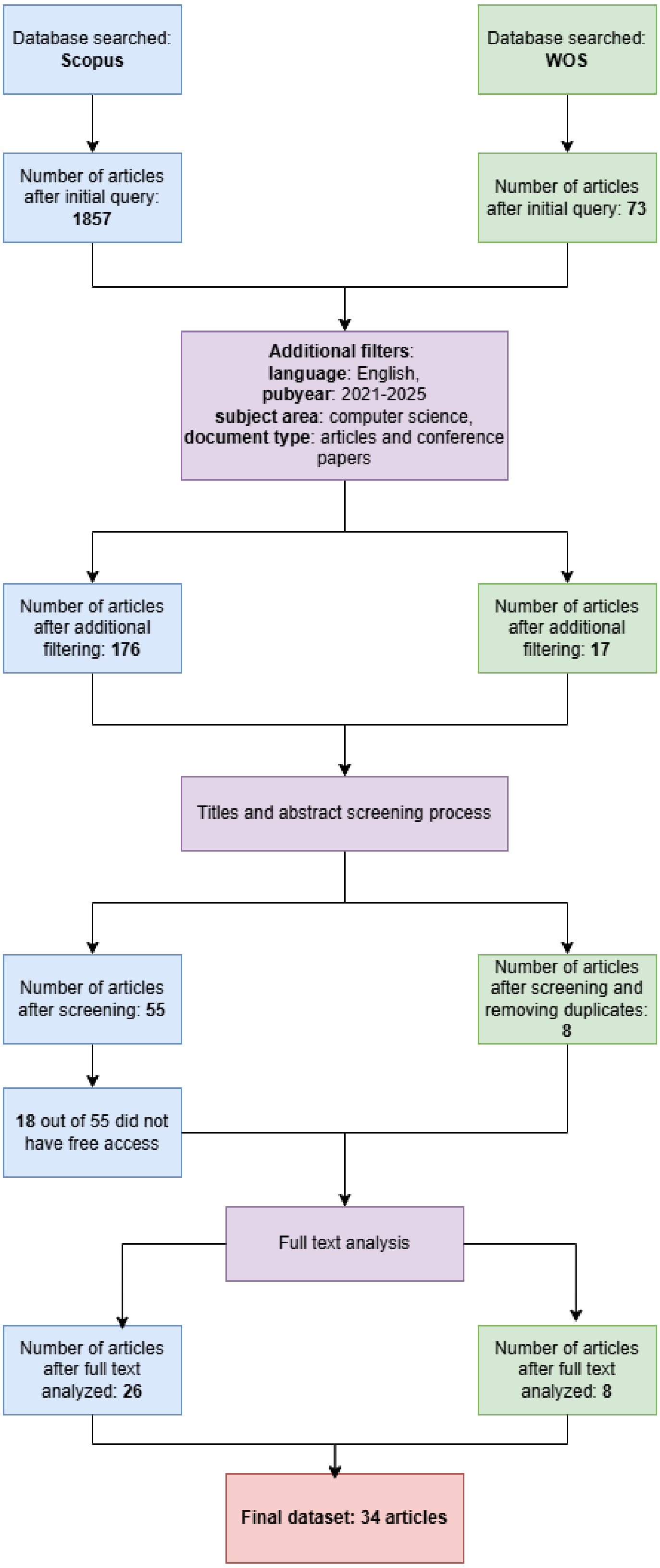

Figure 1: Article selection process for RQ1 and RQ2

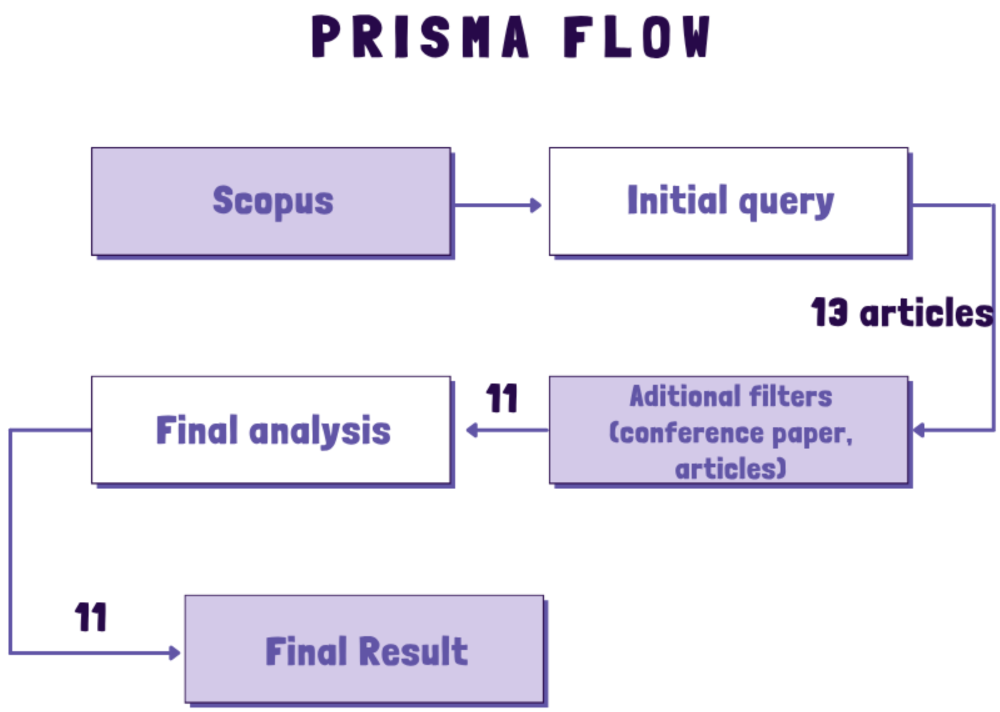

Figure 2: Prisma flow for RQ3

3. Literature Review and Findings

In this chapter, a synthesis of existing studies and the study's research findings is presented in relation to the RQs, with a primary focus on LMS and SM as the two central digital environments shaping student satisfaction, engagement, and academic performance in higher education. While prior research encompasses a wide range of digital tools, this review prioritizes recurring patterns that explain how and under what conditions LMS and SM influence student learning outcomes, rather than offering an exhaustive account of all technologies used in higher education.

To maintain analytical clarity, the findings are discussed through three interrelated lenses:

1. pedagogical value, including perceived usefulness, interaction, and feedback;
2. student experience, encompassing satisfaction, engagement, and motivation; and
3. contextual constraints, such as technological access, digital literacy, and institutional support.

AI and other emerging digital tools are considered cross-cutting enhancements that can modify or amplify LMS and SM functionalities. This framing ensures that AI is acknowledged without creating a third “pillar” of the chapter.

A study comparing students in Israel and Australia using official LMS platforms versus unofficial resources, like YouTube and Wikipedia, showed similar improvements in learning experiences when both were integrated (Cohen, A., Soffer, T., & Henderson, M., 2022). Microsoft Teams and social network sites also enhanced learning by improving resource access, collaboration, and peer–instructor support (Sobaih, A. E. E., Hasanein, A., & Elshaer, I. A., 2021). Additionally, mobile learning and SM promoted collaboration, resource sharing, and entrepreneurial skills but could cause distractions or smartphone addiction (Chen & Ifenthaler, 2021). Table 2. lists the studies in which positive and negative impacts of LMS, SM, and AI in online education were identified.

Table 2: The matrix of references

	POSITIVE INFLUENCE	NEGATIVE INFLUENCE
LMS	(Cohen, A., Soffer, T., & Henderson, M., 2022),(A. E. Sobaih, A. E. E., Hasanein, A., & Elshaer, I. A., 2021), (Saleh et al., 2022), (Navarro et al., 2021), (Kuzmina, N. N., Korotkova, E. G., & Kolova, S. M., 2021), (Pokrovskaia et al., 2021), (Aulia &	(Yunus et al., 2023), (Arefin et al., 2023), (Mabasa, 2023), Bamaga, A., Zafar, B., & Terzis, S., 2023), (Vázquez-Cane & Diez-Arcón, 2021), (Palve S.S. & Palve S.B., 2023), (Petratos, S., Botha, R., & Mtshabe,

	POSITIVE INFLUENCE	NEGATIVE INFLUENCE
	Utami, 2021), (Hasan et al., 2022), (Llantos & Estuar, 2021), (Nasome et al., 2022), (Alkoudmani et al., 2021), (Mabasa, 2023), (Bamaga, A., Zafar, B., & Terzis, S., 2023), (B. A. A. Abbas et al., 2024), (Atmane et al., 2025), (Rafiq, S., Iqbal, S., & Afzal, D., 2024), (Biney & Asamoah, 2023)	M., 2024), (Abbas, 2022), (B. A. A. Abbas et al., 2024)
SOCIAL MEDIA	(Cohen, A., Soffer, T., & Henderson, M., 2022), (Sobaih, A. E. E., Hasanein, A., & Elshaer, I. A., 2021), (Černá & Borkovcová, 2023), (Van Osch et al., 2021), (Liu et al., 2022), (Al-Rahmi et al., 2022), (Yu & Motlhabane, 2022), (Shahbazi et al., 2021), (Ulla & Perales, 2021), (Serradell-Lopez, E., Lara-Navarra, P., & Martínez-Martínez, S., 2023), (Lavlinskaya et al., 2022), (Bamaga, A., Zafar, B., & Terzis, S., 2023), (Petratos, S., Botha, R., & Mtshabe, M., 2024), (Biney & Asamoah, 2023)	(Chen & Ifenthaler, 2021), (Petratos, S., Botha, R., & Mtshabe, M., 2024), (Arefin et al., 2023), (Akbari, 2021), (Elenurm, 2022),(Ibrahim, 2022)
AI	(Kyrilov & Noelle, 2014), (Brown et al., 2024), (Murdoch & Lin, 2023), (Unsriana et al., 2025), (Alieksieieva et al., 2025), (Mbogho, 2017; Stanca & Felea, 2016), (Zelick, 2013), (Delaney & Redman, 2014),	(Warford, 2025), (Atmane et al., 2025)

3.1 How do Learning Management Systems (LMS) Influence Student Satisfaction, Engagement, and Academic Success in Higher Education

Various pieces of research have focused on the benefits of LMS in higher education, particularly the effect of LMS on students' satisfaction, engagement, and academic performance. The research results from Senegal also tell us that LMS platforms contribute more to student engagement than other digital tools (Saleh et al., 2022). In another study combining the Technology Acceptance Model (TAM), the key drivers using learning management system were found to be a perception of academic usefulness and ease-of-use experience among engineering students during COVID-19 pandemic (Navarro et al., 2021). Supportive of previous studies, these constructs suggest that LMS tools such as quizzes, discussion forum, and real-time feedback mechanisms beneficial for learning and thus have a positive effect on student performance.

LMS and SM-based blended models improve academic success.(Kuzmina, N. N., Korotkova, E. G., & Kolova, S. M., 2021) examined how LMS platforms enhance language skills, motivation, and participation. Additionally, a study on digital communication tools found that LMS platforms integrated with SM enhance student engagement by providing flexibility and supporting collaboration (Pokrovskaia et al., 2021). Another study on e-learning effectiveness highlighted that digital tools like discussion boards, multimedia resources, and virtual labs further strengthen engagement and learning outcomes (Aulia & Utami, 2021).

Such sentiments are further reflected in a study exploring the incorporation of Knowledge Management (KM) with Blended Learning during the COVID-19 pandemic. With the integration of KM strategies, network learning helped students stay engaged across, positively on their satisfaction, engagement, and retention during the times of crisis (Hasan et al., 2022). Research on LMS, such as „my.eskewela", highlighted interactive environments that strengthen collaboration among stakeholders, contributing to academic achievement (Llantos & Estuar, 2021). Platforms like „KnowMore", which rely on LMS features along with Machine Learning (ML) and Natural Language Processing (NLP), have also been proven to improve student engagement and personal knowledge management (Nasome et al., 2022). Studies examining the effectiveness of Schoology as e-learning tool also support the positive influence of LMS in educational settings, noting a significant improvement in knowledge scores among pharmacy students and professionals (Alkoudmani et al., 2021). (Shahbazi et al., 2021) conducted a study to explore the use of SM in collaborative learning environments and found that platforms like Edmodo led to increased group performance and student engagement.

Use of technology such as discussion forums has been highlighted as impactful for student retention and success in an Open Distance e-Learning (ODeL) context. The close interaction in these forums helps reduce isolation and encourages engagement. However, academic performance is also influenced by social and economic backgrounds, access to digital resources, and the quality of feedback mechanisms (Mabasa, 2023). Research on mobile learning (m-learning) highlights the flexibility and accessibility of LMS, allowing students to engage with content anytime and anywhere. M-learning not only supports inclusivity but also enhances digital literacy, preparing students for future digital academic environments (Bamaga, A., Zafar, B., & Terzis, S., 2023). Research on interactive lecture platforms designed and built using MATLAB AppDesigner demonstrated tremendous increases in engagement and satisfaction for LMS personalization features: content selection and dual language interface (English and Arabic). Yet some features, such as content sharing, had neutral-related feedback since the system was unfamiliar to users (B. A. A. Abbas et al., 2024).

The integration of AI in LMS platforms has also shown promise in enhancing student engagement and retention. AI-powered tutoring systems and personalized support mechanisms have been found to significantly reduce dropout rates in e-learning environments (Atmane et al., 2025). Moreover, the integration of gamification, virtual office hours, and immediate feedback through LMS platforms has also correlated with increased motivation and enhanced academic success (Rafiq, S., Iqbal, S., & Afzal, D., 2024).

While LMS offer numerous benefits, they also present challenges that negatively impact student satisfaction, engagement, and academic success. A major problem is low student engagement caused by technical barriers. In the LMS used in this study (UNPAK), students experienced unstable access, difficulty following lecture materials, and reduced engagement (Yunus et al., 2023). Limited internet access and poor LMS usability further hinder student engagement in online environments, contributing to weaker academic outcomes (Arefin et al., 2023).

Research on Open Distance e-Learning (ODeL) institutions also highlights challenges related to digital inequality and technological barriers. Although online discussion forums can encourage participation, disadvantaged students facing poverty, digital inequity, and limited technological resources often cannot engage fully, resulting in disparities in academic outcomes (Mabasa, 2023). M-learning provides flexibility but brings issues like device incompatibility and reduced focus due to frequent distractions, which limit interaction (Bamaga, A., Zafar, B., & Terzis, S., 2023).

A big problem is that LMS platforms are much less flexible compared to SM, which enables more fluid and interactive communication. A comparative study in distance education found students preferred SM with its informal nature over the rigidity of LMS (Vázquez-Cane & Diez-Arcón, 2021). What LMS is still unable to provide is a sense of community and social presence, which SM platforms have become synonymous for. LMS sites might also be challenged by insufficient teacher training and student ability, leading to reductions in motivation and learning (Palve S.S. & Palve S.B., 2023).

Furthermore, LMS platforms are limited in their ability to support various learning styles. In a study focused on digital skills in higher education, it was found that lower levels of digital literacy had a negative impact on student engagement and learning experience in terms of navigation in LMS (Petratos, S., Botha, R., & Mtshabe, M., 2024). The absence of an integration between LMS and personalized learning approaches,challenges the effective implementation of critical thought and independent learning (Abbas, A., Martín-Núñez, J. L., & Iqbal, K., 2022). For instance, an interactive lecture platform developed using MATLAB AppDesigner allowed students to personalize their learning by choosing their own pace and content. However, certain features, such as answer scrambling and content sharing, were not as effective due to students' unfamiliarity with the platform, highlighting the challenge of balancing innovative LMS features with student adaptability to ensure optimal engagement and usability (B. A. A. Abbas et al., 2024).

3.2 How Does Social Media Influence Student Satisfaction, Engagement, and Academic Success in Higher Education

Studies show that SM use in higher education positively influences student satisfaction, engagement, and academic success. A longitudinal study found improvements in satisfaction and engagement when Instagram, WhatsApp, and Microsoft Teams were integrated into online learning (Černá & Borkovcová, 2023). WhatsApp and Facebook facilitate academic interaction, while YouTube, Wikipedia, and X provide essential learning resources (Sobaih, A. E. E., Hasanein, A., & Elshaer, I. A., 2022). Enterprise SM in classroom projects, such as Microsoft Teams, strengthens teamwork, knowledge sharing, and productivity, improving student outcomes (Van Osch et al., 2021). Among Chinese university students, SM promoted collaborative and active learning, even when perceived ease of use and usefulness were not significant factors (Liu et al., 2022). In Malaysia, SM did not directly predict satisfaction but strongly influenced performance, highlighting constructivist learning and task-technology fit (Al-Rahmi et al., 2022).

WhatsApp is often seen as a personal, immediate, and collaborative tool, though some students view it mainly as SM, which may reduce its effectiveness as a learning tool (Yu & Motlhabane, 2022). SM also plays a significant role in enhancing academic success by promoting peer interaction, collaboration, and informal learning. During COVID-19, platforms like Facebook improved autonomous learning, creativity, and academic discussion (Ulla & Perales, 2021). Features such as real-time discussion, content sharing, and interactive forums increase student motivation and participation (Serradell-Lopez, E., Lara-Navarra, P., & Martínez-Martínez, S., 2023). Integration of chatbot-assisted learning in SM platforms further supports personalized learning and academic performance (Lavlinskaya et al., 2022). SM can act as a moderator in e-learning, fostering peer contact and collaborative learning, and when combined with formal LMS, enhances instruction and student retention (Bamaga, A., Zafar, B., & Terzis, S., 2023).

It is important to balance the use of SM with other digital learning tools to maintain academic focus. Furthermore, digital literacy is crucial for student success and retention, as students with higher levels of digital literacy are more likely to use social networks effectively to enhance their learning experiences (Petratos, S., Botha, R., & Mtshabe, M., 2024).

While SM offers several benefits for student engagement and academic success, it also presents challenges that can negatively impact these areas. One of the most important concerns is distraction. The overuse of SM affects cognitive capabilities, focus, and the management of time, all of which are essential in academic success for students. According to the study examining students' SM engagement in relation to their academic focus, SM use occurs in the absence of systematic learning, compromising academics (Petratos, S., Botha, R., & Mtshabe, M., 2024).

Additionally, technical and infrastructure challenges significantly affect student access to SM-based learning, particularly in developing countries. For instance, a study from Bangladesh found that poor socio-economic conditions and limited internet access, along with a lack of training in Information and Communication Technology (ICT), constrain effective use of SM in education (Arefin et al., 2023). Similarly, research on the effectiveness of SM-based learning during the COVID-19 pandemic highlighted that students in low-resource settings struggled with unreliable connectivity and insufficient devices, which undermined the benefits of SM for learning (Akbari, 2021). Misinformation and lack of credibility of user-generated content are additional challenges. SM facilitates learning but exposes students to unverified information, requiring instructor guidance (Elenurm, 2022). Moreover, these multiple challenges revolving around data security and digital citizenship are further compounded by privacy concerns and ethical issues surrounding interactions on SM within an academic context. These concerns highlight the need to acquaint students with responsible SM use as a tool in educational settings (Ibrahim, 2022).

Recent empirical studies from our own research (Jaksic & Stancin, n.d.; Stancin, K., Jaksic, D., & Petrovic, A., 2025) further confirm the positive influence of SM and LMS-integrated communication tools on student satisfaction and engagement. Consistent with prior findings on the role of SM in supporting collaboration, immediacy, and interaction (Černá & Borkovcová, 2023; Serradell-Lopez, E., Lara-Navarra, P., & Martínez-Martínez, S., 2023), our results showed that real-time communication, peer collaboration, and flexibility strongly enhance satisfaction (Jaksic & Stancin, n.d.). Another study emphasized the value of improving LMS features that mirror SM dynamics, particularly real-time interaction, informal communication, and enjoyable study-break activities (Stancin, K., Jaksic, D., & Petrovic, A., 2025). Both studies also identified challenges such as distraction, privacy concerns, and unequal participation. Importantly, these findings extend existing research by showing that students increasingly expect seamless integration between LMS and SM, balancing structured academic content with the interactive and adaptive qualities of digital communication environments.

3.3 The Integration of Artificial Intelligence Across Learning Management Systems and Social Media and its Role in Shaping Student Engagement and Satisfaction

The combination of AI, LMS, and SM is changing higher education nowadays. These three technologies combined have the potential to reshape how student engagement and satisfaction develop in online learning environments. This chapter reviews current studies to understand how AI is used across LMS and SM to improve engagement and satisfaction in higher education. The relationships between these tools and student outcomes are illustrated in Figure 3.

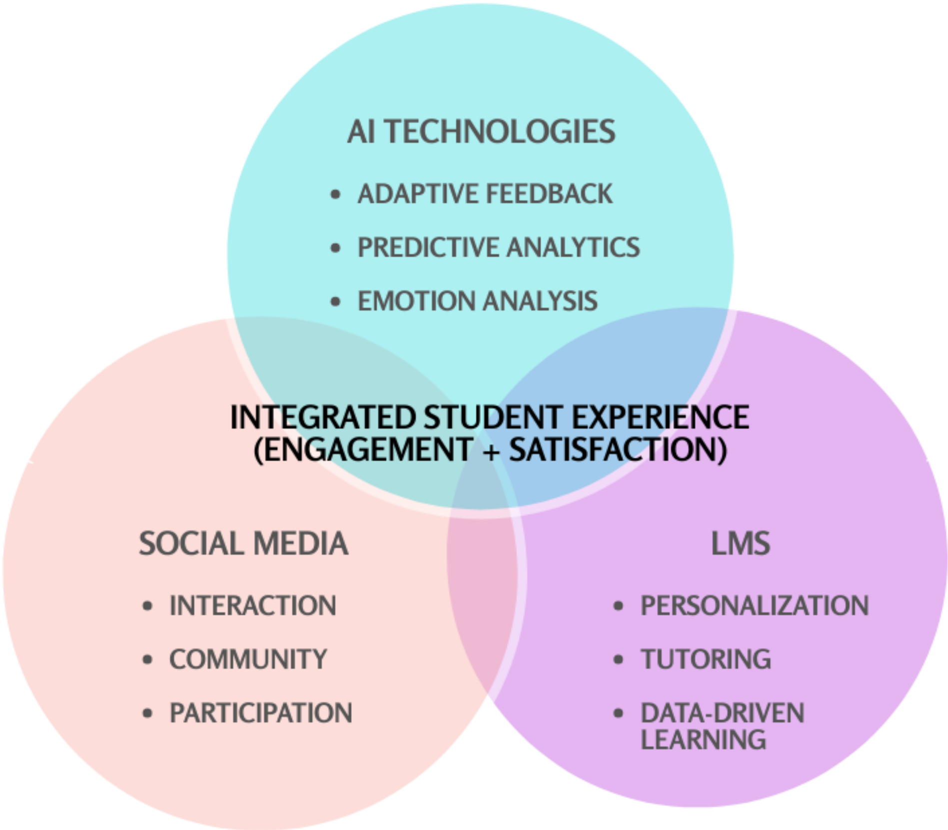

Figure 3: Contribution of each category to student engagement and satisfaction

3.3.1 AI integration within LMS environments

Within LMS environments, AI primarily operates as a supportive mechanism that enhances personalization, feedback and instructional responsivenes which are key drivers of student engagement and satisfaction. Rather than transforming LMS structures, AI tools intensify existing affordances by making learning paths more adaptive and feedback more immediate.

One study introduced a Case-Based Reasoning system acting as a virtual tutor, giving personalized feedback for programming tasks, improving student engagement and satisfaction while reducing teacher workload (Kyrilov & Noelle, 2014).

Later research highlights more advanced data-driven tools. In (Brown et al., 2024) the authorsfound that AI-generated formative practices in an e-textbook LMS increased student reading and interaction, supporting the "doer effect," where active learning improves outcomes and satisfaction. Similarly, (Warford, 2025) studied AI-based annotation tools such as Perusall, which use automated scoring and playful feedback to encourage social learning. While engagement increased, excessive gamification could reduce the perceived value of participation, indicating the need for careful, educationally sound AI use.

One more study examined AI-powered tutoring and predictive analytics in French university LMS, showing that adaptive, data-driven personalization improved engagement and satisfaction by offering individualized support and preventing disengagement (Atmane et al., 2025). However, poor usability and social isolation reduced motivation, highlighting the importance of both technical and emotional considerations. Together, these studies show that AI makes LMS more responsive, personalized, and interactive, with satisfaction arising from both academic performance and digital support.

Overall, these studies suggest that AI enhances LMS-based satisfaction and engagement when it reinforces personalization and feedback while preserving meaningful human interaction.

3.3.2 AI's role in building social and emotional engagement

Beyond cognitive support, AI also contributes to social and emotional engagement, particularly by strengthening perceptions of care, presence, and responsiveness within LMS environments. These factors are closely linked to student satisfaction in online learning.

In (Murdoch & Lin, 2023) online English-Mediated Instruction courses in Korean universities used AI-like adaptive feedback and social networking tools to maintain engagement during the pandemic. Students reported higher satisfaction when data-informed interventions supported communication and instructor presence, suggesting that AI indirectly enhances engagement by reinforcing social connectedness.

In gamified, culturally adapted Japanese literature courses, NLP tools offered adaptive feedback and personalized pacing, while gamification boosted motivation. Engagement increased by over 70%, and satisfaction improved due to more meaningful interactions. However, digital tools may not fully convey cultural elements, reminding educators that AI must fit learning contexts (Unsriana et al., 2025). Similarly, LMS-integrated chatbots in Ukrainian universities provided academic and emotional support during wartime, helping maintain engagement and continuity (Alieksieieva et al., 2025).

Taken together, these studies position AI not as a replacement for social interaction, but as a mechanism that stabilizes and amplifies social presence within LMS environments.

3.3.3 The role of social media In AI-Driven learning

While some studies do not directly foreground AI, research on SM in education provides important context for understanding AI's role in LMS–SM integration. SM platforms have been shown to support collaborative and participatory learning, emphasizing the value of interaction and peer connection (Mbogho, 2017; Stanca & Felea, 2016). These human-centered findings show how SM features such as interaction, instant communication, and peer collaboration resemble what AI tries to automate and improve. When combined with AI analytics, these platforms could offer intelligent moderation, adaptive participation tracking, and personalized social feedback that further deepen engagement.

Web 2.0 technologies have also been examined as part of this evolution, with research describing AI integration as the next step from participatory media toward intelligent learning ecosystems (Zelick, 2013). The move from passive to interactive, student-centered learning through blogs, wikis, and SM has already changed engagement and satisfaction. AI continues this change by adding predictive and emotional analytics to these environments, making interactions more personal and scalable.

3.3.4 Cross-Platform integration of AI for student engagement

Across the reviewed literature, AI consistently enhances engagement and satisfaction by intensifying personalization, interaction, and social presence across LMS and SM platforms. Intelligent chatbots, adaptive recommendations, and emotion-aware analytics support continuous communication and inclusivity, reinforcing key determinants of student satisfaction (Delaney & Redman, 2014).

Importantly, several studies caution against excessive automation. Poorly explained or overly mechanical AI systems can undermine intrinsic motivation and weaken engagement (Atmane et al., 2025; Warford, 2025). The most effective implementations position AI as a supportive layer that augments, rather than replaces, human interaction.

Thus, AI's contribution to digital learning is best understood not as a separate domain, but as an enabling mechanism that strengthens LMS-SM integration, fostering engagement that is both academically and emotionally meaningful.

4. Summary and Discussion

This literature review synthesizes research on how LMS and SM, both independently and in conjunction with AI, influence student satisfaction and engagement in higher education. Particular attention is given to AI-enabled functionalities within LMS and SM environments and how these technologies reshape digital learning experiences. While academic performance is considered where relevant, the primary analytical focus is on how AI-enhanced digital learning ecosystems influence student satisfaction, engagement, and overall student success.

Integration of LMS within blended learning models further boosts motivation, particularly when linked to SM platforms that extend learning beyond formal instructional spaces. For example, a study at the University of Ghana illustrates how combining LMS-based content delivery and assessment with SM-supported discussion can enhance engagement and academic support (Biney & Asamoah, 2023).

The structured environment provided by LMS platforms, along with their ability to facilitate access to educational resources and interactive learning experiences, positively influences student outcomes. LMS-enhanced tools, such as discussion forums, quizzes, and real-time feedback mechanisms, have been shown to increase student engagement and academic performance. Moreover, the incorporation of LMS into blended learning models significantly boosts motivation and participation, particularly when it includes embedded connections to SM platforms. SM, in contrast, serves as a dynamic space for collaboration, fostering peer interaction and informal learning. According to some authors, platforms such as Facebook, X, and WhatsApp enhance student engagement and satisfaction by enabling real-time communication and access to a diverse range of learning materials (Sobaih, A. E. E., Hasanein, A., & Elshaer, I. A., 2022). Importantly, the use of SM in academic settings has been linked to higher motivation and increased knowledge sharing. However, overuse of SM can lead to distractions, reduced cognitive focus, and misinformation, all of which negatively affect academic success.

Despite these advantages, challenges remain in the implementation of LMS and SM-based learning. Certain LMS platforms lack adaptability, and students still face technical barriers, including limited connectivity and usability issues. Moreover, digital inequality continues to pose a significant problem, as students from disadvantaged backgrounds often struggle with technological and financial barriers that hinder their access to digital learning resources. Addressing these challenges requires institutional support, investment in digital infrastructure, and targeted initiatives to improve digital literacy among students. Additionally, the findings suggest that there is still room to optimize the ways LMS platforms are utilized. Universities should provide clear guidelines on the appropriate use of SM in academic settings, ensuring that these platforms enhance rather than detract from the learning experience. Improving LMS usability and functionality can further support student learning.

The fundamental challenge lies in designing a pedagogical model that balances the structured nature of LMS platforms with the informal accessibility of SM, thereby creating an enriched learning experience for students. By effectively integrating LMS and SM, educators can foster a positive learning environment that meets students' needs and promotes greater satisfaction, engagement, and academic success for all involved.

Finally, the integration of AI across both LMS and SM is reshaping student engagement and satisfaction in higher education by fostering adaptive, interactive, and emotionally supportive learning environments. AI's influence extends from personalized learning analytics and intelligent tutoring to socially responsive communication and peer interaction facilitation. The literature consistently affirms that when AI is used ethically and with clear pedagogical purpose, it enhances both engagement and satisfaction by humanizing digital learning spaces. However, sustainable success requires aligning AI's technical capabilities with instructional design principles and social interaction frameworks - ensuring that automation complements rather than replaces the human dimensions of teaching and learning.

Despite promising developments, a significant knowledge gap remains, identification of which is a key scientific contribution of this paper. AI in higher education, especially integrated with both LMS and SM, is a relatively new research area. Only 11 empirical studies were identified, six published since 2020, showing the field is still emerging. This highlights the potential for deeper investigation into structured e-learning environments combining LMS, SM, and AI. Future research could explore how such integrated platforms, with suitable pedagogical methods and ethical frameworks, enhance student motivation, engagement, satisfaction, and learning outcomes.

This research makes an important contribution by showing how LMS AI and SM can work well together and by opening the door to more advanced blended learning systems. AI can make LMS and SM platforms more powerful by offering personalized feedback, instant help for students and interactive virtual classrooms. The study looks ahead to the future of education, where digital tools play a bigger role. Use of new technologies such as AI in combination with well explored approaches such as LMS and SM, could make online learning more flexible and engaging, but only if built on sound methodical framework and existing good.

The findings of this SLR are summarized in the Venn diagram in Figure . illustrating the key benefits and challenges of LMS, SM, and AI.

4.1 Strategies and Policy Recommendations for Diverse Educational Settings

Although LMS, AI, and SM all show benefits to student engagement and academic performance, challenges like digital inequality, limited usability, and inconsistent integration persist, even nowadays. Institutions should aim to improve digital infrastructure and access to ensure all students can connect reliably and use available resources. Promoting digital literacy through training for students and faculty helps them use these technologies more effectively.

Clear guidelines on academic SM and AI use can maximize collaboration and engagement while minimizing distractions and misinformation. Optimizing LMS usability - through mobile compatibility, accessible interfaces, and personalized learning pathways - supports diverse learning needs. Faculty support is important as well, with professional development helping educators integrate AI, LMS and SM to foster ethical and interactive learning. Continuous feedback and evaluation mechanisms can allow institutions to adapt policies and platforms in real time.

Implementing these strategies will enable higher education institutions to create inclusive, engaging and contemporary digital learning environments, enhancing student satisfaction, engagement, and academic outcomes across diverse settings.

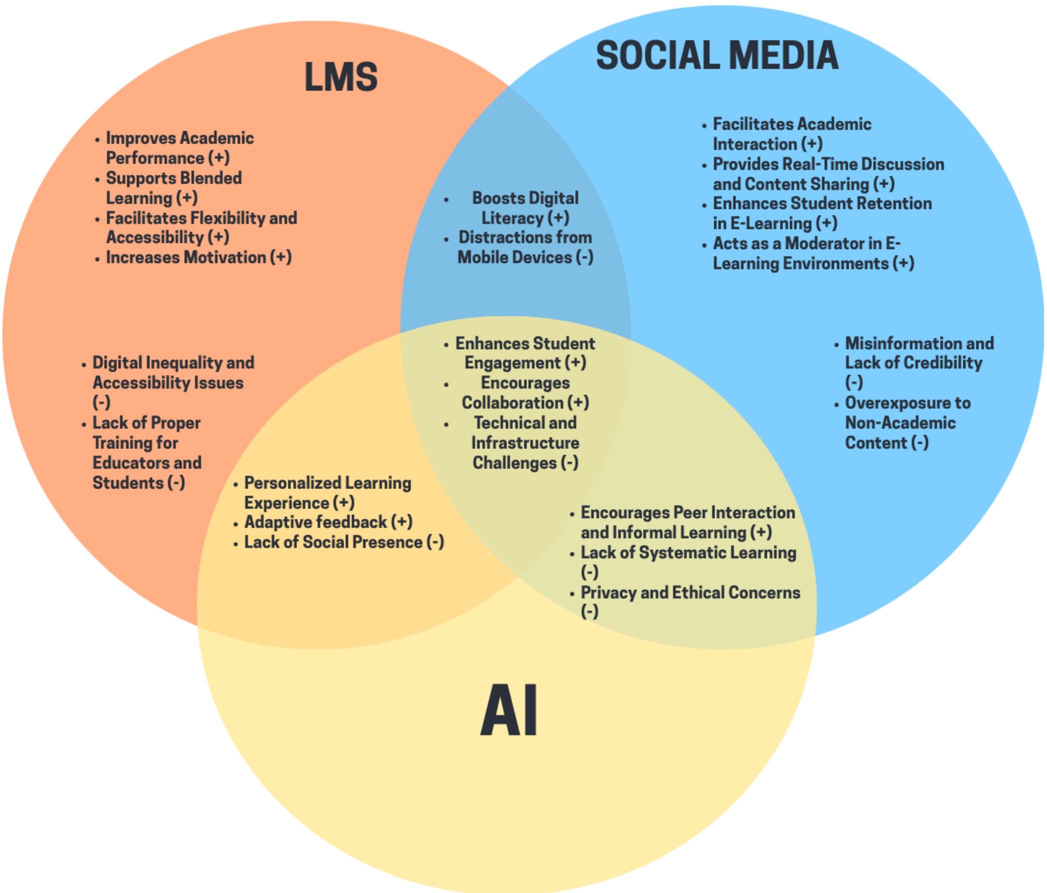

Figure 4: Venn diagram – key benefits and challenges

5. Conclusion and Future Work

This systematic literature review examined how LMS and SM, both independently and in combination with AI, influence student satisfaction and engagement in higher education. The findings indicate that LMS and SM play complementary roles within digital learning environments: LMS platforms provide structure, consistency, and formal academic support, while SM platforms foster interaction, immediacy, and peer-driven learning beyond institutional boundaries. When thoughtfully aligned, these systems can enhance student motivation, engagement, and perceived learning value.

However, the review also shows that despite widespread recognition of the benefits of LMS and SM integration, most existing studies remain descriptive or context-specific. Few propose structured, pedagogically grounded models that clearly define how LMS and SM should be aligned to support learning outcomes in higher education. Reported challenges such as digital distraction, uneven participation, usability constraints, and persistent digital inequalities indicate that integration alone is insufficient without purposeful instructional design and institutional support.

A key contribution of this review lies in its synthesis of emerging evidence on the role of AI within LMS and SM environments. While some studies examine AI-enhanced LMS or AI-supported interaction on SM platforms, the literature reveals a clear absence of empirically validated models that integrate AI, LMS, and SM into a coherent learning ecosystem. This identifies a critical opportunity for advancing digital pedagogy in higher education.

The findings suggest that AI-enabled features including adaptive learning pathways, learning analytics, automated feedback, and conversational agents may help address several limitations identified in LMS-SM integration by supporting personalization, timely intervention, and sustained engagement, particularly in diverse higher education contexts. By clarifying these gaps, this research provides a foundation for improving online and blended learning through a more coherent and pedagogically informed system design, while also informing institutional decision-making related to educational technology planning and curriculum development.

Future research should move beyond exploratory accounts and investigate empirically validated models for AI-enabled LMS-SM integration that are both pedagogically aligned and socially integrated. In particular, longitudinal and mixed-method studies are needed to examine how AI-driven tools, such as chatbots for academic or emotional support, adaptive recommendation engines, and early-warning analytics, influence student motivation, satisfaction, and engagement over time. At the same time, future studies should systematically examine the potential risks associated with AI and SM enabled learning environments, including issues of distraction, over-automation, data privacy, algorithmic transparency, digital inequality, and student well-being. Further research may also explore immersive and virtual social learning spaces, including metaverse-based environments, and their capacity to combine community-building with academic rigor. Overall, this review establishes a pathway toward designing next-generation learning ecosystems that are holistic, adaptive, and student-centered.

AI-enhanced LMS architectures, supported by transparent and ethically governed data practices and human-in-the-loop oversight, have the potential to bridge methodological gaps and promote equitable and impactful digital learning. By aligning the structured design of LMS platforms, the social affordances of SM, and the adaptive capabilities of AI, higher education institutions can cultivate online and blended learning environments that more effectively support student motivation, engagement, and academic success.

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Competing interests: The authors declare that they have no competing interests.

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Appendix 1

Papers that were included in the SLR.

First query output (LMS + SM)	
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Fostering Creativity Through Meta Virtual Project-Based Networked Learning: An In-Depth Examination

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Abstract: This research explores the effectiveness of Meta Virtual Project-Based Networked Learning (Meta VPNL) in fostering student creativity in a fully digital, project-based environment. In the context of 21st-century education, creativity has become an essential skill, driving both economic progress and social innovation. However, traditional education systems often prioritize rote learning and standardized testing, leaving little room for creative exploration. This study investigates how integrating digital tools and collaborative virtual learning can overcome these constraints, thereby offering a more dynamic learning model that promotes creative thinking across domains. The Meta VPNL model was designed to create a flexible, collaborative, and interdisciplinary project environment where students can engage with real-world problems, generate novel ideas, and refine their creative processes. Using an explanatory sequential mixed-methods design, the study combines quantitative and qualitative approaches to assess the impact of the Meta VPNL model on creativity. The quantitative phase involved pre- and post-tests using the Torrance Tests of Creative Thinking (TTCT), assessing four core dimensions of creativity: originality, fluency, flexibility, and elaboration. The qualitative phase included interviews and participant observations to gain deeper insights into student experiences, perceptions, and challenges during the learning process. Results from the study reveal a significant improvement in student creativity across all four dimensions, with fluency and originality showing the most substantial gains. Furthermore, the research highlights the role of prior experience in digital project-based learning, where students with higher levels of prior experience demonstrated enhanced creative performance. Despite the positive outcomes, challenges such as technical issues, inadequate hardware, and group dynamics in virtual settings were reported. However, students were able to overcome these obstacles through collaborative efforts, peer support, and adaptive problem-solving strategies. This study demonstrates that the Meta VPNL model is an effective pedagogical strategy for nurturing creativity in the digital age. It offers valuable insights for educators aiming to integrate technology-driven, project-based learning in classrooms, paving the way for more creative, engaged, and self-directed learners.

Keywords: Creativity, Meta virtual project-based networked learning, Artificial intelligence for learning, Quality education

1. Introduction

In the twenty-first century, scholars and policy-makers alike now agree that creativity drives economic growth and social progress, making its deliberate inclusion in school curricula a pressing concern (Ridwan, Rahmawati, Hadinugrahaningsih, 2021; S.Anagun, 2018). Yet many standard school programs still lean heavily on rote learning and high-stakes tests, leaving little room for students to experiment, daydream, or craft original ideas of their own (Dilekçi and Karatay, 2023). With technology rapidly altering how lessons are planned and delivered, educators are called not only to use digital tools but also to design classroom experiences that spark and sustain creative thought. Recent evidence from a range of educational contexts points to a critical need for persistent attention to creativity, revealing enduring obstacles such as teachers misinterpreting what creative thinking entails (Hashim and Damio, 2023, Mu-dan and Cai, 2020), structural barriers in online learning environments (Mu-dan and Cai, 2020), and the absence of inclusive and formative assessment frameworks (Veber, Pesek, Aberšek, 2023). Therefore, the urge practitioners to build adaptable classrooms, weave creative-process skills into daily tasks, and sustain a habit of reflective evaluation within and outside the lesson (Egwutvongsa, 2023). Creativity dimensions-fluidity, flexibility, originality and elaboration-demand explicit room in curriculum planning, yet even tightly sequenced subjects like mathematics can invite innovative thinking when tasks are framed to question norms and broaden students horizons, while disciplinary learning, such as mathematics, can be reimagined to challenge and expand students' creative perceptions (Aziz and Bakar, 2021; Lubna, Suhirman, Prayogi, 2024). Despite these advancements, fostering creativity remains a complex endeavor that requires sustained innovation in instructional methods and cross-contextual inquiry.

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In today's fast-moving digital age, almost every breakthrough-from new gadgets to social apps-depends on creative thinking. Despite this, many schools still favour rote drills and uniform exams, squeezing imagination out of the routine. Project-based learning (PjBL) steps in as a clearly student-centred answer to that gap. By letting small groups tackle genuine, timed problems, PjBL shifts lessons from quick reviews to serious investigations. Learners therefore master core material while building critical, team, self-management, and creative skills employers now expect.

The advantages of PjBL across different educational settings are magnified when digital technology is woven into the process. Research indicates that a blended PjBL model boosts learners' grammar, comprehension, and vocabulary, resulting in more fluent speaking performance (Hoesny, Setyosari et al., 2024), raises future teachers' awareness of responsible online behaviour (Gu, Ritter et al., 2021), and even shifts educators' views of their responsibilities in a networked world (Avidov-Ungar and Tsybulsky, 2021). Beyond these immediate gains, technology-rich PjBL cultivates both technical and metacognitive competencies that employers increasingly demand from graduate workers (Rohm, Stefl, Ward, 2021), broadens equitable access to scientific content (Fitzgerald and Evans, 2024), uplifts prospective vocational educators' mastery of digital tools (Setuju, Triyono et al., 2024), and sharpens students' overall writing proficiency (Irwandi, Bafadal et al., 2024). Within pre-service teacher programmes, instructors commonly rely on learning-management systems and social-media platforms; nevertheless, research consistently emphasises that careful, ongoing teacher guidance is what ultimately transforms good design into meaningful student learning outcomes (Rahmawati, Suryani et al., 2020). Taken together, these findings portray digitally enriched PBL as a relevant, flexible, and powerful pedagogical strategy for equipping learners with the skills they need to thrive in an increasingly digital age.

Yet, even with its proven advantages, classroom-based project work continues to face challenges related to distance, costs, and uneven access to tools. In response, Meta Virtual Project-Based Networked Learning reimagines the approach in a wholly online setting. By using digital platforms, the model enables nimble, far-reaching collaboration that can occur anytime, anywhere, well beyond the walls of any single school.

The study aims to provide both theoretical insight and practical guidance for designing project-based digital learning environments that genuinely enhance student creativity. Accordingly, it will evaluate how the proposed Meta Virtual Project-Based Networked Learning (Meta-VPNL) model influences four core creative dimensions-originality, fluency, flexibility, and elaboration- and measure the resulting creative performance in a fully virtual classroom. Researchers also aim to document learners' experiences and the obstacles they confront while working online so that educators have a richer, firsthand account of the model's everyday operation. Collectively, the data should clarify how purposeful technology use, responsive instructional design, and peer-centered online collaboration combine to cultivate creative and other essential twenty-first-century skills. From these findings, practical recommendations will emerge, guiding universities toward more relevant, forward-thinking pedagogies that align with the digital era. To fulfill this agenda, the inquiry is framed around three interrelated research questions:

RQ1: To what extent is the Meta VPNL model effective in enhancing student creativity based on the four dimensions of creativity (originality, fluency, flexibility, and elaboration)?

RQ2: How do students' experiences and perceptions of the Meta VPNL model shape their creative development, and how do the challenges encountered affect their learning outcomes?

2. Literature Review

2.1 Creativity in Education

Creativity in education is widely acknowledged as a vital skill, yet it lacks a single, universally accepted definition. Foundational scholars have offered influential perspectives: Torrance views creativity as a process involving the generation of original ideas through divergent thinking, while Guilford emphasizes cognitive aspects such as originality and fluency within problem-solving contexts (Aziz and Bakar, 2021, Gültepe, Akben et al., 2025). Meanwhile, highlights the central role of intrinsic motivation, asserting that creativity flourishes when individuals are genuinely engaged and self-driven (Mejía, D'Ippolito, Kajikawa, 2021). These perspectives converge on four key dimensions commonly used to describe creativity: originality (the uniqueness of ideas), fluency (the quantity of ideas), flexibility (the ability to shift thinking approaches), and elaboration (the depth and detail in ideas) (Fatmawati, Jannah, Sasmita, 2022; Hendrik, Ali et al., 2022). In the context of 21st-century education, creativity is considered a core competency essential for preparing students to navigate complex, fast-changing environments, particularly in fields such as STEM, where innovation, adaptability, and collaboration are paramount (Rahimi, Smith et al., 2024, Yang, 2023).

The cultivation of creativity, therefore, encounters several systemic hurdles. Most school systems, long accustomed to ranking students, lean heavily on standardised tests and memorisation; practices that routinely sweep over deeper, more inventive thinking (Can and Burakgazi, 2022, Zemljak and Virtič, 2022). Compounding this, many teachers have not been prepared in creative methods, so what little innovation does appear in classrooms is patchy and unreliable (Constant, Friston, Clark, 2023; Roth, Conradty, Bogner, 2021). Moving past these blockades requires deliberate reform that weaves creativity into curricula and provides educators with the ongoing training they need to cultivate it with confidence. At its heart, creativity blends originality, fluency, flexibility and elaboration-a blend universities now see as vital to success in a fast-changing world.

2.2 The Need of Creativity Skills in the 21st Century for Learners

In 21 Lessons for the 21st Century, Yuval Noah Harari underscores the growing centrality of creativity as the quintessential human faculty in an era increasingly dominated by automation. Harari contends that as algorithms and robotics transform entire economies by displacing jobs built upon repetition, the singular human aptitude for inventive thought emerges as the principal site of competitive advantage (Harari, 2019). Increasingly, routine operations that once demanded human labour now yield to more efficient machines, thereby rendering the cultivation of imaginative and unconventional problem-solving capacity imperative (Dilekçi and Karatay, 2023). Creativeness, in Harari's view, is not reserved for the conventional arts alone; it is equally demanded of every professional sphere in which obstacles are novel, requisite adaptation is immediate, and the pace of external change is relentless. He suggests that the power to innovate will prove decisive in confronting the intricate, contingent challenges of a society in ceaseless, rapid flux, with special reference to domains such as medicine, engineering, corporate strategy, and civic advancement.

Harari's analysis parallels a broader international discourse advocating for expanded creativity learning in educational settings. Rapidly accelerating technological upheaval has rendered static instructional regimes anchored in memorisation, time rigidity, and uniform evaluation fundamentally inoperative for foresighted social planning (Harari, 2019). Consequently, all education systems face an imperative of purposeful transformation. The author's prognosis posits that future learning environments will centre on competencies in creative and critical cognition, capacities deemed indispensable for adaptive citizenship in an unpredictable, algorithmic economy. To Harari, imaginative agility transcends vocational preference; it constitutes a generalised competency requisite for deciphering multifaceted contemporary challenges. Consequently, contemporary classrooms must recalibrate away from hierarchically ordered, imitation-transmission sequences that explicitly sanction intellectual conformity (Fourniyati, Nuswowati, Cahyono, 2020; Gu, Ritter et al., 2021). Educators are charged instead with cultivating iterative, inquiry-based paradigms that incentivise experiential discovery, collaborative inquiry, and responsible creative experimentation.

This vision aligns with contemporary educational reform initiatives that advocate the deliberate cultivation of creative thinking across all curricular domains, from STEM fields to the humanities. Increasingly, stakeholders urge schools to offer sustained, open-ended investigations, interdisciplinary courses, and collaborative, problem-based learning experiences, each of which is designed to activate and amplify the latent creative capacities of all learners (Harari, 2019). Harari's scholarship underscores that, for students to flourish in the 21st Century, the educational enterprise must move beyond the mere transmission of factual content to the deliberate cultivation of generative thought and innovative action. Such an evolutionary shift is not an optional enhancement, but a fundamental prerequisite for equipping the forthcoming cohort to navigate the multifaceted challenges and asymmetric opportunities that will define the coming epoch.

2.3 Project-Based Learning (PjBL) in Education Activities

Project-Based Learning (PjBL) positions learners at the centre of sustained, open-ended projects that resemble real-world issues, thereby connecting theoretical material to hands-on practice. Central to the model are student initiative, prolonged teamwork, and inquiry across weeks or months, as groups formulate compelling questions, investigate them, build, test prototypes, and step back to evaluate what worked and why (Budiarti, Johari et al., 2022; Melkonyan, Tanajyan, Khachatryan, 2024). Because each project typically draws on science, art, mathematics, and other disciplines, the experience does not feel contrived; instead, it unfolds as an authentic interdisciplinary narrative (Ridwan, Rahmawati, Hadinugrahaningsih, 2021). Multiple studies show that creativity flourishes under this structure: when students face loosely defined problems, they must generate and revise novel options, rather than reciting memorized steps (Mite, Eveline, Situmorang, 2021). Bell argues that the controlled space PjBL provides encourages learners to tinker with ideas, try different strategies, and fail productively, habits strongly associated with advanced cognitive processes (Almulla, 2020). Interpersonal production reinforces mastery because explaining logic to teammates and conveying understanding through videos, reports, prototypes, or code both clarify an individual's knowledge and reveal gaps.

Framing projects within online platforms then maintains enthusiasm and broadens toolboxes for planning, recording and globally sharing work, amplifying authenticity, speeding feedback and encouraging iteration. In short, Project-Based Learning fosters creativity because it ties classroom tasks to fundamental questions and collaborative problem solving, which increases when instructors purposely integrate technology into the projects. Studies repeatedly show that this model lifts students' artistic capacities and overall interest in school, making it a promising tactic for the progressive classrooms of the future.

2.4 Meta Virtual Project-Based Networked Learning (Meta VPNL)

Meta-Virtual Project-Based Networked Learning builds on conventional project-based learning by situating all learning tasks in rich, shared online environments. New hardware and software tools across the education ecosystem provide constant connectivity, low-latency interaction, remote collaboration, and a persistent sense of virtual presence for students and instructors alike (Fourniyati, Nuswowati, Cahyono, 2020; Sungkono and Ekaputra, 2023). Participants from different countries undertake interdependent activities, jointly refining research questions, prototype designs, and evaluation criteria through a single, unified suite of digital dashboards and applications. The entire experience rests on three banners: virtuality, which grounds the curriculum in an always-on simulated campus; connectivity, which links learners, mentors, and tools with cross-device, real-time messaging; and interactivity, which opens space for instant feedback, peer dialogue, and instructor coaching as each project milestone appears (Faridah, Salahudin et al., 2021, Khusnul, Sumarno et al., 2025).

Preliminary studies of networked learning indicate a consistent, positive link to creativity, with evidence suggesting that the collaborative framework of Meta VPNL can notably enhance learners' imaginative products (Khusnul, Rusijono, Andi, 2024). In a similar vein, Melisa and colleagues document that participants in networked project-based learning exhibit greater motivation and more inventive thought, attributing these gains to the broad array of viewpoints exchanged within the online community (Melisa, Nawahdani, Alam, 2024). Wangs review further asserts that such environments enrich the creative context by facilitating information sharing and sustained collaboration, cornerstones of innovative cognition (Wang, 2022). Because these virtual classrooms are flexible and fast-moving, they urge learners to test theories, tinker with tools, and confront problems under changing conditions, strengthening both digital skills and adaptive problem-solving (Wang, Tie et al., 2023). Collectively, this blend of responsive, technology-rich space and project-driven inquiry widens access to knowledge while cultivating critical reason, experimentation, and creative expression. Thus, Meta VPNL offers a forward-looking pedagogical model that integrates virtual teamwork with PjBL tenets, thereby laying a solid foundation for richer, more interconnected, and interactive learning experiences. A growing body of evidence now shows that when project-based work is paired with well-organised digital platforms, students gain in creative thinking (Ekayana, Parwati et al., 2025; Yustina, Syafii, Vebrianto, 2020). Still, few studies have used established tools such as the TTCT in online settings, leaving a gap in our overall picture of how models like Meta VPNL affect creativity. Hence, future work should not only measure Meta VPNL quantitatively but also connect these metrics to teaching strategies that foster exploration, collaboration, and reflection within a structured digital space.

2.5 Theoretical Framework

The theoretical framework behind Meta Virtual Project-Based Networked Learning (Meta VPNL) deliberately draws on a suite of established educational theories that illuminate the links between learning and creativity. Core constructivist ideas from Piaget and Vygotsky suggest that learners build knowledge most effectively when they engage actively with peers, artifacts, and social contexts (Alhassan, Akparep, Ngmenkpieo, 2022; Hashim and Damio, 2023). This view closely aligns with Meta VPNL's insistence that students tackle real-world problems in virtual spaces, a practice that makes learning purposeful, collaborative, and embedded in meaningful situations. Vygotsky's attention to dialogue and joint activity shows up in faculty-designed projects that cultivate a community of practice where peer-to-peer mentorship becomes routine (Rahayuningsih, Kamaruddin et al., 2024). Taken together, these strands argue that a well-structured, dynamic online environment enhances intrinsic motivation and, in turn, yields higher levels of creative output within the Meta VPNL model.

Networked Learning Theory backs the idea that online learning is first and foremost a social activity, a point made by Goodyear and Siemens and echoed in more recent studies (Kim, Grijalva et al., 2023, Malik, Nadeem et al., 2022). According to this framework, new ideas emerge not from solitary study but from the back-andforth exchanges among students, with technology acting as the bridge that connects distant locations and sparks collective creativity. The theory thus underpins the current investigation, which plans to measure student inventive thinking using both widely accepted tests and real-world assignments. By emphasizing interaction as the engine of online courses, Networked Learning Theory shows how learners co-build knowledge and freely experiment with solutions in varied settings. When viewed together, these insights make the Meta VPNL model appear to be a solid system for boosting creativity through guided teamwork and, crucially, through empowering students to take charge of their own learning journeys.

3. Method

3.1 Study Design

By embedding project-based teaching in persistent, collaborative, and networked digital contexts, Meta VPNL enhances it. Conventional teaching uses episodic lectures, inert texts, and isolated tasks to teach pupils without applying knowledge outside the classroom. Meta VPNL challenges students to solve real, complicated problems, form diverse international teams, and use digital tools like asynchronous forums and interactive modeling software to innovate and inquire. VPNL transforms subject mastery into systems thinking, invention, and negotiation, helping students synthesize information, create new replies, and criticize peer work. Importantly, the architecture embraces the unknowable difficulties of the 21st century, featuring an agile, multimodal classroom that can bridge disciplinary and temporal divisions and skills and scaffolding that will be instantly useful after the educational moment.

The research adopted an explanatory sequential mixed-methods design to assess how the model influences student creativity (McKim, 2017). In the initial quantitative phase, survey scores were collected and analyzed to measure shifts in four creativity dimensions: originality, fluency, flexibility, and elaboration. Following this, a qualitative phase used interviews and focus groups to explore learners' experiences and perceptions, thus clarifying and contextualizing the earlier numerical findings about their engagement with Meta VPNL activities (Leech and Onwuegbuzie, 2009).

3.2 Participants

The study drew its participants from the Audio/Radio Media Development course offered at the State University of Surabaya in Indonesia. Researchers chose this class because its design, which is completely centred on project-based learning, digital media production, and team assignments, aligns with the goals and tools of the Meta Virtual Project-Based Networked Learning (Meta-PVNL) model. In all, 184 students volunteered, coming from different classes but still the same department. Ethical approval was secured prior to the study, and all volunteers signed informed-consent forms confirming their willingness to participate (Asenahabi and Peters, 2023).

3.3 Intervention

In this study, researchers integrated the Meta Virtual Project-Based Networked Learning (Meta-VPNL) model into a virtual classroom to guide the instructional design. Working through the university's adapted Learning Management System, students took part in organized project activities that required them to collaborate across disciplines while addressing complex problems, with the platform intentionally modified to support four creativity dimensions: originality, fluency, flexibility, and elaboration. The model was rolled out in a sequenced manner: Needs Assessment & Goal Setting identified student and course requirements; Orientation Platform Virtual introduced relevant technologies; Project Planning structured tasks; Design & Implementation involved executing project work; Collaboration coordinated distributed teams; Assessment & Reflection guided formative evaluation; and, finally, Evaluation & Exhibition showcased results. As shown in Figure 1, each phase includes concrete subtasks that prompt idea exploration, online teamwork, and the creative application of knowledge to authentic challenges.

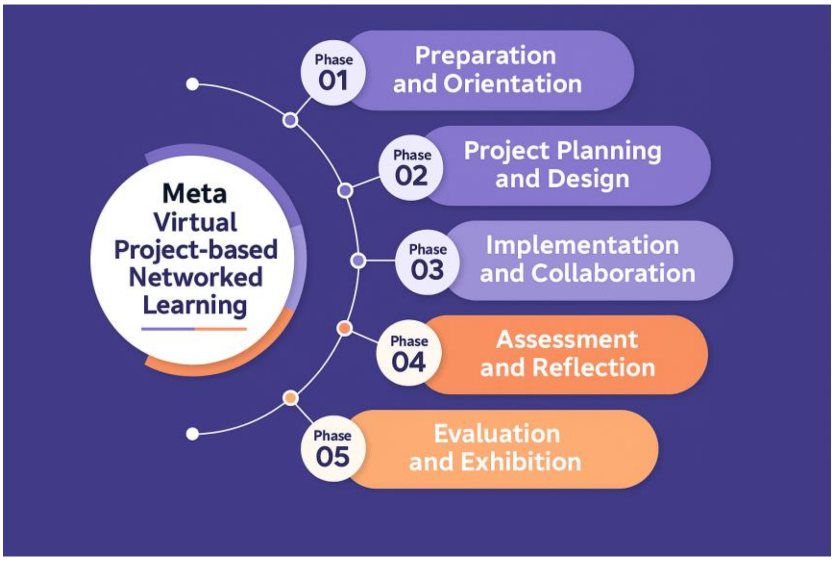

Figure 1: The Meta Virtual Project-based Networked Learning

Figure 2 presents detailed information on the Meta VPNL syntax. In sum, this orderly sequence of activities aims to develop students' creative skills within a digital, networked learning environment.

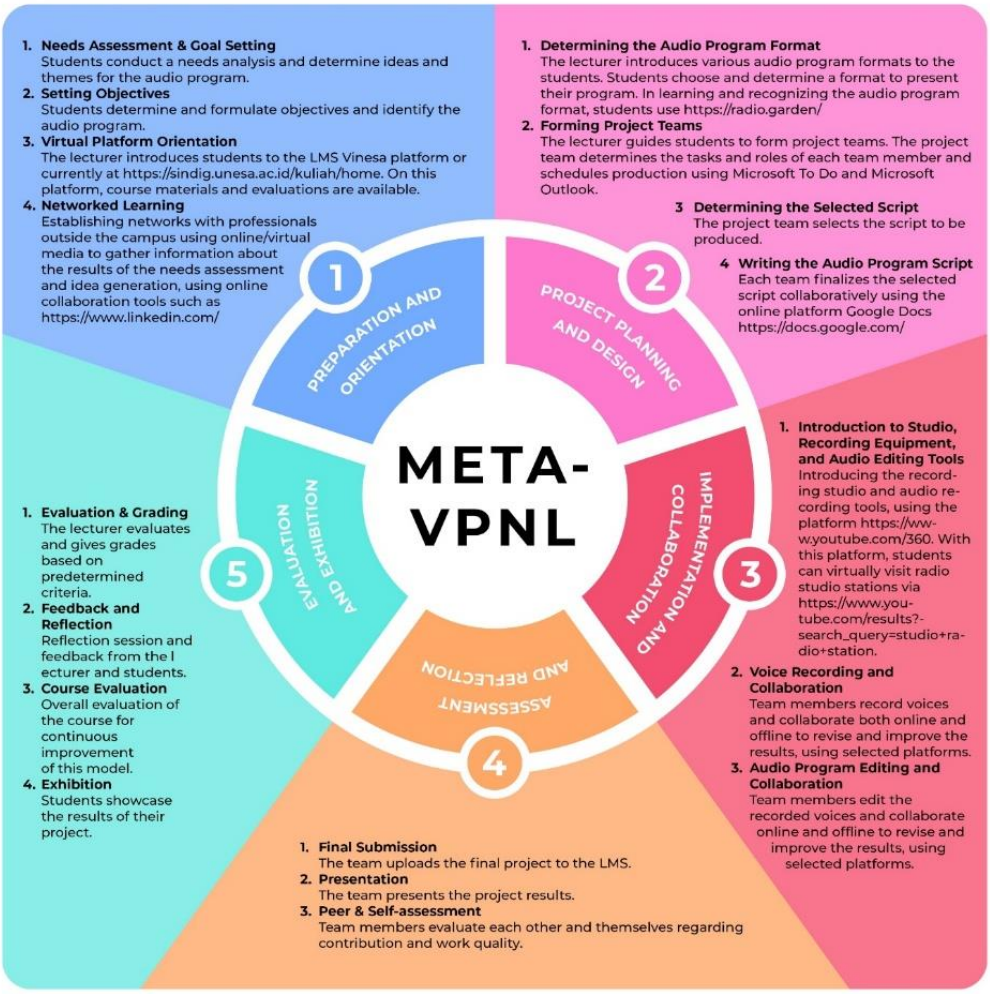

Figure 2: The Meta Virtual Project-based Networked Learning's Steps

3.4 Data Collection and Research Instrument

This study employed a combination of quantitative and qualitative instruments to comprehensively assess the impact of the Meta Virtual Project-Based Networked Learning (Meta VPNL) model on students' creativity.

Quantitative data were collected using two instruments. First, the Torrance Tests of Creative Thinking (TTCT) were administered in both pre-test and post-test formats to measure four key components of creativity: originality, fluency, flexibility, and elaboration. These components were assessed using standardized scoring guidelines provided by the TTCT manual. The rubric employed a four-level scale (novice to expert) for each assessed dimension. Prior to its full implementation, the rubric underwent expert review and a pilot test to ensure its content validity and reliability. The table 1 shows the instrument blueprint of Torrance Test of Creative Thinking (TTCT).

Table 1: Instrument Blueprint – Torrance Tests of Creative Thinking (TTCT)

No	Assessed Component	Operational Definition	Indicator	Instrument
1	Originality	Ability to produce unique or uncommon ideas	Unusual and original ideas that differ from the norm	TTCT
2	Fluency	Ability to produce a large number of ideas	The quantity of ideas generated within a given task	TTCT
3	Flexibility	Ability to shift perspectives or approaches to problem-solving	Range and variation in ideas within a given task	TTCT
4	Elaboration	Ability to develop and expand ideas in detail	Level of detail and enrichment in idea development	TTCT

Adapt from research (Avcı & Yildiz Durak, 2023; Jia et al., 2019; Saeed & Ramdane, 2022)

As for table 2 illustrates the creative performance rubric and was adapted from (Anita Rahmawaty et al., 2021; Barron & Harackiewicz, 2003; Wiyono et al., 2021)

Table 2: Instrument Blueprint – Creative Performance Rubric

No	Assessed Aspect	Operational Definition	Performance Criteria	Instrument
1	Idea Generation	Ability to generate original ideas in audio-based projects	Novice – Developing – Proficient – Expert	Performance Rubric
2	Problem-Solving Ability	Ability to independently resolve issues during project work	Novice – Developing – Proficient – Expert	Performance Rubric
3	Use of Learning Media	Creativity in the use of audio and digital media	Novice – Developing – Proficient – Expert	Performance Rubric
4	Collaboration	Effectiveness in working within a networked, collaborative virtual environment	Novice – Developing – Proficient – Expert	Performance Rubric

Adapt from research (Anita Rahmawaty et al., 2021; Barron & Harackiewicz, 2003; Wiyono et al., 2021)

To deepen understanding of the numeric results, researchers gathered qualitative evidence through semi-structured interviews and participant observations. These methods sought to probe students' learning experiences, views on creative growth, and obstacles faced while using the Meta VPNL model. By combining multiple sources, the team enhanced both the credibility and richness of the overall findings. A detailed overview of the qualitative tools can be seen in Table 3.

Table 3: Instrument Blueprint – Qualitative Data Collection

No	Explored Aspect	Indicator	Data Collection Method	Instrument
1	Learning experience with Meta VPNL	Descriptions of activities, interactions, and student reflections	Semi-structured interview	Interview Guide
2	Perceived creativity improvement	Student narratives regarding the development of creative skills	Semi-structured interview	Interview Guide
3	Support and barriers in virtual learning	Accounts of technical or non-technical challenges	Participant observation	Interview Guide

3.5 Research Hypothesis

In line with the explanatory sequential mixed-methods design, the study formulated explicit hypotheses to guide the quantitative analysis. Hypothesis testing was conducted to determine whether the Meta Virtual Project-Based Networked Learning (Meta VPNL) framework produced measurable effects on student creativity as assessed by the Torrance Tests of Creative Thinking (TTCT). The hypotheses were established as follows:

- **Null Hypothesis (H_0):** There is no significant difference in students' creativity scores between the pre-test and post-test when using the Meta VPNL framework.
- **Alternative Hypothesis (H_1):** Students' creativity scores will significantly improve across the four dimensions of creativity (originality, fluency, flexibility, and elaboration) after participating in the Meta VPNL framework.

3.6 Data Analysis

The analysis followed an explanatory sequential mixed-methods design, beginning with a quantitative investigation. Creators' originality, fluency, flexibility, and elaboration scores, gathered from the Torrance Tests of Creative Thinking and a custom rubric, were summarized using descriptive statistics (Mishra, Pandey et al., 2019). Subsequently, a paired-sample t-test revealed whether mean pre-test and post-test scores differed significantly, providing evidence for the overall impact of the Meta VPNL intervention. To explore how student background moderated that impact, a one-way ANOVA compared post-intervention performance across subgroups defined by prior experience and class section. All tests were conducted in SPSS, and results were considered statistically significant at $p < 0.05$. To supplement the quantitative findings, interview transcripts and field notes from participant observations were examined thematically, in line with Braun and Clarke's six-step guide (Sofaer, 2002). This qualitative layer surfaced students' views, lived experiences, and hurdles with online teamwork and creative work, thus weaving together statistical patterns and rich stories for a fuller reading of how the Meta VPNL framework operates.

4. Research Findings

4.1 Enhancing Creativity Through Meta VPNL: Evidence from Paired t-Test Results

The Meta VPNL model was implemented to enhance students' creativity scores (N=184) across all four dimensions. The average total score increased from 52.50 (SD=12.44) in the pre-test to 69.88 (SD=14.92) in the post-test, a 17.38 point (33.1%) increase. The Fluency dimension exhibited the most significant growth (M=4.85), followed by Originality (M=4.33), Elaboration (M=4.27), and Flexibility (M=3.93). The Meta VPNL model's efficacy in enhancing creativity, particularly in the Fluency element, was demonstrated by the distribution of post-test scores, which indicated that the majority of students (67.9–71.7%) were in the medium category in all dimensions. Fluency had the highest proportion in the medium category (71.7%), while Flexibility had the highest proportion in the low category (19.0%) in accordance with the information provided in table 4.

Table 4: Descriptive Statistics and Distribution of Creativity Score Categories for Pre-test and Post-test

Dimension	Pre-test		Post-test		Difference	Post-test (%)		
	Mean	SD	Mean	SD	Mean	Low (≤25%)	Moderate (26-75%)	High (≥76%)
Originality	12.45	2.85	16.78	2.62	4.33	14.3	61.9	23.8
Fluency	14.82	3.24	19.67	2.95	4.85	9.5	66.7	23.8
Flexibility	11.96	2.78	15.89	2.53	3.93	19.0	66.7	14.3
Elaboration	13.27	3.02	17.54	2.71	4.27	14.3	71.4	14.3
Average Creativity Score	13.13	2.41	17.47	2.15	4.34	-	-	-

Note: Mean and SD are calculated from pre-test and post-test scores. The mean difference reflects the improvement in scores after the intervention. The categorical distribution is for post-test scores only.

To assess the significance of pre- and post-implementation differences in creativity scores, a paired-samples t-test was conducted (Table 5). The analysis indicated a statistically significant increase across all four dimensions of creativity.

Table 5: Paired Sample t-Test Results for Creativity Dimensions

Creativity Dimension	t-value	df	p-value	95% CI		Cohen's d
				Lower	Upper	
Originality	-14.78	183	<0.001*	-4.91	-3.75	1.20
Fluency	-13.95	183	<0.001*	-5.54	-4.16	1.09
Flexibility	-12.84	183	<0.001*	-4.53	-3.33	1.01
Elaboration	-13.42	183	<0.001*	-4.90	-3.64	1.04
Average Creativity Score	-16.89	183	<0.001*	-4.97	-3.72	1.29

*Description: * p < 0.001 (very significant), CI = Confidence Interval, df = degree of freedom*

The statistical analysis revealed that implementing the Meta Virtual Project-Based Networked Learning (Meta VPNL) model resulted in a statistically significant increase across all dimensions of student creativity, as indicated by paired-samples t-tests ($p < 0.001$). This improvement was observed consistently in all four creativity components: originality, fluency, flexibility, and elaboration. Among these, the most substantial gain in absolute terms occurred in fluency, with an average increase of +4.85 points, while the highest percentage increase was found in originality (34.8%). These results suggest that the structured, collaborative, and digitally mediated learning environment provided by the Meta VPNL model effectively supported students in developing a broader range of ideas, generating more original outputs, and refining their creative thinking processes. The findings affirm the model's potential to enhance essential creative skills, particularly in the context of digital media-based project learning.

4.2 Unpacking Group Variations in Creative Performance: Insights from ANOVA and Rubric Evaluation

A one-way ANOVA analysis was conducted to assess the variations in total creativity scores following the implementation of the Meta VPNL model. The analysis was based on two classification factors: class (A, B, C, and D) and prior experience level in digital project-based learning (low, medium, or high). Table 6 presents the ANOVA results and descriptive statistics. Each of the four classes (A, B, C, and D) comprised 46 students. The mean total creativity scores across the classes differed slightly, with Class A having the highest average (M = 71.24, SD = 14.15) and Class C having the lowest (M = 68.95, SD = 14.86). The ANOVA test results indicated that there was no significant difference in creativity scores between the courses ($F(3,180) = 0.229$, $p = 0.876$, $\eta^2 = 0.004$). These results suggest that the Meta VPNL model consistently enhances pupil creativity in all classes, irrespective of class differences.

Participants were classified into three groups according to their past experience level: low (n = 62), medium (n = 78), and high (n = 44), as shown in Table 6. The high experience group achieved the greatest mean creativity score (M = 73.82, SD = 15.44), succeeded by the medium group (M = 70.67, SD = 14.92) and the low group (M = 66.45, SD = 13.89) (Table 6). ANOVA analysis indicated a significant disparity in creativity scores according to prior experience level ($F(2,181) = 4.38$, $p = 0.014$, $\eta^2 = 0.046$). The impact size ($\eta^2 = 0.046$) suggested that past experience level exerted a minor to moderate influence on the variability of creativity ratings. The findings indicate that students with greater prior experience in digital project-based learning tend to demonstrate enhanced creativity following engagement with the MetaVPNL paradigm. The analytical results indicated that the Meta VPNL model effectively enhanced student creativity across classes, particularly among students with greater prior experience in digital project-based learning.

Table 6: Descriptive Statistics and ANOVA Test Results of Total Creativity Scores Based on Class and Experience Level

Group	N	Mean	SD	95% CI (Lower, Upper)	F	p-value	η²
Based on Class					0.229	0.876	0.004
Class A	46	71.24	14.15	(67.04, 75.44)			
Class B	46	69.78	15.42	(65.21, 74.35)			
Class C	46	68.95	14.86	(64.54, 73.36)			
Class D	46	69.54	15.18	(65.06, 74.02)			

Group	N	Mean	SD	95% CI (Lower, Upper)	F	p-value	η²
Based on Performance					4.38	0.014*	0.046
Low	62	66.45	13.89	(63.02, 69.88)			
Moderate	78	70.67	14.92	(67.31, 74.03)			
High	44	73.82	15.44	(69.13, 78.51)			

*Note: *p < 0.05. The F-value, p-value, and η² for the ANOVA test are shown in the main group row.*

Meanwhile, to identify which groups differ significantly, a Tukey HSD post-hoc test was conducted (table 7).

Table 7: Tukey HSD Post-hoc Results for Experience Level

Comparison	Mean Difference	SE	p-value	95% CI	
				Lower	Upper
Moderate vs. Low	4.22	2.13	0.117	-0.73	9.17
High vs. Low	7.37*	2.52	0.011	1.49	13.25
High vs. Moderate	3.15	2.42	0.403	-2.50	8.80

Post hoc analysis revealed that students with extensive experience exhibited significantly higher originality scores than those with no experience (p = 0.011, difference = 7.37 points). The evaluation of students' creative performance (N = 184) utilizing a rubric with a 1–4 scale across four dimensions revealed that Use of Learning Media attained the highest mean score (M = 2.89, SD = 0.76), with 53.3% of students classified as Proficient. This was followed by Collaboration (M = 2.84, SD = 0.82; 50.0% Proficient), Idea Generation (M = 2.78, SD = 0.84; 48.4% Proficient), and Problem-Solving Ability (M = 2.65, SD = 0.79; 44.6% Proficient). The mean Total Rubric Score was 11.16 (SD = 2.81) (Table 8). The score distribution indicates that most students are at the Proficient level across all dimensions, with Use of Learning Media exhibiting the highest performance, hence demonstrating the efficacy of the Meta VPNL model in facilitating the innovative application of learning media.

Table 8: Descriptive Statistics and Frequency Distribution of Creative Performance Rubric Assessment

Aspect	Mean	SD	Novice (%)	Developing (%)	Proficient (%)	Expert (%)
Idea Generation	2.78	0.84	9.8	29.3	48.4	12.5
Problem-Solving Ability	2.65	0.79	12.5	33.2	44.6	9.8
Use of Learning Media	2.89	0.76	6.5	26.1	53.3	14.1
Collaboration	2.84	0.82	8.7	28.1	50.0	13.0
Total Rubric Score	11.16	2.81	-	-	-	-

The correlation study demonstrated a substantial positive association between all dimensions of the Torrance Tests of Creative Thinking (TTCT) and the evaluated components of the creative performance criteria (Table 9). Robust correlations were identified between the overall TTCT score and Idea Generation (r = 0.534), as well as with the total rubric score (r = 0.548), signifying a substantial level of convergent validity between the two measures employed to assess creativity. Subsequent study of group performance and rubric evaluations revealed numerous significant findings. The implementation of the Meta VPNL model exhibited uniform effects across all class sections, indicating the lack of bias associated with class grouping. Secondly, students possessing greater prior expertise in digital project-based learning demonstrated enhanced creative performance relative to their less experienced counterparts. Third, regarding rubric-based performance, most students attained a proficient level throughout the evaluated dimensions, with Use of Learning Media identified as the highest-performing element. These findings collectively affirm the efficacy of the intervention and the dependability of the assessment instruments in capturing varied manifestations of student creativity.

Table 9: Pearson Correlation between TTCT Scores and Rubrics

Dimension of TTCT	Idea Generation	Problem-Solving	Media Use	Collaboration	Total Rubric
Originality	0.542**	0.378**	0.421**	0.356**	0.501**
Fluency	0.487**	0.423**	0.398**	0.389**	0.486**
Flexibility	0.398**	0.512**	0.367**	0.434**	0.478**

Dimension of TTCT	Idea Generation	Problem-Solving	Media Use	Collaboration	Total Rubric
Elaboration	0.465**	0.389**	0.523**	0.401**	0.502**
Total TTCT	0.534	0.467	0.481	0.436	0.548

$^{**}p < 0.01$

4.3 Creativity in Action: Student Reflections on the Meta VPNL Experience

The qualitative study drew on semi-structured interviews with twenty-four students selected purposefully to represent a wide range of creative expression and involvement in Meta VPNL activities. These interviews were enriched by field notes gathered during twelve weeks of continuous participant observation, providing a deeper context for the interaction patterns within the virtual learning environment.

Thematic analysis of student interviews revealed three broad experiences during the course: active engagement, meaningful collaboration, and facilitated self-directed exploration. First, learners almost unanimously reported being more alert and invested than they were in conventional classroom settings, a shift most noticeable while making audio content; many described losing track of time in discussion forums, experimenting with unfamiliar tools, and pitching original solutions to artistic challenges that arose along the way. System logs support that recollection, showing average weekly time in the course jumping from an early baseline of forty-five minutes to roughly one hundred twenty-seven minutes by the final week. Meaningful collaboration deepened, participants argued, because the online format compelled them to monitor time-zone differences, upload files to shared drives, and leave comments with built-in annotations. Facing tight deadlines, respecting one another's expertise, and revising drafts in public view, they explained, exposed them to viewpoints they might never meet in a localized studio environment. That qualitative benefit is mirrored in the metrics: the average number of weekly peer messages grew from about twelve in the earliest weeks to roughly thirty-four as major submission dates approached.

Students consistently praised the flexible project scaffolding, remarking that the freedom to choose their own topics enhanced their capacity for self-directed learning. On-demand guides and carefully curated links supported these independent inquiries, allowing each learner to steer his or her path while still satisfying course objectives. Usage data confirms the student feedback: weekly resource views have averaged 7.8 per learner, up from 3.2 only a semester ago. Collectively, this evidence implies that the Meta VPNL framework is fostering an interactive, collaborative climate that builds learner autonomy and, in turn, fuels creative development. A summary of these metrics appears in Table 10.

Table 10: Summary of Thematic Findings on Student Experiences in Meta VPNL

Theme	Key Findings	Supporting Evidence
Active Engagement	Students showed high participation and creative experimentation	LMS usage time increased (45 to 127 minutes/week)
Meaningful Collaboration	Students developed teamwork and feedback skills in a virtual setting	Peer interactions increased (12 to 34 per week)
Facilitated Self-Exploration	Students engaged in self-paced learning and accessed additional resources	Resource access increased (3.2 to 7.8 per week)

Despite the overall positive impact of the Meta VPNL model on student creativity, the implementation process was not without challenges. Thematic analysis of interview and observational data revealed three major areas of concern: technical limitations, initial adaptation to the virtual environment, and group dynamics in digital collaboration settings. The first theme, technical and infrastructural barriers, emerged as a primary obstacle experienced by many students, particularly those with limited access to stable internet connections and adequate hardware. Several participants reported that lag and connection instability disrupted real-time collaborative tasks, particularly during joint audio-editing sessions. Others highlighted difficulties in running complex software on outdated personal devices, which limited their ability to engage in the creative process outside scheduled lab sessions. Observational records confirmed that 32% of students faced significant technical challenges during the first four weeks of the program, with connectivity issues being the most frequent (48%), followed by hardware constraints (31%) and tool complexity (21%).

The second theme, early adaptation to the virtual classroom, showed up most clearly in students with little digital experience. Moving from in-person lectures to self-paced online modules demanded more than a quick pivot; it required weeks of steady practice. Interview data reveal that newcomers often felt their attention split between learning course material and mastering new tabs, buttons, and notifications. When researchers tracked their progress, a strong pattern emerged: time to comfort matched earlier tech exposure. Students branded "proficient" absorbed the platform, posted discussions, and submitted quizzes in about two to three weeks, while counterparts with minimal training needed roughly five to six weeks to feel the same level of ease and confidence. Digging deeper into virtual group work, a second theme surfaced that highlighted the social and emotional threads woven into remote teams. Respondents cited slow trust-building, up-and-down motivation, and the difficulty of settling disputes when body language was absent as persistent hurdles. Often, a member would go quiet, leaving peers with an uneven load, which then ignited familiar arguments over who was doing what. Still, 78% of the groups reported breaking through these bottlenecks by rewriting the ground rules and leaning on the informal authority of classmate veterans.

Team members also reported slow but clear growth in how they worked together; their confidence and ability to address challenges in the partnership improved steadily as the project progressed. Viewed in tandem, these trends point to the Meta VPNL framework as a helpful framework for creative learning, though its benefits depend on each person's basic tech skill, flexible tool use, and the shared grit of peers who meet and collaborate entirely online. See Table 11 for a summary.

Table 11: Thematic Summary of Challenges in Meta VPNL Implementation

Theme	Description of Challenge	Supporting Evidence
Technical and Infrastructural Barriers	Students faced issues with connectivity, hardware, and software complexity	32% of students reported technical difficulties; 48% related to the internet, 31% to hardware, 21% to software compatibility
Initial Adaptation to Virtual Learning	Transition to digital platforms required time and mental effort, especially for students with low digital literacy.	Low-experience students needed 5–6 weeks to adapt; high-experience students adapted within 2–3 weeks.
Virtual Group Dynamics	Students struggled with team communication, motivation, and conflict management	23% of groups experienced productivity-affecting conflict; 78% eventually adapted through communication restructuring and informal leadership mechanisms

Integrating both qualitative and quantitative data gives clear guidance for refining and rolling out the Meta Virtual Project-Based Networked Learning model. On the numbers side, every creativity measure, apart from originality or fluency, showed marked improvement; the open-ended feedback in interviews explained why by showing that learners felt free to experiment and support one another. Students reported being encouraged to chase non-standard ideas because the learning-management-system layout was flexible and each project prompt left room for personal spin, linking the rise in original thought to that design freedom. The boost in fluency echoed the stories of students revising work often and exchanging quick, candid notes in real-time workrooms, a rhythm evident in the survey scores. Qualitative comments also flagged hurdles, such as stubborn tech glitches, the need for step-by-step digital tools, and the tangled politics of virtual teams. Those points suggest that strong troubleshooting, gradual scaffolds, and clear team-building exercises remain critical if teachers want every learner to contribute fully and grow. Combined, the evidence shows that structured online guidance plus room for student agency can spark meaningful creative growth, even where infrastructure and pedagogy still carry weighty limits.

5. Discussion

The experiment showed that using the Meta Virtual Project-Based Networked Learning model increased overall creativity, as measured by the Torrance Tests of Creative Thinking, particularly in originality, fluency, flexibility, and elaboration, with p-values < 0.001. Because the digital platform organized tasks around clear projects, students seemed more eager to develop new ideas, grow their idea pool, shift mental frames, and flesh out thoughts in detail. These results add fresh support to claims that blending project work with online tools lifts both engagement and creative skills. Earlier studies endorsed similar approaches, finding that Project-Based Learning linked with STEAM or Think-Pair-Share exercises, also nourished creativity across diverse disciplines (Ekayana, Parwati et al., 2025, Liu, Sun et al., 2021). Moreover, project-based hybrid and blended learning has been shown to enhance critical thinking and problem-solving abilities (Kurniawan, Masitoh et al., 2024, Lubna, Suhirman, Prayogi, 2024), consistent with the core tenets of MetaVPNL. The efficacy of MetaVPNL is substantiated by empirical evidence and is consistent with modern educational philosophy and practice, which regards creativity as a fundamental ability in 21st-century learning.

ANOVA revealed that students' prior exposure to digital, project-based learning influenced their creativity after working in Meta-VPNL (F = 427, p = .010). Learners with a larger project portfolio outperformed peers in flexibility and elaboration, indicating they produced ideas and adapted problem-solving moves more readily. Rubric scores mirrored this pattern; the Use of Learning Media criterion received the highest average, indicating that students employed audio features in their digital tasks inventively. These findings reinforce earlier evidence that intrinsic motivation, full-class involvement, and self-directed behaviour drive creative output (Liu, Sun et al., 2021; Ma, Yang et al., 2018; Zhong, Qu, Zhang, 2024). Personal traits-experiential history, growth mindset, and level of schooling-matter for divergent thinking skill (Egwutvongsa, 2023, Gu, Ritter et al., 2021). The uneven creative lift brought by Meta VPNL across student groups suggests that any creativity-focused learning design should carefully weigh individual backgrounds and classroom dynamics.

One important finding was a greater increase in fluency compared to other dimensions of creativity. This result may be partly explained by several factors, including the ease of using virtual learning, where students can exchange ideas quickly, compared to face-to-face situations. The relative anonymity of online interactions often lowers psychological barriers, which naturally increases the likelihood of participants contributing more freely, although not all ideas presented by students can be turned into relevant project solutions (Mishra, Pandey et al., 2019). It should also be acknowledged that other factors, such as learning styles, intrinsic motivation, and prior knowledge variables, not systematically measured in this study, may further explain the differences between groups (McKim, 2017) . Therefore, future research should integrate these moderating variables and examine not only the quantity but also the originality and applicability of ideas in virtual project-based contexts.

Early case studies show that when students work in Meta VPNL, three features blend together: active involvement, steady teamwork, and personalized help for independent tasks-and this combination lifts their creative output. Inside the platform, learners join conversations willingly, stretch their own ideas, and share dependable collaboration, hinting that the setting itself fuels their motivation. Its flexible but thoughtfully organized structure leaves room for students to pick tools, solve problems, and pull in many resources, which strengthens their sense of ownership. By matching clear digital design with that freedom, Meta VPNL encourages deep, reflective, and imaginative learning. These findings are consistent with an emerging body of international research that links online team-based formats to higher gains in knowledge, skill development, and learner satisfaction, a trend recently observed across nursing education (Männistö, Mikkonen et al., 2019). The overall effectiveness of e-learning still hinges on instructor availability, the quality and frequency of peer interactions, and the seamless blending of digital and face-to-face activities (Gustavo Ramírez, Gabriela Elizabeth Rojas Munive De et al., 2024, S. Lockman and R. Schirmer, 2020). Furthermore, everyday digital tools-messaging apps, social media, and mobile platforms-continue to prove valuable in amplifying collaboration and boosting course outcomes (Ansari and Khan, 2020). Within this landscape, Meta VPNL serves as a project-based approach that deliberately pairs mixed modalities with a strong, visible instructor presence, thereby fostering learner agency and the self-direction needed for successful online teamwork (Intaratat, Osman et al., 2024, S. Lockman and R. Schirmer, 2020, Saqr, Fors et al., 2018). In practice, the Meta VPNL design nurtures internal curricular innovation and illustrates current best evidence on adaptive, collaborative digital learning environments.

While the Meta VPNL model boosted students' creativity, its rollout was hampered by spotty internet, mismatched devices, hesitance to dive into digital tools, and tangled group interactions. Those obstacles point to the need for dependable tech support, step-by-step guidance, and a course flexible enough to meet different comfort levels with technology. Linking numerical data with students' comments shows that higher creativity scores come when learners balance teamwork with moments of self-directed exploration online. A major strength of the model is its mix of scaffolded project-based tasks and open time for personal creative work. Moving forward, schools should upgrade networks, prepare teachers to guide classes in virtual spaces, and pilot similar approaches in other subjects to see how far the benefits can spread.

6. Conclusion and Suggestions

This investigation shows that the Meta Virtual Project-Based Networked Learning (Meta VPNL) framework significantly boosts student creativity, as measured by the Torrance Tests of Creative Thinking. Improvement occurs on all four TTCT dimensions-originality, fluency, flexibility, and elaboration-indicating that the approach nurtures creative thought, not just quantity of ideas. By blending a project-centered curriculum with online tools, the model promotes collaboration, reflection, and independent work, thereby keeping learners actively engaged. To confirm these gains, subsequent studies should apply Meta VPNL in diverse academic, cultural, and institutional contexts so that findings can be compared and generalized beyond the original cohort. Designers of future interventions also need to map participants' digital backgrounds, offering targeted support for those with limited hardware or bandwidth and raising equity of opportunity. Finally, a longitudinal component-such as yearly follow-up assessments-would reveal whether creativity gains persist, showing whether Meta VPNL fosters lasting shifts in cognition or merely short-term improvement.

AI Statement: Gemini and OpenAI GPT were used for brainstorming. Elicit AI was employed to identify resources and materials. Grammarly was used to check the Grammar.

Ethics and Consent: All subjects provided informed consent for inclusion prior to participating in the study. The study was conducted in accordance with the Declaration of Helsinki.

Declaration of Conflict of Interest: The authors have no conflicts of interest to declare.

Data availability: Data will be made available upon request.

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From Assistance to Autonomy: AI Integration in Structured Research-Based Learning for Higher Education

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Abstract: Despite the growing interest in artificial intelligence (AI) for science education, little is known about its role within structured research-based learning (RBL) frameworks that balance technological assistance with developing independent research competencies. Existing studies often focus on AI as an isolated tool or a single-stage intervention, leaving a gap in understanding how AI can be systematically embedded across the research process without diminishing students' cognitive engagement. This study addresses that gap by implementing the newly developed IFTAR model, which organizes RBL into five sequential phases—Identification, Find Literature, Determine Methodology, Accommodate/Analyze/Interpret Data, and Report & Present—with AI selectively integrated into the literature search and data analysis stages. A quasi-experimental, non-equivalent control group PreTest–PostTest design was conducted with ninety undergraduate physics education students assigned to one control and two experimental groups. Cognitive outcomes were measured using a validated instrument and analyzed through classical ANCOVA, rank-based ANCOVA, and robust ANCOVA to account for assumption violations. Across all analytical approaches, both experimental groups significantly outperformed the control group, with no significant difference between the experimental conditions. These findings demonstrate that phase-specific AI integration within a transparent and scaffolded RBL framework can enhance cognitive performance while preserving methodological autonomy, offering a replicable model for purposeful AI use in STEM higher education.

Keywords: Artificial intelligence, Research-Based learning, IFTAR model, Physics education, Cognitive learning outcomes, Structured pedagogy

1. Introduction

Artificial intelligence (AI) has increasingly become a central component of higher education, transforming instructional practices and students' learning experiences across disciplines, including physics (Bitzenbauer, 2023; Festiyed et al., 2024). In the context of physics education, AI tools have been employed to support tasks such as literature searching, data analysis, simulation modeling, and the generation of instructional materials, functions that also align with the role of cognitive scaffolds that can enhance inquiry processes when appropriately guided (Fadillah, Usmeldi, & Asrizal, 2024; Linn et al., 2015; Sirisathitkul & Jaroonchokanan, 2025). Recent developments in generative AI, large language models (LLMs), have demonstrated capabilities in producing coherent and contextually relevant responses, which can aid in scaffolding students' inquiry and research-based learning (RBL) (Steinert et al., 2024; West, 2023). However, despite this promise, integration in formal physics curricula often remains fragmented, with AI applications limited to specific activities rather than embedded within coherent pedagogical designs (Kotsis & Vakarou, 2025; Leon, Lipuma, & Oviedo-Torres, 2025). This partial adoption may hinder the potential of AI to foster higher-order thinking, deep conceptual understanding, and sustained engagement in the learning process (Fadillah, Usmeldi, & Asrizal, 2024).

While AI adoption in education offers significant opportunities, it also presents challenges that require careful pedagogical consideration. Overreliance on AI-generated content can reduce students' opportunities for independent reasoning and critical thinking (Watts et al., 2023; Yik & Dood, 2024). Additionally, AI systems may provide linguistically fluent outputs but conceptually inaccurate outputs, posing risks to students' scientific understanding when used without appropriate guidance (Kortemeyer & Bauer, 2024; Sirnoorkar et al., 2024). Ethical issues such as plagiarism, data privacy, and bias in AI outputs further complicate integration in academic settings (Cotton, Cotton, & Shipway, 2024; Khowaja et al., 2024; Siregar et al., 2026). Furthermore, disparities in

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students' familiarity with AI tools and access to technological resources may lead to unequal learning experiences and exacerbate educational inequities (Agyare et al., 2025; Fadillah, Usmeldi, & Ravanis, 2025; Fadillah et al., 2026; Najdawi et al., 2024). These challenges emphasize the need for structured instructional approaches that balance AI's benefits with preserving students' active cognitive engagement. In light of these complexities, it becomes essential to anchor AI-supported instruction within robust theoretical foundations that can guide its pedagogical use. Research-based learning (RBL) positions students as active constructors of knowledge through iterative inquiry cycles (Brew, 2010; Healey, 2005), whereas scaffolding theory and cognitive apprenticeship emphasize modelling, guided participation, and the gradual release of responsibility to the learner (Collins, Brown, & Newman, 2018; Linn et al., 2015). From this theoretical perspective, AI can be conceptualized as a "conditional scaffold", a support mechanism that is activated selectively at cognitively demanding stages while ensuring that core reasoning and methodological autonomy remain with the student.

Building on these foundations, the present study investigates the integration of AI into a structured form of RBL within an undergraduate physics research methodology course. This instructional approach builds upon the pedagogical foundations of active, inquiry-oriented learning while introducing explicit scaffolding to guide students through the research process (Brew & Jewell, 2012; Brew & Saunders, 2020; Suyatman et al., 2021). Within this structure, the IFTAR model is used to organize the research process into sequential, transparent phases, clarifying where AI support is pedagogically appropriate and where independent reasoning must be preserved. By comparing cognitive outcomes between AI-supported structured research-based learning, the same model without AI, and traditional instruction, the study aims to provide empirical insights into how AI can be meaningfully embedded in physics higher education.

Accordingly, this study aims to examine how phase-specific AI integration within the IFTAR model influences students' cognitive learning outcomes, how these outcomes compare with those achieved through the same structured model without AI, and whether selective AI assistance can enhance learning without reducing students' autonomy in carrying out essential research tasks. This objective provides the basis for the following research questions:

RQ1: Does the integration of AI at selected stages of the IFTAR model improve students' cognitive learning outcomes compared to conventional instruction?

RQ2: How do the cognitive outcomes of students experiencing AI-supported structured RBL differ from those experiencing the same model without AI?

RQ3: To what extent does phase-specific AI integration support cognitive performance while preserving methodological autonomy?

2. Literature Review

2.1 Artificial Intelligence in Physics Learning

Research on AI in physics education has expanded rapidly, with recent work increasingly focused on how LLMs such as ChatGPT and GPT-4 shape students' conceptual understanding and problem-solving performance. Studies agree that LLMs produce fluent and structured explanations, yet they often contain subtle scientific inaccuracies or contradictory reasoning (Dahlkemper, Lahme, & Klein, 2023; Gregorcic & Pendrill, 2023). This tension—high linguistic quality but inconsistent epistemic reliability—recurs across the literature. For example, while Dao and Le (2023) and Tong et al. (2024) found GPT-4 performing at or above the level of many students on standard physics questions, Horchani (2025) and Kortemeyer (2023) showed that the same model struggles with context-rich problems requiring realistic assumptions and modelling. These contradictory findings suggest that AI performance is highly sensitive to task structure: LLMs excel when patterns are clear and representations familiar, but fail where domain reasoning must be constructed from physical principles.

Beyond accuracy, several studies examine how AI responses influence students' reasoning processes. Fadillah, Usmeldi, & Asrizal (2024) show that clarity, coherence, and conceptual links in AI outputs can support higher-order thinking in inquiry tasks. Yet these benefits materialize only when students engage critically with the output rather than accept it unexamined (Fadillah et al., 2025). This aligns with findings by Dahlkemper, Lahme, & Klein (2023), who report that students trust AI explanations even when errors are present, highlighting the importance of disciplinary literacy and evaluation skills.

A growing strand of research also raises concerns about bias, access, and academic integrity. Work by Bolukbasi et al. (2016) and Najdawi et al. (2024) underscores that AI systems can reproduce societal biases or exacerbate inequities when access to advanced tools is uneven. Similarly, Kortemeyer and Bauer (2024) warn that unsupervised AI use may undermine authentic problem-solving efforts. Synthesizing these threads shows that the central challenge is not merely AI performance but how students and instructors manage AI as both a cognitive aid and a potential source of distortion. Thus, the literature points to the need for structured pedagogical frameworks that embed AI deliberately and ethically in physics learning.

2.2 Research-Based Learning and the Need for Structured Models

RBL is widely recognized for fostering deep engagement, authentic inquiry, and transferable research skills across STEM disciplines (Ward, Clarke, & Horton, 2014; Wessels et al., 2021). In physics, its alignment with disciplinary epistemic practices makes it particularly valuable, as students learn to design experiments, analyze data, and communicate results in ways consistent with professional scientific work (Docktor & Mestre, 2014; Ruf, Ahrenholtz, & Matthé, 2019). Numerous studies demonstrate that participation in RBL enhances students' analytical reasoning, methodological understanding, and confidence as emerging researchers (Bauer & Bennett, 2003; Lloyd, Shanks, & Lopatto, 2019; Russell, Hancock, & McCullough, 2007). However, this body of work also reveals important inconsistencies. While RBL is generally praised for promoting autonomy, several empirical studies show that insufficient structure can overwhelm students, especially in disciplines with high conceptual and methodological demands like physics (Estuhono, Festiyed, & Bentri, 2019; Redish, 2000; Thiem, Preetz, & Haberstroh, 2023). Wessels et al. (2021) highlight that the balance between independence and guided support is crucial: autonomy enhances ownership, but excessive independence before students achieve methodological readiness can lead to fragmented or superficial inquiry. This nuance is often overlooked in the literature, where autonomy is sometimes uncritically equated with authenticity.

Another layer of complexity emerges when considering educational levels. Thiem, Preetz, & Haberstroh (2023) demonstrate that undergraduate students benefit from exposure to the full research cycle for the first time, while master's students require deeper engagement with advanced analytical tools. Pourhejazy and Isaksen (2024) similarly argue that RBL must be adapted to students' disciplinary trajectories and prior experience. When taken together, these studies expose a fragmented landscape in which RBL is implemented inconsistently, often relying on instructors' interpretations rather than standardized or transparent structures. This highlights a growing need for RBL models that articulate steps clearly, support disciplinary progression, and maintain conceptual coherence.

2.3 Artificial Intelligence Within Structured Research-Based Learning Models

As AI becomes more present in higher education, researchers have begun examining how it can support different stages of RBL. AI tools can assist in literature searching, summarizing scientific texts, analyzing data, and visualizing results (Bitzenbauer, 2023; Bubeck et al., 2023; Hidayanto, Phusavat, & Kurnia, 2025; Woo, Guo, & Susanto, 2025). When used strategically, AI functions as a cognitive scaffold that frees students to focus on higher-order reasoning activities (Kortemeyer, 2023; Li, Huang, & Liu, 2024; West, 2023). However, current studies often examine isolated stages—such as literature review or data analysis—without considering how AI contributes across the full research cycle. As a result, the cumulative pedagogical impact of AI within RBL remains poorly understood.

Existing evidence also reveals contradictions. Some studies show that guided AI use enhances inquiry processes and improves students' interpretation of results (Dao et al., 2023; Hidayanto, Phusavat, & Kurnia, 2025). Others caution that unguided or excessive reliance on AI may distort reasoning or diminish essential cognitive effort (Gregorcic & Pendrill, 2023; Kortemeyer & Bauer, 2024). These contrasting findings suggest that the effectiveness of AI in RBL depends heavily on the structure in which it is embedded. Without clear boundaries and checkpoints, students may bypass core analytical processes or treat AI outputs as authoritative. Ethical considerations further complicate AI integration. Issues such as academic integrity, data privacy, transparency of AI-generated content, and algorithmic bias are increasingly emphasized in higher education research (Cotton, Cotton, & Shipway, 2024; Najdawi et al., 2024). While several studies recommend training and institutional guidelines, few explicitly connect these ethical tensions to students' development of epistemic responsibility—the ability to evaluate evidence, justify methodological decisions, and critique AI outputs. This gap reinforces the need for structured frameworks that integrate AI not only as a tool but as a catalyst for reflective and responsible inquiry.

2.4 Gaps in the Literature and Research Contribution

While integrating generative AI tools such as ChatGPT into science education has gained momentum, research examining their role within structured RBL frameworks remains limited. Studies such as Gregorcic and Pendrill (2023) have shown how ChatGPT can support conceptual reasoning in physics through Socratic-style dialogue, yet also reveal its limitations in delivering nuanced explanations. Similarly, West (2023) and Bubeck et al. (2023) highlighted GPT-4's advanced reasoning capabilities, which could be leveraged to scaffold inquiry stages in RBL. Woo, Guo, & Susanto (2025) further demonstrated the potential of AI-driven feedback to enhance iterative refinement of student work, aligning well with the formative assessment dimension of RBL. These findings collectively suggest that AI could strengthen the inquiry process in science education; however, they also underscore the need for structured and purposeful integration within pedagogical models.

At the same time, existing research on RBL in higher education, particularly within science and engineering, has consistently demonstrated its benefits in fostering deep engagement, critical thinking, and authentic research skills (Bauer & Bennett, 2003;Russell, Hancock, & McCullough, 2007; Wessels et al., 2021). The foundational work of Brew (2010) and Healey (2005) emphasizes that RBL is most effective when students are engaged as active participants in the construction of knowledge, supported by a clear pedagogical structure. Nonetheless, the adaptation of RBL to online and AI-enhanced learning contexts remains underexplored. Emerging studies, such as those by Hosel et al. (2022), Hidayanto, Phusavat, & Kurnia (2025), Li, Huang, & Liu (2024), and Zawacki-Richter et al. (2019), indicate that AI can facilitate inquiry cycles, data analysis, and collaborative research in both physical and virtual environments. However, these studies generally focus on isolated stages of research rather than offering a comprehensive framework for AI integration throughout the process.

Existing RBL models, such as those outlined by Shaban, Abdulwahed, & Younes (2015), Tabuena et al. (2021), and Susiani, Salimi, & Hidayah (2018), typically present a sequence of research activities, including problem identification, literature review, methodology selection, data collection, analysis, and dissemination. While pedagogically valuable, these models often involve overlapping sub-stages, which can be difficult for novice students to follow. The challenge becomes even more pronounced in AI-integrated environments, where clearly defined boundaries between stages are essential for ensuring that AI tools are applied appropriately and do not inadvertently dominate or fragment the learning process. Without such clarity, students risk becoming overly reliant on AI without understanding the underlying cognitive and methodological steps in conducting research.

In response to these limitations, the present study introduces the IFTAR model, a streamlined adaptation of RBL designed to consolidate core research activities into five sequential phases: Identification of the problem and research question, Find Literature, Determine Methodology, Accommodate/Analyze/Interpret Data, and Report & Present. This reconfiguration draws from established RBL frameworks but intentionally reduces complexity, making the process more transparent and manageable for students. Importantly, it also provides clear entry points for integrating AI tools in ways that are aligned with constructivist and inquiry-oriented principles. By mapping specific AI functions to each IFTAR phase, the model seeks to balance technological support with the development of students' independent research competencies. A comparative visualization of traditional RBL frameworks and the proposed IFTAR model is provided to highlight these differences (see Figure 1).

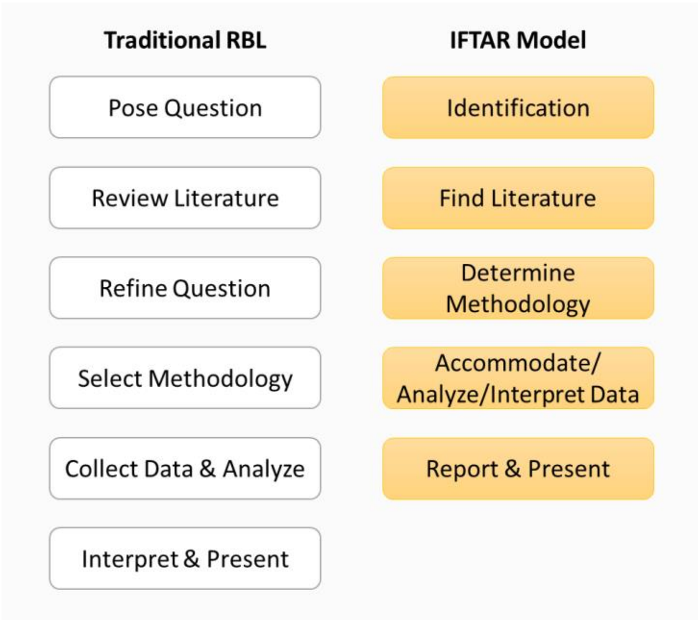

Figure 1: Comparison between traditional research-based learning and the IFTAR model proposed

Despite the potential advantages of such a structured approach, there remains a lack of empirical research that systematically examines how AI can be embedded in each phase of the IFTAR model. This gap is significant because, without phase-level integration strategies, the use of AI in RBL risks being fragmented, misaligned with intended learning outcomes, or ethically problematic. Furthermore, unresolved concerns regarding academic integrity (Cotton, Cotton, & Shipway, 2024; Kortemeyer & Bauer, 2024), algorithmic bias (Bolukbasi et al., 2016), and governance of AI in education (European Parliament, 2023; Najdawi et al., 2024) have yet to be addressed comprehensively in the context of student-led research. Therefore, this study aims to fill two critical gaps: mapping AI applications systematically across the IFTAR model stages and providing comparative insights into their pedagogical impact across educational levels and disciplinary contexts.

3. Methodology

This methodological design directly operationalizes the research gap and contribution outlined in Section 2.4, highlighting the lack of studies examining the pedagogical impact of AI integration at specific stages of structured research-based learning. The study was conducted in a higher education physics learning context, where integrating AI into structured, research-oriented learning can enhance students' critical thinking, autonomy, and conceptual understanding. The instructional model employed is the IFTAR model, representing the stages of Identification, Find Literature, Determine Methodology, Accommodate/Analyze/Interpret Data, and Report & Present. Adapted from the broader RBL framework (Shaban, Abdulwahed, & Younes, 2015; Susiani, Salimi, & Hidayah, 2018; Tabuena et al., 2021), IFTAR offers a more transparent and scaffolded structure, especially suited for embedding emerging technologies like AI. In this design, AI tools were strategically integrated into two specific stages, Find Literature and Accommodate/Analyze/Interpret Data, while the remaining stages were conducted without AI assistance to preserve students' independent reasoning and methodological autonomy. This partial integration approach allows a phase-specific analysis of AI's contribution to cognitive learning outcomes. The conceptual framework of the IFTAR model, including its AI integration points, is illustrated in Figure 2, showing clearly which stages are AI-assisted and which remain fully non-AI.

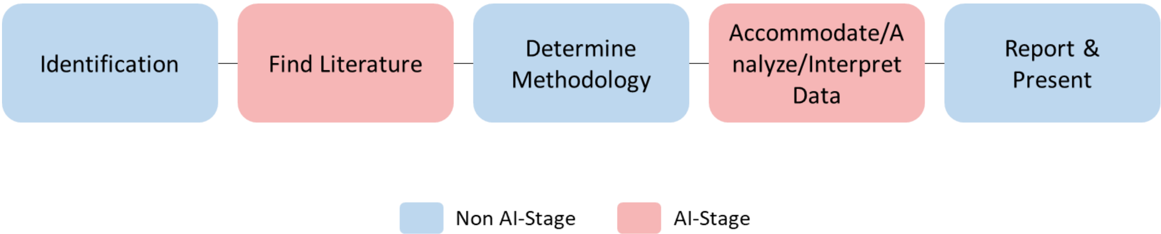

Figure 2: The IFTAR model stages highlight AI integration points. Blue sections represent stages conducted without AI assistance (Identification, Determine Methodology, and Report & Presenting), while red sections indicate AI-assisted stages (Find Literature and Accommodate/Analyze/Interpret Data)

3.1 Research Design

A quasi-experimental, non-equivalent control group PreTest–PostTest design was employed to evaluate the effectiveness of the IFTAR model with AI integration. Three intact classes participated in the study, each consisting of thirty undergraduate students, for a total of ninety participants. One class served as the control group and received conventional instruction, while the other two served as experimental groups taught using the IFTAR model with AI integration. All groups completed a PreTest at the beginning of the instructional period and a PostTest after learning. Figure 3 illustrates the study flow, from identifying participants through applying different instructional treatments and assessing outcomes via PostTest.

To reduce potential biases associated with non-equivalent intact classes, several control procedures were implemented. Baseline equivalence was examined by comparing PreTest scores and demographic characteristics, confirming no significant differences prior to the intervention. All groups were taught by the same instructor to eliminate variations in teaching style, and scheduling arrangements were structured to prevent treatment diffusion between groups. Random assignment at the individual level was not feasible due to institutional scheduling constraints, making intact class assignment the most ecologically valid approach for this quasi-experimental design.

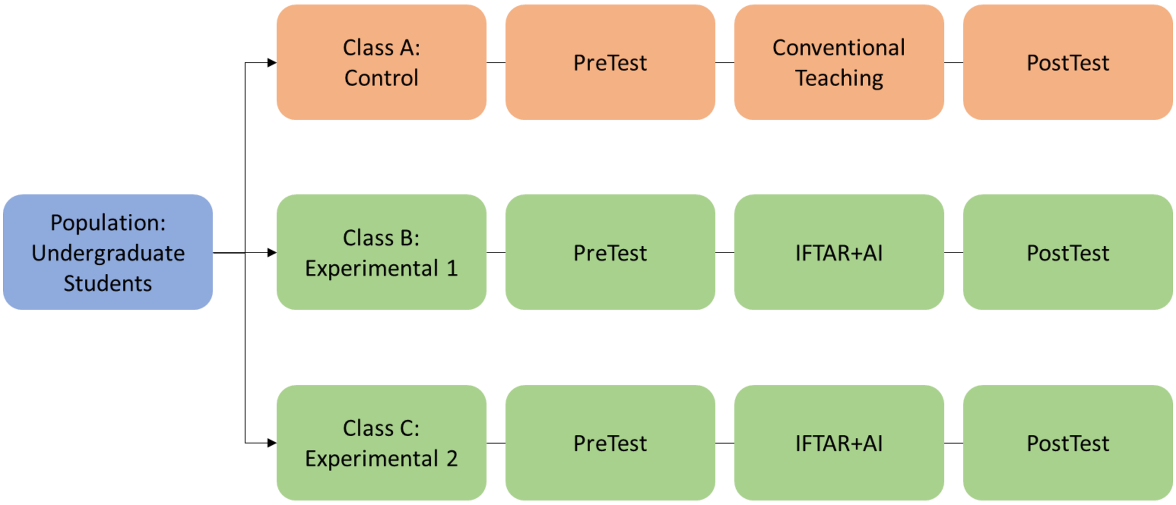

Figure 3: Research design flow from participant selection to instructional treatments and final assessment

3.2 Participants

The study involved ninety undergraduate students from the Physics Education program, all of whom were enrolled in the Research Methodology course during the semester of the study. The three intact classes, each consisting of thirty students, were assigned as follows: the control group (Class A) comprised 18 females and 12 males; Experimental Group 1 (Class B) included 19 females and 11 males; and Experimental Group 2 (Class C) consisted of 16 females and 14 males. This distribution resulted in fifty-three females and thirty-seven males across the sample. All participants had prior experience with AI tools, including platforms like ChatGPT, ensuring a uniform baseline familiarity with AI-supported learning across the sample. Additionally, students were well-accustomed to technology-enhanced learning environments, regularly engaging with digital platforms for materials, assignments, and collaboration. This consistency in technological background minimized variability in digital literacy, allowing differences in cognitive outcomes to be more confidently attributed to the instructional model implemented. The sample size of ninety participants also meets recommended guidelines for quasi-experimental designs with ANCOVA analysis. According to Cohen (2016), detecting a medium effect size ($f = 0.25$) at a power level of 0.80 with three groups requires a minimum sample of 66 participants. Similarly, Bujang and Baharum (2022) emphasize that a minimum of 20–30 participants per group for ANCOVA with one covariate is generally sufficient to achieve reliable statistical estimates. The allocation of 30 students per group in the present study ensures acceptable statistical power and is methodologically justified.

Ethical approval for the study was obtained from the Faculty Research Ethics Committee, and all participants provided informed consent prior to data collection. Participation was voluntary, and students were informed that their responses would remain confidential and would not affect course grades. Sampling followed a cluster-based approach, as students were already organized into intact course sections, which is appropriate for quasi-experimental designs in real instructional settings.

3.3 Intervention

The twelve-week intervention was implemented following the IFTAR learning model, distinguishing between AI-supported and traditional approaches. In the AI-supported approach, students can use various AI tools, such as ChatGPT, to support their process. All participants first completed a PreTest before Week 1. In Week 1, the control and experimental groups engaged in the Identification stage, defining research topics and formulating initial research questions. The control group followed instructor guidance and peer discussions, while the experimental group applied the same process but were informed of upcoming AI integration in later stages. Weeks 2–3 focused on the Find Literature stage. The control group performed manual searches using library databases, textbooks, and existing notes. The experimental groups, in contrast, used AI tools to generate keywords, locate relevant sources, and organize literature summaries, although final selection was made independently to maintain critical evaluation skills. In Weeks 4–5, all groups engaged in the Determine Methodology stage without AI assistance. They designed research procedures collaboratively, guided by instructor feedback, ensuring that methodological reasoning was entirely student-driven. Weeks 6–8 encompassed the Accommodate / Analyze / Interpret Data stage. The control group processed and interpreted data manually using a spreadsheet and statistical software, while the experimental groups utilised AI tools to organise datasets, run preliminary analyses, and draft interpretations, retaining responsibility for verifying accuracy and validity. During Weeks 9–11, all groups participated in the Report & Present stage without AI support, preparing written reports and oral presentations to preserve originality and synthesis skills. Finally, in Week 12, all participants completed the PostTest to measure learning gains. Figure 4 illustrates this timeline, clearly marking the two stages where AI was integrated for experimental groups, while the control group followed traditional, non-AI-supported approaches throughout.

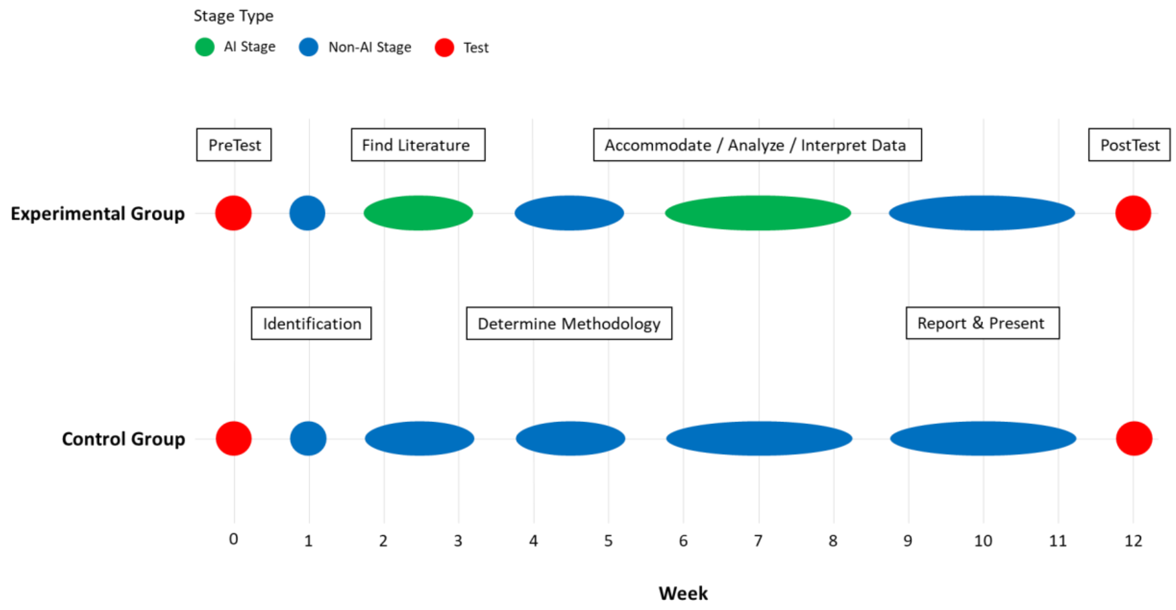

Figure 4: Timeline of intervention stages with AI integration

3.4 Cognitive Assessment Instrument

Cognitive learning outcomes were assessed using a test designed to align with the competencies targeted in each stage of the IFTAR learning model throughout the twelve-week intervention. The instrument was administered twice, once as a PreTest before the intervention and again as a PostTest upon its completion, to capture students' cognitive gains. It consisted of twenty items, comprising fifteen multiple-choice (MC) questions scored dichotomously (1 = correct, 0 = incorrect) and five open-ended (OE) tasks scored using a 0–5 analytic rubric reflecting accuracy, completeness, and reasoning quality.

The MC items measured factual and conceptual understanding of research methodology and educational inquiry. For example, one item asked: *"A student intends to investigate the effectiveness of simulation-based learning media. Which of the following should be the first step: developing a student satisfaction questionnaire, determining the number of respondents, constructing a theoretical framework from relevant literature, or clearly formulating the research problem?"* (correct answer: formulating the research problem). The OE tasks were designed to elicit higher-order thinking by placing students in authentic scenarios that required them to apply, analyze, and evaluate information. For instance: *"Explain the steps that should be taken to ensure that a research topic is relevant to the needs of physics education in schools?"*

The raw total score (maximum = 40) was transformed to a 0–100 scale to ensure comparability across formats. The instrument's content validity was established through an expert review by two specialists in physics education and research methodology, ensuring alignment with the intended learning outcomes for each stage of IFTAR. A pilot study involving fifteen respondents produced an internal consistency coefficient (Cronbach's alpha) of 0.745, which meets the generally accepted threshold of 0.70 for research purposes. Bujang, Omar, and Baharum (2018) show that a sample size of fewer than 30 can still provide reliable estimates for a single-coefficient alpha test when the minimum desired effect size is 0.70. This finding supports the adequacy of the pilot sample and confirms that the instrument demonstrates an acceptable level of reliability for measuring students' cognitive achievement.

3.5 Data Analysis

The data were analyzed using three complementary ANCOVA (analysis of covariance) approaches to ensure the robustness of the findings. The analysis began with assumption checks for the classical model, including Shapiro–

Wilk tests for residual normality and Levene's test for homogeneity of variance; the results indicated that these assumptions were not fully met (see Section 4.2 for more detail). First, a classical parametric ANCOVA was conducted in SPSS with PostTest as the dependent variable, PreTest as the covariate, and Group (Control, Experimental 1, Experimental 2) as the between-subjects factor, following standard procedures outlined by Field (2024). Second, a rank-based ANCOVA was performed in R to address the observed assumption violations by transforming the dependent variable into ranks before estimation, reducing sensitivity to distributional shape while retaining the interpretability of a linear model (Conover & Iman, 1981). Third, a robust ANCOVA in R using an M-estimator, implemented via the *lmrob* function in the *robustbase* package, was applied to down-weight influential observations and mitigate the effects of heteroscedasticity and outliers (Wilcox, 2011). These three analytical strategies allowed a thorough evaluation of the treatment effect's stability across methods with differing assumptions, ensuring that distributional irregularities or extreme cases did not unduly influence conclusions.

4. Results

4.1 Descriptive Statistics

Table 1 combines descriptive statistics for PreTest and PosTest so the reader can inspect baseline performance and outcomes after the intervention. For PreTest, group means were relatively similar: Control M = 52.00 (SE = 0.828, SD = 4.533, 95% CI [50.31, 53.69]), Experimental 1 M = 56.57 (SE = 2.527, SD = 13.843, 95% CI [51.40, 61.74]), and Experimental 2 M = 51.57 (SE = 2.561, SD = 14.026, 95% CI [46.33, 56.80]). These baseline values indicate no extreme initial advantage for any group, although Experimental 1 shows greater variance than the others. For PosTest, the pattern is more distinct: Control M = 60.60 (SE = 0.961, SD = 5.263, 95% CI [58.63, 62.57]), Experimental 1 M = 81.00 (SE = 2.377, SD = 13.017, 95% CI [76.14, 85.86]), and Experimental 2 M = 78.77 (SE = 2.573, SD = 14.093, 95% CI [73.50, 84.03]). The PosTest already points toward notable gains in the experimental groups relative to the control. Because raw PosTest differences do not account for baseline variability, ANCOVA (with PreTest as covariate) was applied to estimate adjusted group differences more accurately (see following subsections and Table 3–6).

Figure 5 presents a gain chart illustrating the mean PreTest and PostTest scores for each group to provide a more precise depiction of score progression. The lines connecting the points represent the average performance shift from the baseline to the post-intervention measurement. The control group showed a modest improvement, whereas both experimental groups displayed a substantial gain, with Experimental 1 exhibiting the largest increase. This pattern visually reinforces the descriptive statistics in Table 1, suggesting that the intervention methods implemented in the experimental groups were more effective than conventional instruction. Error bars in the figure represent 95% confidence intervals, allowing visual inspection of the precision of the mean estimates.

Table 1: Descriptive statistics for PreTest and PosTest by group

Group	N	PreTest Mean	PreTest SE	PreTest SD	PreTest 95% CI	PosTest Mean	PosTest SE	PosTest SD	PosTest 95% CI
Control	30	52.00	0.828	4.533	[50.31, 53.69]	60.60	0.961	5.263	[58.63, 62.57]
Experimental 1	30	56.57	2.527	13.843	[51.40, 61.74]	81.00	2.377	13.017	[76.14, 85.86]
Experimental 2	30	51.57	2.561	14.026	[46.33, 56.80]	78.77	2.573	14.093	[73.50, 84.03]

Note. The table shows means, standard errors (SE), standard deviations (SD), and 95% confidence interval (CI) as reported in SPSS output.

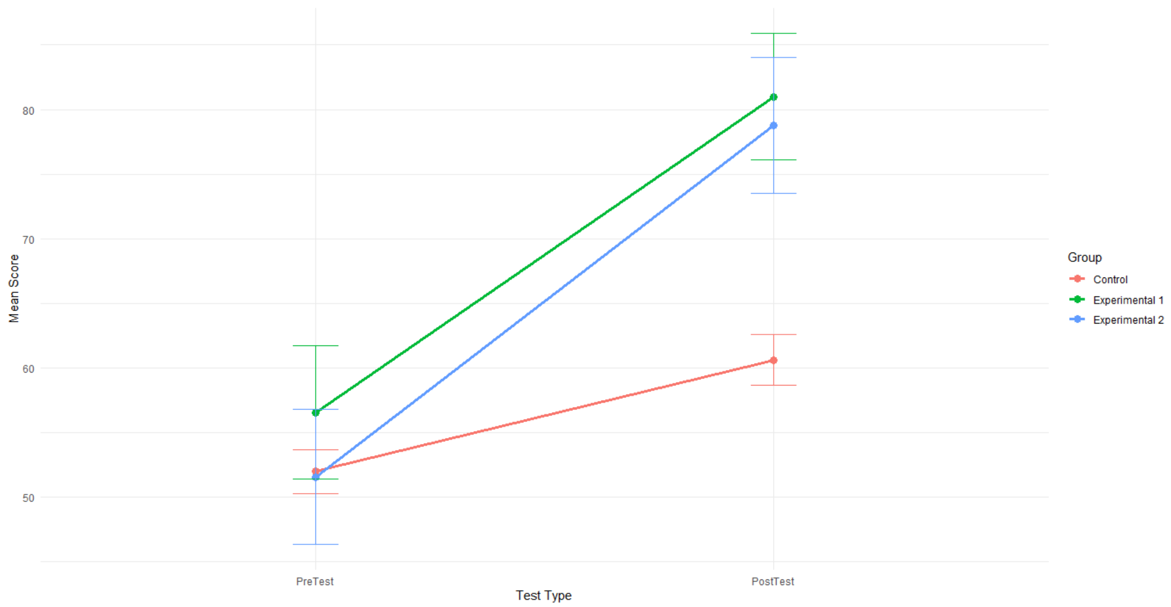

Figure 5: PreTest and PostTest mean scores by group

4.2 Assumption Checks

Before interpreting parametric ANCOVA, we evaluated key assumptions. Shapiro–Wilk tests for PosTest show deviations from normality in each group (Control W = 0.924, p = 0.034; Experimental 1 W = 0.909, p = 0.014; Experimental 2 W = 0.930, p = 0.048), indicating that residuals are not strictly normal at the group level. In contrast, PreTest showed no firm evidence of non-normality in SPSS (Control W = 0.971, p = 0.575; Experimental 1 W = 0.969, p = 0.509; Experimental 2 W = 0.939, p = 0.085), which supports its use as a covariate but does not remove concern for PosTest distributional shape. Levene's test for equality of error variances on PosTest was highly significant ($F(2,87) = 18.330$, $p < 0.001$), indicating heterogeneity of variances across groups. These results (non-normal PosTest distributions and heteroscedasticity) justify supplementing classical ANCOVA with rank-based and robust procedures to ensure violated assumptions do not drive inference. See Table 2 for the assumption-test summary.

Table 2: Assumption checks

Test	Group / Statistic	Value	p-value
Shapiro–Wilk (PosTest)	Control W	0.924	0.034
	Experimental 1 W	0.909	0.014
	Experimental 2 W	0.930	0.048
Levene's test (PosTest)	F(2,87)	18.330	< 0.001

4.3 Classical (Parametric) ANCOVA

The parametric ANCOVA (PostTest ~ PreTest + Group) is summarised in Table 3. The corrected model was significant: $F(3, 86) = 20.983$, $p < 0.001$, with $R^2 = 0.423$ (adjusted $R^2 = 0.402$). The covariate PreTest had a modest but statistically significant effect on post-test scores, SS = 513.202, $F(1,86) = 4.026$, $p = 0.048$, partial $\eta^2 = 0.045$, indicating baseline performance explained a small portion of variance in the outcome after controlling for Group. The main effect of Group was large and highly significant, SS = 7069.107, $F(2,86) = 27.726$, $p < 0.001$, partial $\eta^2 = 0.392$. Estimated marginal (adjusted) means at PreTest = 53.38 were: Control = 60.887 (SE = 2.066), Experimental 1 = 80.337 (SE = 2.088), and Experimental 2 = 79.143 (SE = 2.070). Bonferroni-corrected pairwise comparisons showed both experimental groups significantly exceeded the control (Experimental 1 − Control = 19.450, SE = 2.953, $p < 0.001$; Experimental 2 − Control = 18.257, SE = 2.916, $p < 0.001$), while the difference between Experimental 1 and Experimental 2 was not significant (mean diff = 1.193, SE = 2.961, $p = 1.000$). In short, the parametric ANCOVA—despite assumption concerns—shows a robust and large group effect favoring the two instructional interventions.

In addition, Figure 6 visualises the adjusted PostTest means derived from the ANCOVA model, which controls for differences in PreTest scores. The black dots represent the adjusted means, and the blue shaded bars indicate the 95% confidence intervals. Red arrows between groups illustrate the direction of mean differences: an arrow pointing from one group to another indicates that the latter group has a higher adjusted mean score. In this study, arrows point from the Control group toward both Experimental 1 and Experimental 2, confirming that both experimental groups outperformed the control. Arrows are bidirectional between the two experimental groups, reflecting their nearly identical adjusted means and a nonsignificant statistical difference. This figure complements the numerical ANCOVA results, providing an intuitive visual confirmation of the intervention's positive effect.

Table 3: Classical ANCOVA

Source	SS	df	MS	F	p-value	partial η²
Corrected Model	8024.957	3	2674.986	20.983	< 0.001	0.423
PreTest	513.202	1	513.202	4.026	0.048	0.045
Group	7069.107	2	3534.554	27.726	< 0.001	0.392
Error	10963.365	86	127.481			
Adjusted Means (PreTest = 53.38)						
Group	Mean	SE				
Control (1)	60.887	2.066				
Experimental 1 (2)	80.337	2.088				
Experimental 2 (3)	79.143	2.070				
Pairwise comparisons (Bonferroni)						
Comparison	Mean Difference	SE	p-value			
Experimental 1 − Control	19.450	2.953	< 0.001			
Experimental 2 − Control	18.257	2.916	< 0.001			
Experimental 1 − Experimental 2	1.193	2.961	1.000			

Note. SS (Sum of Squares), df (degrees of freedom), MS (Mean Square), SE (standard error), F is the significance test statistic, and partial η² (partial eta squared) is the effect size that shows the proportion of explained variance.

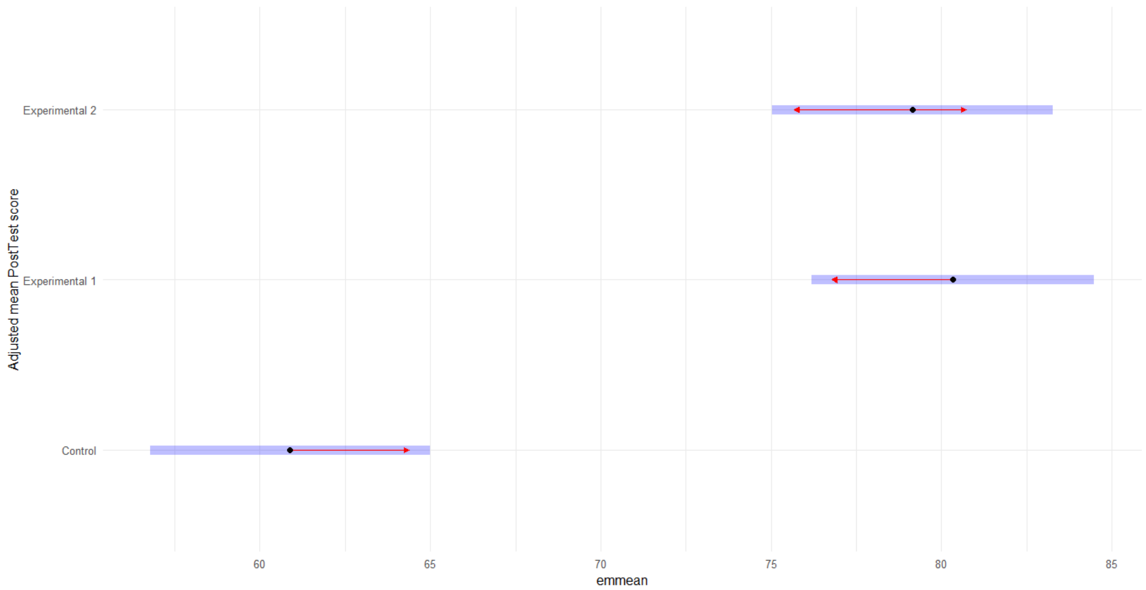

Figure 6: Adjusted PostTest means (ANCOVA)

4.4 Rank-Based ANCOVA

Because of the distributional violations observed above, we fitted a rank-based ANCOVA (rfit) in R, which operates on ranks and reduces sensitivity to non-normal shapes. The rank ANCOVA confirmed the presence of a covariate effect: PreTest estimate = 0.2459 (SE = 0.1142), $t = 2.1535$, $p = 0.034$. Group contrasts were large and highly significant: Experimental 1 estimate = 20.1303 (SE = 3.2530), $t = 6.1882$, $p < 0.001$; Experimental 2 estimate = 19.0744 (SE = 3.2113), $t = 5.9397$, $p < 0.001$. The model's robust $R^2 = 0.359$ and the reduction-in-dispersion test (statistic = 16.03, $p < 0.001$) further indicate a consistent treatment effect that persists when analysis is performed on ranks. This result implies that the group differences are not driven solely by extreme values or skewness in the distributions—the ordering of scores across groups still favors the experimental conditions strongly. See Table 4 for the rank-ANCOVA coefficients.

Table 4: Rank ANCOVA

Predictor	Estimate	SE	t-value	p-value
(Intercept)	48.6664	6.4252	7.5743	< 0.001
PreTest	0.2459	0.1142	2.1535	0.034
Group: Experimental 1	20.1303	3.2530	6.1882	< 0.001
Group: Experimental 2	19.0744	3.2113	5.9397	< 0.001

4.5 Robust ANCOVA

An M-estimator-based robust ANCOVA (lmrob) was fitted to further protect inference from outliers and heteroscedasticity. The robust model again indicates strong group effects: Experimental 1 estimate = 19.4791 (SE = 3.0165), t = 6.457, p < 0.001; Experimental 2 estimate = 18.5714 (SE = 3.6466), t = 5.093, p < 0.001. Unlike the parametric and rank results, the covariate PreTest was not statistically significant in the robust fit (estimate = 0.25520, SE = 0.1824, t = 1.399, p = 0.165), suggesting that a few influential observations may have influenced the small covariate effect seen earlier. The robust model reports Multiple R^2 0.436 (adjusted = 0.417) and a robust residual standard error = of 10.34; robustness weights show that most observations received near-full weight while some were down-weighted (min weight = 0.533). The robust analysis supports the conclusion that the treatment effect is not an artifact of outliers and remains substantively important. See Table 5 for robust estimates.

Table 5: Robust ANCOVA

Predictor	Estimate	SE	t-value	p-value
(Intercept)	47.3843	9.5879	4.942	< 0.001
PreTest	0.25520	0.1824	1.399	0.165
Group: Experimental 1	19.4791	3.0165	6.457	< 0.001
Group: Experimental 2	18.5714	3.6466	5.093	< 0.001

4.6 Comparative Interpretation

Table 6 summarises the key conclusions across analytical approaches: parametric ANCOVA, rank-based ANCOVA, and robust ANCOVA. Across all three methods, the central finding is consistent: both Experimental 1 and Experimental 2 produced substantially higher post-test scores than the Control group, and the difference between Experimental 1 and Experimental 2 was negligible and not statistically significant. The main divergence concerns the role of the covariate PreTest: it was statistically significant in the classical parametric ANCOVA ($p = 0.048$) and in the rank ANCOVA ($p = 0.034$), but non-significant in the robust ANCOVA ($p = 0.165$). This pattern suggests that while baseline performance contributes to variance in some analytic frames, its effect is sensitive to a small number of influential observations or heteroscedastic errors; nonetheless, the group (treatment) effect is robust to these modeling choices. In substantive terms, we can be confident that the instructional interventions led to meaningful learning gains relative to conventional instruction, and that this conclusion holds under multiple estimation strategies that address different assumption concerns.

Table 6: Brief summary of analysis results

Analysis	Is PreTest significant?	Are groups significant?	Pattern
Parametric ANCOVA	Yes ($p = 0.048$)	Yes ($p < 0.001$)	E1 > Control; E2 > Control; E1 ≈ E2
Rank ANCOVA	Yes ($p = 0.034$)	Yes ($p < 0.001$)	E1 > Control; E2 > Control; E1 ≈ E2
Robust ANCOVA	No ($p = 0.165$)	Yes ($p < 0.001$)	E1 > Control; E2 > Control; E1 ≈ E2

5. Discussion

The present study set out to examine the pedagogical impact of integrating AI into a structured RBL framework, specifically the newly proposed IFTAR model, within an undergraduate physics research methodology course. The major finding is that both experimental groups, which adopted the IFTAR model with AI integration at two critical stages, literature searching and data analysis, achieved significantly higher post-test scores than the control group that received conventional instruction. This improvement was consistent across three complementary analytical approaches, classical ANCOVA, rank-based ANCOVA, and robust ANCOVA, thereby strengthening the robustness of the conclusions despite deviations from statistical assumptions. Notably, no statistically significant difference emerged between the two experimental groups, suggesting that the benefits of the AI integration were stable and did not depend on additional variations within the experimental treatment.

These findings underscore the importance of targeted AI integration within a well-defined pedagogical structure. Rather than allowing AI tools to permeate all aspects of the research process indiscriminately, the selective embedding of AI into specific phases of the IFTAR model appears to strike an effective balance between technological support and the preservation of students' independent cognitive engagement. It aligns with earlier research by Hidayanto, Phusavat, & Kurnia (2025) and West (2023), which suggested that AI is most beneficial when purposefully positioned within scaffolded learning activities rather than as a wholesale replacement for human reasoning. The current results extend these insights by providing empirical evidence at the whole-course level in physics education, demonstrating that even partial AI integration, when coupled with a transparent and sequential research framework, can yield substantial cognitive gains.

Beyond these empirical patterns, the findings also illuminate the underlying mechanisms through which AI supports learning within the IFTAR framework. Theoretically, the results are consistent with the principle of "augmented cognition," wherein technology amplifies, rather than replaces, human reasoning by reducing extraneous cognitive load during complex research tasks (Li, Huang, & Liu, 2024; Sweller, 2020). By embedding AI only at analytically intensive phases, the IFTAR model appears to operationalize a distributed cognition system (Hollan, Hutchins, & Kirsh, 2000), in which computational tools handle low-level processing while students retain responsibility for conceptual interpretation and methodological decisions. This alignment between technological affordances and cognitive task structure may explain why the experimental groups achieved higher-order gains without evidence of overreliance—a concern highlighted in prior studies (Gregorcic & Pendrill, 2023; Kortemeyer & Bauer, 2024). Conceptually, this positions the IFTAR model not merely as a procedural scaffold but as an advancement of existing RBL frameworks by providing a theory-based rationale for when and why AI should be integrated within inquiry cycles.

When viewed alongside previous studies, the outcomes of this research suggest both convergence and advancement. Similar to the work of Fadillah, Usmeldi, & Asrizal (2024) and Steinert et al. (2024), the integration of generative AI facilitated higher-order thinking skills, particularly in tasks requiring the synthesis of literature and the interpretation of complex datasets. However, whereas prior studies often examined AI as a single-stage intervention or as an auxiliary tool in isolated assignments, this study incorporated AI into a coherent pedagogical flow. Moreover, the structured nature of the IFTAR model mitigated common pitfalls identified in earlier evaluations, such as cognitive overload in open-ended inquiry tasks (Wessels et al., 2021) and overreliance on AI outputs without critical verification (Gregorcic & Pendrill, 2023). It provides a model for translating AI's potential into sustained learning gains, avoiding the fragmented adoption that has been criticized in the literature (Kotsis & Vakarou, 2025).

Although the results are encouraging, alternative explanations warrant consideration. The observed gains were partially influenced by novelty effects, wherein the introduction of AI tools generated heightened engagement independent of their cognitive utility. Students in the experimental groups might also have benefited from increased collaborative interactions during AI-assisted tasks, which could have contributed to learning gains irrespective of the AI's direct outputs. Furthermore, the instructor's role in guiding the AI-supported phases may have provided additional scaffolding that is not fully replicable in purely student-led contexts. While these factors do not diminish the observed group differences, they suggest that the benefits of AI integration may be intertwined with broader motivational and social dynamics in the classroom.

From a practical perspective, the findings hold several implications for educational design in physics and other STEM disciplines. The phase-specific AI integration demonstrated here offers a replicable model for institutions seeking to incorporate emerging technologies without undermining core disciplinary skills. In teacher education contexts, where graduates must both conduct and supervise research, structured AI-assisted RBL could prepare future educators to leverage technology responsibly while fostering critical thinking among their students. Beyond physics, the model could be adapted for other domains that require literature synthesis, methodological rigor, and data interpretation, making it relevant for interdisciplinary and professional training programs.

Taken together, these findings highlight the study's contribution to advancing both the theory and practice of AI-supported inquiry learning. Conceptually, the IFTAR model provides a refinement of existing RBL frameworks (Brew & Jewell, 2012; Wessels et al., 2021) by articulating clearer phase boundaries and aligning them with specific cognitive functions where AI can serve as an epistemic partner rather than a procedural shortcut. Practically, the model offers a replicable structure for educators seeking to integrate AI responsibly without diminishing students' agency, addressing a gap frequently noted in the literature on fragmented or unguided AI adoption in higher education (Leon, Lipuma, & Oviedo-Torres, 2025; Zawacki-Richter et al., 2019). This dual contribution—conceptual clarification and practical design—demonstrates how AI-enhanced RBL can be systematically structured to maximize learning while preserving methodological autonomy.

Nevertheless, certain limitations must be acknowledged. The study was conducted within a single institution and involved a relatively homogenous sample of physics education undergraduates, which may limit the generalizability of the findings to other disciplines, educational levels, or cultural contexts. Although the sample size was adequate for the statistical analyses employed, larger-scale replications would allow for more nuanced subgroup analyses, such as gender differences or prior research experience. In addition, while cognitive learning outcomes were the primary focus, other dimensions such as long-term retention, metacognitive development, and attitudes toward AI-assisted learning were not measured, leaving important questions for future exploration.

Future research could build on these findings by examining the longitudinal effects of structured AI-supported RBL, particularly whether short-term cognitive gains evolve into sustained research competence and metacognitive growth over time (Linn et al., 2015; Thiem, Preetz, & Haberstroh, 2023). Such investigations would also clarify whether the phase-specific integration strategy proposed in the IFTAR model produces durable learning trajectories distinct from conventional AI-enhanced instruction. Comparative studies across disciplines and educational settings could test the adaptability of the IFTAR framework, while experimental variations could examine the optimal number and type of AI-assisted phases. Furthermore, qualitative investigations could provide richer insights into students' perceptions, strategies for validating AI outputs, and the socio-emotional aspects of engaging with AI in collaborative research environments. Such work would contribute to refining not only the pedagogical model but also the broader discourse on ethical, equitable, and effective AI integration in higher education.

6. Conclusion

This study demonstrates that artificial intelligence's strategic, phase-specific integration into a structured RBL framework, operationalized through the IFTAR model, can substantially improve students' cognitive outcomes while preserving essential research skills. By limiting AI assistance to the literature search and data analysis stages, the approach ensured that students benefited from technological efficiency without diminishing opportunities for independent reasoning and methodological decision-making. The consistent superiority of the experimental groups over the control group across multiple analytical approaches confirms that this balance between human agency and AI support is achievable and pedagogically effective. These findings highlight a clear direction for practice: for educators and curriculum designers, the key implication is that AI can be a powerful enabler in inquiry-driven learning when embedded purposefully within a transparent, scaffolded process. Unrestricted use risks replacing rather than enhancing student thinking, whereas deliberate, well-timed support can deepen understanding, foster autonomy, and prepare learners for the realities of research in AI-rich academic and professional environments. Future studies should explore how this model adapts to different disciplines, cultural contexts, and long-term learning trajectories, ensuring that AI integration functions as a catalyst for—not a substitute for—critical and creative inquiry.

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Understanding Teacher Workload in Blended Learning: Insights Through the Job Demands-Resources Model

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Abstract: Blended learning (BL) has become an increasingly prevalent instructional model in primary and secondary education, yet its implementation has intensified concerns about teacher workload and well-being. While prior research has documented workload pressures associated with digitalization and AI integration, there remains limited empirical insight into how teachers experience, interpret, and manage these demands in blended learning environments. Guided by the Job Demands-Resources (JD-R) model, this qualitative study investigates how BL reshapes teachers' job demands and resources, and how educators respond to these changes in practice. Specifically, this study explores how BL influences teachers' perceived workload (RQ1), the specific challenges they encounter during BL implementation (RQ2), and the strategies and resources they employ to manage these demands effectively (RQ3). Semi-structured interviews were conducted with ten primary and secondary schoolteachers in Flanders (Belgium) who had experience implementing blended learning. Data were analysed using a reflexive thematic analysis supported by NVivo, following a systematic and iterative coding process. The JD-R model informed the analytical lens, enabling the identification of workload-related demands, available resources, challenges and coping strategies within teachers' everyday practice. Regarding RQ1, the findings demonstrate the dual nature of blended learning as both intensifying workload and providing supportive resources. Teachers reported increased demands from dual-mode lesson design, technological integration, expanded assessment requirements, and institutional platform mandates, leading to cognitive and emotional strain. Conversely, automated assessment, reusable digital materials, learning platforms, and inclusive tools reduced administrative effort and supported organization, partially decreasing these heightened demands. With regard to RQ2, workload pressures were intensified by challenges in digital classroom management, frequent technical disruptions, and the continuous need to learn and support new technologies. Teachers also reported emotional and organizational strain linked to ineffective collaboration, time constraints, infrastructural shortcomings, and resistance to pedagogical change, particularly during early stages of blended learning (BL) adoption. In response to RQ3, teachers described a range of coping strategies and supportive resources. These included reusing and adapting digital materials, employing AI-supported tools for automated assessment, developing digital skills through peer support, and implementing structured classroom routines. Institutional resources, such as reliable IT support, modular professional development, collaborative planning, clear BL guidelines, and leadership support, functioned as key job resources that buffered workload pressures and supported sustainable BL practices. This study contributes to the literature by applying the JD-R model to the K-12 blended learning context, offering a theoretically grounded account of how workload pressures and supports interact in teachers' daily work. Beyond documenting challenges, the findings generate actionable insights for school leaders and policymakers, highlighting the need for systemic workload-sensitive BL implementation, structured collaborative planning, and sustained professional development aligned with instructional realities. By reframing blended learning through a job demands-resources perspective, this study advances understanding of sustainable technology integration in compulsory education.

Keywords: Blended learning, JD-R, Workload, Challenge, Strategy, Teachers, Primary and secondary school, Belgium

1. Introduction

With technological change transforming the nature of work and societal participation, educational institutions must evolve accordingly, adopting pedagogical models that equip learners with the competencies needed to succeed in a rapidly shifting and digitally mediated environment. To achieve this, schools are increasingly moving away from exclusively face-to-face instruction toward more flexible, personalized, and engaging approaches such as online, blended, or hybrid learning models (LeBlanc, 2020). Blended learning (BL), in particular, has gained prominence as a pedagogical model that combines traditional classroom instruction with digital tools, offering adaptability to diverse learner needs (Bonk & Graham, 2012). BL is recognized for promoting individualized learning opportunities, real-time interaction, and sustained student engagement (Rasheed, Kamsin, & Abdullah, 2020). However, the integration of digital technologies into everyday teaching practice also creates new demands for teachers, requiring them to redesign lessons, incorporate new tools, and continuously

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monitor student progress. These additional tasks substantially increase workload not only in terms of time but also in terms of cognitive and emotional demands (Crews et al., 2008; MacIntyre, Gregersen, & Mercer, 2020). Such pressures are consistent with the Job Demands-Resources Model (Bakker & Demerouti, 2017), which posits that heightened job demands without sufficient resources can lead to strain and decreased work engagement, making workload an essential theoretical lens for understanding BL implementation.

Specifically, in primary and secondary education, emerging research underscores the intensified workload challenges teachers face in BL contexts. For example, Mendoza (2023) found that in special education settings, teachers experienced heavier workloads due to unstable internet, lack of training, and insufficient parental support, and coped by modifying lessons and relying on peer collaboration. Similarly, Wang et al., (2025) explored the effects of teachers' perceived workload on their work engagement in Chinese primary and secondary schools using a person-centered approach. In the European context, evidence from Belgium highlights that workload is not only increasing in absolute hours but also intensifying, with teachers performing more administrative and instructional tasks per unit of time under BL (Creagh et al., 2023). This is particularly relevant given that Belgian schools are under strong policy pressure to integrate digital technologies following the COVID-19 pandemic, supported by national initiatives such as the Digisprong programme (Flemish Ministry of Education, 2021). Yet, these reforms have not been accompanied by sufficient understanding of how BL affects teachers' daily working conditions.

While the literature has examined workload in higher education (Garone et al., 2022; Hill & Smith, 2023) and indicates that previous reviews often lack a deep exploration of how teaching methodologies influence workload perception (Radovan & Radovan, 2024), relatively little is known about how primary and secondary school teachers in Belgium perceive workload changes specifically attributable to BL, how they experience the challenges associated with these changes, and which coping strategies they employ. Addressing this gap is not only empirically necessary but also theoretically important. A better understanding of teacher workload in BL contributes to refining JD-R-based interpretations of technology-enhanced teaching, while also offering practical insights for Belgian schools navigating post-pandemic digitalisation mandates. Without such insights, schools risk implementing BL in ways that unintentionally intensify teacher workload and undermine both teacher wellbeing and instructional quality.

To bridge the research gap mentioned above, the research questions addressed in this research are as follows:

RQ1: How do primary and secondary school teachers in Belgium perceive workload changes (increases and/or decreases) associated with blended learning (BL), particularly in terms of job demands?

RQ2: What specific job demands and resource-related challenges do Belgian primary and secondary school teachers encounter when implementing BL?

RQ3: What job resources and coping strategies do Belgian primary and secondary school teachers identify as most effective in managing their workload in a blended learning context?

2. Theoretical Background

Belgian primary and secondary schools have undergone accelerated digitalisation in recent years, particularly following the COVID-19 pandemic and the launch of digitalisation initiatives such as the Flemish Digisprong programme (Flemish Ministry of Education, 2021). These reforms require teachers to adopt blended learning (BL) on a large scale, often without proportional increases in time, training, or instructional support. Because BL simultaneously introduces new pedagogical, technological, and organisational demands, a theoretical lens that captures the interaction between workload pressure, available support systems, and teacher well-being is needed. The Job Demands-Resources (JD-R) Model provides such an integrated perspective. Unlike technology-specific models such as TPACK (Mishra & Koehler, 2006), TAM (Davis, 1989), or UTAUT (Venkatesh et al., 2003), which focus primarily on technology acceptance or teacher knowledge, the JD-R framework allows researchers to examine how digitalisation affects teachers' working conditions, strain, engagement, and coping strategies, which are core concerns in Belgian BL implementation. This makes JD-R particularly appropriate for analysing BL-related workload in the Belgian context.

2.1 Job Demands-Resources (JD-R) Model

According to Demerouti et al. (2001), Job Demands-Resources (JD-R) Model explains how job demands and available resources influence perceived workload and teacher well-being. Illuminated by this model, this research explores how job demands, available digital tools and support, when teachers adapt to blended learning, influence perceived their workload and teacher well-being. In the context of Belgian BL implementation, where teachers must redesign lessons, integrate digital tools, manage parallel modalities, and support diverse learners, the JD-R model provides a mechanism for understanding how these combined pressures contribute to perceived workload intensification (Bakker & Demerouti, 2007; Rasheed, Kamsin, & Abdullah, 2020).

While previous research identifies multiple BL-related demands, these studies often appear fragmented or descriptive. Synthesising these findings reveals three recurring demand patterns: (1) Pedagogical complexity, including the need to design content for both online and face-to-face modalities (MacIntyre, Gregersen, & Mercer, 2020); (2) Technological demands, such as acquiring digital literacy and solving technical issues (Rasheed, Kamsin, & Abdullah, 2020; Bower et al., 2015; Batista-Toledo & Gavilan, 2025); and (3) Emotional and interactional demands (Batista-Toledo & Gavilan, 2025; Liao et al., 2025), particularly associated with continuous monitoring, online communication, and supporting diverse learners (Schipor & Duca, 2021). The JD-R model integrates these multidimensional pressures into a unified structure, allowing analysis not only of the quantity of tasks but also of the quality and intensity of the cognitive, behavioural, and emotional efforts required.

In addition, the JD-R model emphasizes that job resources, such as infrastructure, training, collegial collaboration, administrative support (Liao et al., 2025), and leadership practices (Cheng & Zhu, 2021; 2023; 2024), can buffer the negative effects of high demands and foster motivation (Bakker & Demerouti, 2017). In the Belgian context, where digital infrastructure and teacher support systems vary widely across schools (European Schoolnet & University of Liège, 2012), understanding the availability and perceived usefulness of resources is crucial. This study therefore applies the JD-R model to examine how teachers experience the balance between BL-related demands and available resources, and how this balance influences their overall workload and well-being.

2.2 Variations in Decreased Workload and Increased Workload

The JD-R framework further explains why teachers in similar BL environments may perceive workload differently. Some digital tools can reduce workload by automating tasks, streamlining communication, or easing assessment processes (Kumar et al., 2021; Alkhayat et al., 2022). Through synthesizing across studies, we can find these workload-reducing resources typically involve:

- Automation and digital organisation systems (Kumar et al., 2021)
- Data-driven monitoring tools enabling more efficient feedback (Alkhayat et al., 2022)
- Collaborative or self-directed learning structures that reduce direct supervision (Bishop & Verleger, 2013; Sari & Hermawan, 2022)

However, these potential efficiency gains contrast with empirical evidence showing that BL often increases workload, particularly when demands outweigh resources (Feng, Wang, & Wu, 2018). Studies report that teachers face increased planning time, technological uncertainty (Batista-Toledo & Gavilan, 2025), and demands for constant communication (Shahkarami et al., 2025) and monitoring (Crews et al., 2008; MacIntyre, Gregersen, & Mercer, 2020; Liao et al., 2025) in BL. When digitalisation policies advance faster than school-level support structures, as occurs in many Belgian schools, the imbalance between demands and resources intensifies stress and reduces work engagement (European Schoolnet & University of Liège, 2012). This synthesis highlights a theoretical gap in existing BL workload research: many studies document challenges (Shahkarami et al., 2025; Batista-Toledo & Gavilan, 2025) or benefits (Alkhayat et al., 2022; Kumar et al., 2021; Shahkarami et al., 2025) separately but rarely examine how teachers manage the simultaneous coexistence of work-increasing and work-reducing factors. The JD-R model is particularly suited to addressing this gap because it conceptualises workload not as a linear outcome but as a dynamic equilibrium between multiple demands and resources. By applying the JD-R model, this study identifies specific BL-related demands (e.g., technological literacy, parallel lesson planning, classroom diversity, technical troubleshooting; Feng, Wang, & Wu, 2018) and insufficient resources (e.g., uneven infrastructure, limited PD, inconsistent leadership support; Crews et al., 2008; MacIntyre, Gregersen, & Mercer, 2020), and explores how these shape teachers' perceptions of workload and well-being (Demerouti et al., 2001; Bakker & Demerouti, 2007). Thus, the JD-R model provides a theoretically rigorous basis for understanding teacher workload in BL environments. It enables an analysis not only of the pressures teachers face but also of the conditions under which BL may become either a source of strain (Radovan & Radovan, 2024) or a source of motivation.

3. Methodology

3.1 Design

This study employs a qualitative research approach, with Moustakas' (1994) phenomenological method, participants discuss and share their experiences regarding their experiences concerning workload and the challenges they are facing in BL environments. Qualitative data is gathered through semi-structured interviews. The interview questions focus on teachers' personal experiences, challenges, and strategies related to workload management in BL contexts.

3.2 Participants

This research was conducted within the context of primary and secondary schools in Belgium, particularly those that have integrated BL, which is an educational method that merges conventional on-site instructions with digital learning experiences and integrates various forms of technology (Davis & Fill, 2007; Mintii, 2023). Ten teachers from primary or secondary schools in Belgium with experiences in BL environments were interviewed (**Table 1**). To maintain the diversity of the samples, different gender, age, or teaching experiences were considered during sampling.

Table 1: Demographic information of the participants

Participants	Gender	Experience	Age	Subject	Level
P1	Female	1 year	24	General education*	Primary school
P2	Female	17 years	49	Art history & Architecture	Secondary school
P3	Male	8 years	31	Biology, chemistry and Physics	Secondary school
P4	Female	21 years	49	Catholicism, religion.	Secondary school
P5	Female	5 years	31	Visual arts & physical Education	Primary & secondary school
P6	Male	7 years	30	Sexuality education, Spanish	Primary & secondary school
P7	Female	8 months	22	English, Dutch, history	Secondary school
P8	Female	20 years	44	Science, English	Secondary school
P9	Female	3 years	23	English, Dutch	Secondary school
P10	Male	13years	44	Math, science	Secondary school

*General education in the PYP system (mathematics, English, history and science)

3.3 Data Collection

An instrument guide has been developed to guide the design of the semi-structured interview protocol. The guide/grid mapped each interview question to the study's research questions and key theoretical constructs derived from the Job Demands-Resources (JD-R) model, comprising questions designed to elicit information about the practices, specific challenges, the types of support and resources that teachers require to manage their workload, and the strategies teachers find most effective in dealing with the workload in BL environments. This ensured conceptual alignment between data collection and the analytical framework. The semi-structured interviews were arranged either face-to-face or online. The duration of the interviews were approximately 30 to 40 minutes and were recorded and subsequently transcribed into text.

3.4 Ethical Consideration

All the participants were informed of the confidentiality and anonymity of data collection and the purpose of the study. Before the interviews, researchers notified interviewees of the confidentiality of the research for the second time and asked permission to record the interviews. Researchers obtained participants' data collection agreements by a written and signed informed consent form.

3.5 Data Analysis

The data were analyzed using reflexive thematic analysis guided by Braun and Clarke's (2006) six-phase framework, implemented in Nvivo, a qualitative data analysis software that assists researchers in organizing, analyzing, and deriving insights from non-numerical or unstructured data. Thematic analysis allows researchers to identify, analyze, and interpret patterns of meaning within qualitative data, thereby deepening understanding of the studied phenomenon. While the analytic procedure followed Braun and Clarke's thematic framework, the interpretive orientation was informed by phenomenological principles (Moustakas, 1994; Creswell, 2009), this approach facilitated an in-depth exploration of participants' experiences regarding their workload in blended learning (BL) settings. This combination was deliberate, thematic analysis provided a systematic coding and theme development structure, and phenomenology guided the interpretive lens.

The analysis process was conducted iteratively and collaboratively. Initially, researchers read and familiarize (phase 1) themselves with the data and independently coded (phase 2) an initial sample of transcripts line-by-line, capturing both semantic content (explicit meanings) and latent patterns (underlying assumptions or tensions), memoing was used to support reflexive thinking during coding. Coding was continuously reviewed, refined, and organized using NVivo's node hierarchy and visual mapping tools. Consensus was reached through iterative negotiation and reflexive discussion, disagreements were resolved through dialogue and reflexive engagement with the data until a shared interpretive understanding was reached. Preliminary codes were then grouped into potential themes (phase 3), which were then reviewed and refined through regular re-examination of the coded extracts (phase 4) and the dataset as a whole by three researchers collaboratively. Themes were defined and named (phase 5) with clear descriptions of their scope and analytic contribution, and ultimately integrated into a narrative account (phase 6) aligned with the Job Demands-Resources (JD-R) model. In order to ensure the research trustworthiness, validity and reliability, peer debriefing and co-author cross-checking were conducted to help identify blind spots and strengthen confirmability (Lincoln & Guba, 1985; Birt et al., 2016). Throughout the process, the researchers collaboratively compared and discussed codes' discrepancies, and refined the codebook to maintain analytic trustworthiness and ensure that the findings faithfully represented participants' experiences.

4. Results

BL brings a complex dynamic to the teaching environment, which impacts teacher workload in diverse ways. This section presents the exploration of teachers' perception of the workload in BL environments, underscoring their experience with both the increase and decrease in workload, and teachers' perceived strategies for managing workload in BL.

4.1 Perceived workload changes in BL (RQ1)

4.1.1 Increased workload (job demands)

The findings in **Table 2** reveals that teachers perceive a significant increase in workload associated with blended learning (BL), primarily due to elevated job demands. Instructional complexity emerged as a central burden, with participants reporting the need for dual-mode planning, creating both digital and in-person materials, often without access to standard course books, requiring substantial time investment (P7). Technological challenges further compounded the workload, as teachers faced the dual task of mastering new platforms and teaching digital literacy to students, which added an additional layer of complexity to lesson integration (P3). Assessment practices also shifted under BL, replacing spontaneous oral feedback with time-intensive written documentation, thus increasing administrative effort (P5). Lastly, psychological pressures contributed to workload intensification, as institutional mandates around digital platform usage created rigid expectations and stress (P3). These findings align with the job demands aspect of the Job Demands-Resources model, indicating that the implementation of BL often amplifies cognitive, emotional, and logistical burdens on teachers.

Table 2: Perceived workload increase associated with BL in terms of job demands

JD-R Category	Code	Quote
Job Demands	Instructional Complexity	"You don't have any course books and you need to make all your material yourself." (P7)
	Technological Challenges	"When you're having to embed that into your curriculum... it definitely increased workload." (P3)
	Assessment and Feedback	"Written feedback replaced oral... spend more time writing everything down." (P5)
	Psychological Pressure	"You must use this platform this many times... it was demanding." (P3)

4.1.2 *Decreased workload (job resources)*

Table 3 highlights several key job resources that help alleviate the workload associated with blended learning (BL) as perceived by Belgian primary and secondary school teachers. Automation in assessment plays a significant role, as tools with auto-grading features and centralized digital platforms streamline feedback and reduce the administrative burden of collecting and organizing student work (P10). The availability of reusable digital materials from platforms like Twinkl, Kahoot, and BookWidgets further supports workload management by minimizing lesson preparation time and allowing teachers to focus more on instructional delivery. Additionally, digital platforms enhance efficiency through systematic tracking of student progress, enabling better organization and reducing redundant work (P5). Inclusive and collaborative tools such as text-to-speech software, translation services, and platforms like Digipad also contribute to teaching efficiency by accommodating diverse learning needs and facilitating group interaction (P1). Together, these resources reflect the supportive side of the Job Demands-Resources model, demonstrating how digital innovations can buffer against the intensified demands of BL environments.

Table 3: Perceived workloads decrease associated with BL in terms of job resources

JD-R Category	Code	Quote
Job Resources	Automation in Assessment	“Everything is in one location… I don’t have to collect things.” (P10)
	Material Reusability / Access	“Flexible and reusable materials… saving time.”
	Digital Monitoring / Student Data	“Everything is more well-organized… you can see if they have made progress." (P5)
	Inclusive Tools / Collaboration	“Translation software… text-to-speech… Digipad for group work.” (P1)

4.2 Workload Challenges when implementing BL (RQ2)

The implementation of blended learning (BL) introduces a range of workload-related job demands for teachers, as detailed in **Table 4**. Teachers report that digital content creation is especially time-intensive, particularly when developing interactive materials like those required by platforms such as BookWidgets (P2). Additionally, the need to align teaching content with rigid platform structures adds an extra layer of complexity and time commitment (P3). Classroom management also becomes more challenging in digital contexts, with multitasking students displaying disruptive behavior when disengaged (P4). Technical disruptions, such as unreliable internet connections and broken links, further undermine instructional flow, often derailing entire lessons (P4). Communication with colleagues is another point of strain, marked by feelings of isolation and ineffective collaboration (P2, P5). Teachers also face the ongoing burden of learning to use new technologies, maintaining existing tools, and assisting students with tech issues (P3, P8). Infrastructural deficits, including the absence of basic devices like projectors or screens, limit effective lesson delivery (P9), and insufficient, surface-level training leaves educators underprepared and overwhelmed (P5, P7). Time management remains a pervasive issue, with many teachers struggling to prioritize tasks in the face of constant workload pressures. Lastly, shifting to a digital pedagogy often meets internal resistance, especially among those accustomed to traditional teaching methods (P10).

Table 4: Job demands and resource-related challenges when implementing BL

JD-R Category	Code	Quote
Job Demands	Digital Content Creation	“It is a lot of work to make all the things because I use Book Widgets…” (P2)
	Platform Format Misalignment	“Aligning myself with the platform… that was what took the time.” (P3)
	Student Management	“When students are not busy… they get annoyed… you get emotional again.” (P4)
	Technical Breakdowns	“Just one site that doesn’t work… can ruin the entire session.” (P4)
	Communication and Collaboration	“We are both on a different island.” (P2); “Feels like running all the time.” (P5)
	Tech Integration & Maintenance	“Must constantly adapt and upskill…” (P8); “Basic tech assistance for students” (P3)

JD-R Category	Code	Quote
	Infrastructure Gaps	"The only support that I need is a projector or a TV screen…" (P9)
	Inadequate Training	"Short sessions lack depth…" (P5); "Modular training is better." (P7)
	Time Management Pressure	"Never-ending to-do lists… need specific training to prioritize tasks."
	Pedagogical Shift Challenges	"I was hesitant at first to switch over to the computer." (P10)
Job Resources	On-Site Tech Support (Needed)	"Having like people who know a lot… so teachers can ask for help." (P7)
	Modular Training Approach (Needed)	"Modular training… progress by mastering particular skills." (P7)

Amid these challenges, teachers also identified crucial job resources that could help mitigate the demands of BL (see Table 4). Foremost among these is the need for on-site technical support, readily available experts who can provide immediate, personalized assistance with digital tools and troubleshooting (P7). Teachers also called for a modular training approach that enables progressive skill-building, with each module focusing on specific competencies in digital instruction. This training model, as suggested by participants, would allow for more sustained and meaningful professional development compared to short, superficial sessions (P7). These findings underscore the importance of structural and institutional support in sustaining teacher well-being and instructional quality in blended learning contexts.

4.3 Strategies for Managing Workload in BL (RQ3)

A variety of strategies have been shown to be helpful in addressing the various challenges that Belgian primary and secondary school teachers have when teaching students in a BL setting. This section focuses on the strategies put up by the participants for coping with challenges in **4.2**, strategies framed in eight aspects in terms of Job Demands and strategies framed in four aspects in terms of Job Resources are highlighted.

The results reveal a range of teacher-initiated strategies developed to cope with the job demands of implementing blended learning (BL) (see **Table 5**). To address the heavy workload of content creation, teachers increasingly rely on pre-made digital resources from platforms like Canva and Kahoot, as well as AI tools such as ChatGPT for automating quizzes and summaries (P6). For those struggling with digital literacy, continuous upskilling through modular, skill-based training and peer support proved essential (P2, P7). Challenges related to student management in tech-rich environments are mitigated through structured laptop use and proactive classroom control techniques (P7, P10). Technical issues and infrastructure limitations are countered with backup plans, enhanced IT support, and advocacy for smart school platforms (P1, P4). To combat emotional stress, teachers adopt mindfulness practices and benefit from institutional policies promoting well-being, such as "no emails on weekends" (P4, P6). Teachers also streamline assessment tasks by leveraging auto-grading and formative feedback tools like BookWidgets and Kahoot (P3, P6), while digital planning tools such as Seesaw, Google Calendar, and organized file systems aid in managing time more effectively.

Table 5: Identified coping strategies regarding Job Demands in managing teachers' workload in BL

JD-R Category	Code	RQ2: Challenges Faced by Teachers	RQ3: Strategies to Manage Workload
Job Demands	Content Creation Workload	High time investment to create quizzes, activities, and adapt content to LMS platforms (P2, P3)	Use of AI to automate quizzes/summaries (P6); pre-made resources from Canva, Kahoot
	Tech Literacy & Learning Curve	Difficulty due to lack of digital skills; trial-and-error approach to new tools (P2, P5, P8)	Continuous upskilling; modular, longer training; peer support; integrated systems (P2, P7)
	Student Management & Distraction	Students multitasking during lessons; control challenges in tech-based settings (P10)	Structured use of laptops (turning off when needed), proactive classroom management (P7)
	Technical & Infrastructure Issues	Tech breakdowns, slow internet, device limitations, interruptions during class (P1, P4, P9)	Backup plans (P1); improved infrastructure (P9); smart school platforms (2); IT support (P5)
	Collaboration & Communication Load	Feelings of isolation; need to coordinate across departments and give feedback (P2, P5)	Regular colleague discussions; peer observations; resource-sharing via online platforms (P3, P10)

JD-R Category	Code	RQ2: Challenges Faced by Teachers	RQ3: Strategies to Manage Workload
	Emotional & Mental Load	Stress, frustration from unpredictability, tech problems, student disengagement (P4, P5)	Mindfulness, meditation (P6); school policies that support wellbeing; no-emails-on-weekends (P4, P10)
	Assessment & Feedback	Time-consuming grading, lack of tools to provide feedback efficiently (P3, P4, P6)	Automated tools for quizzes and feedback: Book Widgets, ChatGPT; formative tools like Kahoot
	Time Management	Struggling with to-do lists; lack of training in prioritization (P5); short, insufficient training	Use of planning tools like Seesaw, Google Calendar, to-do apps; modular PD; organized file systems

In terms of enhancing job resources (see **Table 6**), peer collaboration emerged as a critical support mechanism. Teachers reduced feelings of isolation by engaging in regular discussions, peer observations, and collaborative lesson design using tools like Microsoft Teams and Digipad (P3, P10). Organizational support was also key, with calls for reliable IT personnel, designated tech-support staff, and streamlined digital ecosystems (P2, P7). Professional development was identified as a pivotal area for improvement; teachers advocated for longer, modular, and hands-on training formats that directly apply to classroom scenarios, particularly involving AI tools like ChatGPT and interactive video plugins (P6, P7). Moreover, teachers emphasized the need for greater autonomy and recognition in adopting BL tools, proposing policies that promote work-life balance and leadership strategies that validate teacher innovation and initiative (P4, P10). Together, these strategies reflect an adaptive and resourceful response by teachers to the multidimensional demands of blended learning environments.

Table 6: Identified coping strategies regarding Job resources in managing teachers' workload in BL

JD-R Category	Code	RQ2: Challenges Faced by Teachers	RQ3: Strategies to Enhance Resources
Job Resources	Peer Support & Collaboration	Feelings of isolation; minimal peer interaction in BL implementation (P2)	Regular colleague discussions; peer learning via lesson observations (P3); online communities (P10)
		Lack of shared resources or common knowledge base (P5)	Use of collaboration tools like Teams and Digipad to share resources and co-create lessons
	Organizational Support	Absence of dedicated tech experts; unclear processes for getting help (P7)	Access to reliable IT support; assigning tech-savvy staff to support teachers (P7); smart school tools
		Teachers feel alone in navigating BL without institutional help (P2)	Smart school integration to streamline access to materials and reduce workload (P2)
	Professional Development	Training too short or too shallow; not applicable to real-life classroom issues (P5)	Modular, skill-focused PD; longer sessions; opportunities for hands-on training and progression (P7)
		Lack of AI training despite relevance to BL tasks (P2)	Introduction of AI tools in PD; hands-on use of tools like ChatGPT and video quiz plug-ins (P6)
	Autonomy & Recognition	Low control over tool choice; lack of recognition from leadership (P4)	Policies promoting work-life balance (e.g., no weekend email); leadership support for teacher autonomy
		Hesitation or doubt about switching to tech due to lack of encouragement (P10)	Creating a culture of trust and independence in tech adoption; celebrating innovation (P10)

5. Discussions

The main results of the study show that BL has the potential for both increasing and decreasing teacher workload. There are also identified specific challenges and workload management strategies. These results support and supplement the literature already available on the topic, while also bringing out gaps and providing novel perspectives that have rarely been addressed before.

5.1 Perceived Workload Changes in BL (RQ1)

5.1.1 Increased workload (job demands)

Teachers in blended learning (BL) environments report a substantial rise in workload, particularly due to intensified task complexity, cognitive demands, and technological pressures. The creation of digital content, including assessments, lesson materials, and instructional videos, emerges as a significant task demand that demands high cognitive and time investment. This aligns with previous literature emphasizing that BL implementation involves complex, multi-level instructional efforts (Timperley & Robinson, 2000). Increased technological demands are also evident, particularly in the need to navigate diverse platforms, troubleshoot technical issues, and respond to students' varying digital competencies. Teachers must often provide real-time support to students lacking digital skills, compounding the pressure on instructional time (MacIntyre, Gregersen, & Mercer, 2020). This finding supports prior research on how student diversity, especially in terms of technological literacy, contributes to teacher workload (Schipor & Duca, 2021). Moreover, emotional demands are elevated in BL contexts. Teachers experience heightened stress when classroom control diminishes due to digital distractions, and when unanticipated technical breakdowns derail lessons. Some participants reported a sense of being "always on", juggling multiple roles without clear boundaries between instruction, IT support, and emotional caregiving. The strain is intensified by insufficient organizational support, such as the absence of onsite tech experts and inadequate training tailored to the realities of BL instruction. A notable finding underexplored in existing literature is the removal of traditional textbooks in some schools, requiring teachers to create all course content from scratch (P7). This substitution of core instructional materials with teacher-generated digital content significantly magnifies their workload and highlights a unique material challenge within certain BL contexts.

5.1.2 Decreased workload (job resources)

Despite these pressures, teachers also identify key job resources within the BL environment that can alleviate workload when effectively utilized. Most notably, the integration of digital tools and platforms offers opportunities for automation, planning, and instructional efficiency. Tools like Kahoot, BookWidgets, and Seesaw reduce the time needed for grading, feedback, and lesson design. This corroborates Kumar et al.'s (2021) findings that automation in administrative tasks can allow teachers to redirect time and energy toward instructional quality. The availability of pre-made resources and AI-supported tools (e.g., auto-grading, quiz generation, translation) further enables teachers to streamline content creation and differentiation (Alkhayat et al., 2022). These tools support adaptive instruction by facilitating adjustments for language needs, special education support, and various learning styles, functions that would otherwise require considerable effort (Kumar et al., 2021). Another crucial resource is the use of centralized platforms (e.g., Smart School, Teams) that consolidate access to learning materials, student submissions, and communication tools. Such platforms enhance organizational efficiency, reducing the cognitive load involved in managing multiple systems. From a collaboration and communication perspective, peer observation, digital communities, and school policies (e.g., no emails on weekends) contribute to a sense of support and autonomy, helping teachers manage the emotional toll of their workload. As shown in studies by Bishop and Verleger (2013) and Sari & Hermawan (2022), these collaborative systems promote self-directed learning among students, thereby shifting some responsibility for learning away from the teacher and reducing direct oversight demands.

5.2 Workload Challenges When Implementing BL (RQ2)

The findings underscore a multifaceted set of job demands that significantly impact teachers working in blended learning (BL) contexts. Teachers face heightened cognitive and emotional strain due to inadequate technological literacy, insufficient time management strategies, and the need to manage student behavior in digital settings, particularly the issue of off-task laptop use. These challenges align with prior research indicating that digital integration can provoke discomfort and cognitive overload, especially when teachers are expected to design, deliver, and troubleshoot technology-enhanced instruction with limited preparation (Baran & Correia, 2014; Rasheed, Kamsin, & Abdullah, 2020). Furthermore, emotional demands emerge from feelings of professional isolation and limited inter-collegial support, exacerbated by a lack of effective collaboration platforms. The resistance to adopting a BL mindset, noted by participants and consistent with Lightner and Lightner-Laws (2023), further highlights the need for psychological and pedagogical shifts that go beyond technical skills.

To address these demands, the research identifies a clear need for job resources that include targeted professional development, peer support, and structural investments. Participants emphasized that sustained improvements in digital proficiency and pedagogical confidence resulted from comprehensive training, echoing

Zhao and Song's (2021) call for continuous, context-specific professional development. Teachers also advocated for expanded digital literacy programs that address advanced instructional applications, not merely basic skills (Ali et al., 2005). Importantly, the need for infrastructure and financial support emerged as critical, participants stressed the importance of reliable internet, centralized platforms, and access to quality digital resources. Beyond material needs, teachers pointed to the motivational value of emotional support and recognition from leadership (Cheng, Zhu, & Dinh, 2024), reinforcing prior findings that perceived organizational support enhances teacher well-being and job satisfaction in technology-rich environments (Zhao & Song, 2021). Collectively, these findings support a JD-R perspective that effective workload management in BL requires not only the reduction of demands but also the strategic enhancement of resources across individual, interpersonal, and institutional levels.

5.3 Strategies for Managing Workload in BL (RQ3)

Based on the findings regarding RQ3, teachers in blended learning (BL) settings employ a variety of strategies to mitigate workload, aligning with the Job Demands-Resources (JD-R) model by converting high-strain demands into manageable tasks using job resources. Key strategies include the automation of content creation and assessment via AI-powered tools (e.g., ChatGPT, Book Widgets), the integration of pre-made digital resources (e.g., Canva, Kahoot), and centralized platforms for planning and communication (e.g., Smart School, Teams). These tools reduce the cognitive and temporal demands placed on teachers by streamlining instructional planning and feedback delivery (Kumar et al., 2021; Alkhayat et al., 2022). Time management is further supported through digital scheduling tools such as Google Calendar and Seesaw, allowing for more efficient task organization and workload distribution.

Equally important are the social and emotional job resources that support teacher resilience and job satisfaction. Peer collaboration, via lesson observations, shared resource banks, and online communities, fosters a sense of professional belonging and reduces isolation, echoing research that underscores the value of collegial support in digital teaching contexts (Zhao & Song, 2021). In addition, schools that actively cultivate teacher well-being through mindfulness resources, clear boundaries (e.g., no weekend emails), and recognition of teacher autonomy report higher motivation and lower burnout risk (Baran & Correia, 2014; Sari & Hermawan, 2022). These findings highlight the critical role of institutional and technological support systems in transforming the BL model from a potential burden into a sustainable, enriching pedagogical framework.

6. Limitations

There are a few limitations to take into account. The limited sample size may affect the findings' applicability to other educational contexts. Future research can include more participants from other geological areas to increase the generalizability of the findings. Furthermore, when novel tools are developed, the findings may change due to the quick advancement of technology. In addition, how teacher's confidence is in BL can be affected by continuous training. By carrying out longitudinal studies to investigate the long-term impacts of BL on teachers' job satisfaction and retention, future research might solve these limitations.

7. Conclusion and Implications

This study illustrates how blended learning (BL) presents a dynamic balance of job demands and resources for teachers in the context of Belgian primary and secondary schools, as framed by the Job Demands-Resources (JD-R) model. The findings emphasize that the key to managing BL-related workload lies in providing sufficient support structures, enabling teachers to effectively navigate demands and maintain well-being. This confirms the JD-R model's utility in understanding teacher workload in BL environments and highlights the importance of balancing demands with resources to sustain quality teaching and teacher well-being (Bakker & Demerouti, 2007; Baran & Correia, 2014; Zhao & Song, 2021).

Theoretically, this study contributes to the broader understanding of workload management in technology-integrated pedagogies by applying the JD-R model to the context of blended learning. It demonstrates how BL introduces a unique constellation of stressors and supports that can either hinder or facilitate teacher performance depending on the surrounding institutional framework. This reinforces the need to conceptualize teacher workload not only as a function of task quantity, but also of task complexity, autonomy, and resource availability (Schaufeli & Taris, 2014). Moreover, the study extends prior work by identifying digital infrastructure, peer support, and strategic professional development as critical resources that can mediate the impact of elevated demands. These findings underscore the importance of job design that considers not only the technical but also the emotional and cognitive aspects of teaching in BL settings.

Practically, the findings point to targeted implications for school leadership, teacher professional development, and education policy, particularly within the Belgian context of increasing school autonomy and ongoing digital transformation. At the school level, workload pressures associated with blended learning (BL) can be alleviated through structured professional development that is sustained over time rather than delivered as one-off workshops. For example, schools could allocate a minimum number of annual professional development hours specifically to blended instructional design, digital assessment practices, and time-management strategies, complemented by structured peer-mentoring or coaching models during BL implementation phases (Ali et al., 2005; Zhao & Song, 2021). Reducing teaching loads or reallocating non-instructional duties during transitional periods may further enable teachers to redesign courses without exacerbating strain. Embedding co-planning sessions, aligned with Belgium's collective bargaining frameworks reducing teaching loads during BL transitions, and adopting user-friendly platforms for automated tasks can support collaboration and reduce duplicated preparation work. Simultaneously, students must be trained to engage responsibly with digital tools, may help mitigate behavioral and monitoring demands placed on teachers in BL environments. From a policy perspective, the findings suggest the need to align BL initiatives with broader digital education strategies in Belgium, including investments in infrastructure, clear quality standards for blended instruction, and policy guidance that explicitly recognizes workload implications. Leadership practices should operationalize teacher well-being (Cheng, Caliskan, & Zhu, 2023; Cheng & Zhu, 2025) by embedding mental health resources, protected non-teaching time, and regular workload monitoring into school improvement plans.

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Analysis of Blended Learning in Higher Education Based on CiteSpace (2001-2024)

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Abstract: This study presents a comprehensive bibliometric analysis of blended learning in higher education (BLHE) research published between 2001 and 2024. Using CiteSpace, 2,125 publications retrieved from the Web of Science Core Collection were analyzed to map the intellectual structure, thematic evolution, and research dynamics of the field. The results indicate a sustained growth in BLHE research since 2013, with peak productivity in 2018 and 2019, reflecting the increasing academic and institutional attention to blended learning in higher education. Conference proceedings emerged as prominent publication venues, underscoring the field's strong orientation toward practice-related innovation and the rapid dissemination of emerging ideas. Document co-citation analysis identified several that have shaped the development of BLHE, with Garrison and Kanuka's (2004) Community of Inquiry framework forming a central theoretical foundation. Cluster analysis revealed 11 major research themes, demonstrating a clear evolution from foundational models of blended learning toward more learner-centered and process-oriented approaches, including blended learning foundations, self-regulated learning, game-based learning, and work-integrated learning. These clusters highlight the multifaceted nature of BLHE research and its integration with various pedagogical approaches and technologies. Our analysis also uncovered several research gaps, including a need for more diverse cultural perspectives, longitudinal studies examining long-term impacts, and research on innovative assessment strategies in blended environments. While the field has made significant progress in understanding BLHE implementation, challenges remain in addressing cultural diversity and long-term effectiveness. This study provides researchers, educators, and policymakers with insights into the field's intellectual structure, emerging trends, and future directions. Beyond mapping research trends, the findings offer practical guidance for e-learning and blended learning practice by informing course design, supporting learner self-regulation, and guiding teacher development, while methodologically advancing the field through CiteSpace-based longitudinal and structural analysis that outlines a clear future research agenda. As blended learning continues to shape higher education, addressing identified research gaps will be crucial for developing more effective, inclusive, and transformative learning experiences.

Keywords: Blended learning in higher education, Bibliometric analysis, Research trends, Thematic evolution

1. Introduction

The educational landscape is evolving owing to technological advancements, historical occurrences, labour market transformations, and economic fluctuations. These pressures are transforming educational objectives and methodologies. Contemporary studies underscore the need for varied pedagogical methods (Markauskaite et al., 2024). In this context, blended learning (BL) has arisen as an innovative instructional method, receiving considerable attention in scholarly literature (Kang & Kim, 2021). The past global pandemic has accelerated the use of blended learning approaches, positioning them at the front of educational innovation. By using technology advancements, BL has preserved its relevance and reinforced its significance in contemporary educational systems. The concept of BL, also known as mixed or hybrid learning (Atwa et al., 2019) has been subject to numerous interpretations in international literature. Despite the variety of definitions that exist, a common thread emerges: BL aims to harmonize the strengths of distance and face-to-face teaching methodologies (Garrison & Kanuka, 2004). At its core, BL is characterized by the seamless integration of online and traditional in-person educational processes. This integration is not merely a theoretical concept but a practical approach that has been tested and refined over time. The dynamic nature of BL has become particularly evident with the changing structure of both learners and learning environments. The COVID-19 pandemic, which forced a rapid and widespread adoption of online learning, has served as a catalyst for this change. The experiences gained during this period have boldly underlined the utility and resilience of the blended learning model. As a result, such cases have indicated a significant shift towards preferring this model in the future, a tendency that is both observable and likely to continue growing (Bozkurt & Sharma, 2022; Pelletier et al., 2021; Cruz-Cárdenas et al., 2023; Hebebci & Ozer, 2023).

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In the realm of higher education, blended learning has become increasingly pivotal (Harasim, 2000). Universities and colleges worldwide are recognizing its potential to enhance the learning experience and outcomes for students (Adebayo et al., 2019). By combining the flexibility and resource-rich environment of online platforms with the interpersonal dynamics of face-to-face instruction, Blended Learning in Higher Education (BLHE) has offered a unique opportunity to cater to diverse learning styles and needs (Bhowmik, Meyer & Phillips, 2019). It has allowed for the optimization of both independent study and collaborative learning, preparing students for the digital-forward yet human-centric workplaces of the future (Stepanova, 2020). Moreover, BLHE has not merely been a matter of integrating technology; it has been a fundamental change in the pedagogical approach that promotes digital literacy, critical thinking, and active learning, all of which are essential in the knowledge economy of today (Laufer et al., 2021). As higher education institutions grow, BL has emerged as a fundamental innovation, aiming to reconcile conventional academic excellence with the requirements of our increasingly linked and digital landscape(Harasim, 2000). Furthermore, its significance in higher education has grown exponentially, arousing the interest of scholars from various disciplines including education, psychology, technology, and sociology (Just, 2021; Ma & Lee, 2021). The complex characteristics of BL have resulted in a substantial and varied body of research, indicating its capacity to transform educational practices in higher education globally. BL has significantly evolved since its inception, influenced by technological breakthroughs and shifting pedagogical methodologies. Over the past two decades, researchers from different fields have contributed to our understanding of blended learning, exploring its impact on student engagement, learning outcomes, and institutional effectiveness (Bhowmik, Meyer & Phillips, 2019; Cacciamani, Perrucci & Fujita, 2021; Zhu, Berri & Zhang, 2021).

Blended learning in higher education (BLHE) has been the subject of numerous review papers in recent years, each addressing different subtopics within this broad field of inquiry. For instance, Balakrishnan et al. (2021) conducted a systematic review and meta-analysis focusing on the effectiveness of blended learning in pharmacy education, demonstrating significant enhancements in knowledge and abilities among pharmacy students compared to conventional teaching approaches. Short et al. (2021) performed a systematic mapping evaluation of research trends regarding teacher preparation for K-12 mixed contexts, highlighting the insufficient emphasis on K-12 blended learning and underscoring the need for more extensive studies in this domain. While these reviews provided valuable insights into specific aspects of blended learning, they do not offer a comprehensive bibliometric analysis of the field. Some researchers have attempted to address this gap. Specifically, Ibarra-Vargas, Awad and Velásquez (2023) undertook a bibliometric and cluster analysis of blended learning literature, establishing six topic groupings and emphasizing the prevalence of qualitative studies of hybrid course experiences. Similarly, Limaymanta et al. (2021) carried out a bibliometric analysis of the flipped classroom in higher education, proposing a framework for its implementation in various learning modalities. More recently, Cruz-Cárdenas et al. (2023) and Hebebci and Ozer (2023) have conducted bibliometric analyses specifically focusing on BLHE. Cruz-Cárdenas's study identified four main areas of interest, including the impact of COVID-19, the effectiveness of blended learning, its organization and design, and the technological tools used. Hebebci and Ozer's analysis mapped the development of blended learning research from 2005 to 2021, identifying key contributing countries and authors.

Despite these efforts, bibliometric studies in education are characterised by several methodological constraints. The findings of bibliometric studies in education are highly contingent on the choice of database which represents a key sources of structural bias. As recent comparative evaluations suggest, major bibliographic databases differ substantially in their indexing policies, disciplinary coverage, language scope, and treatment of publication types (Gusenbauer, 2024). Web of Science (WoS), for example, offers comprehensive coverage of high-impact journals inclusion criteria, ensuring the reliability and academic quality of retrieved documents. However, its focus on English-language, high-impact, and international journals introduces structural biases that tend to underrepresent regional, practitioner-oriented, and non-English scholarship in education and e-learning (Singh et al., 2020). In contrast, databases such as Scopus provide broader journal coverage and often include more education and educational-technology journals as well as conference proceedings, thereby capturing more applied and context-specific research (Singh et al., 2020; Guerrero-Bote et al., 2021). As systematic reviews in education suggest, relying on a single source like WoS may narrow the scope of literature retrieval and risk missing relevant studies, especially those published in non-mainstream or non-English outlets Zawacki-Richter et al. (2019). Furthermore, empirical evidence shows that discipline-specific education databases outperform general multidisciplinary sources in retrieving relevant literature for systematic reviews in education, suggesting that a combination of specialized and general databases may yield the most comprehensive coverage (Heck, Keller & Rittberger, 2024). Despite the documented limitations of relying on a single database—particularly the underrepresentation of regional, practitioner-oriented, and non-English publications—Web of Science (WoS) remains the most widely used and methodologically stable data source in bibliometric studies in education. WoS provides high-quality, well-standardized metadata and applies stringent journal selection criteria, which are crucial for generating reliable co-citation, co-word, and clustering networks using CiteSpace (Pranckutė, 2021). CiteSpace is optimally designed to process the field-tagged ISI format used by WoS, whereas others databases likes Scopus exports often require substantial preprocessing or contain incomplete cited-reference information, which can compromise the reliability of longitudinal and network-based analyses in education bibliometrics (Pranckutė, 2021). Moreover, the core international journals that shape the intellectual structure of educational technology and blended learning research are predominantly indexed in WoS.

Recent bibliometric studies of BLHE have frequently relied on co-word analysis to map thematic structures. However, co-word methods present several domain-specific limitations in the BLHE context. First, terminology in BLHE is inconsistent—blended, hybrid, flipped and technology-enhanced learning are often used interchangeably—resulting in fragmented clusters unless rigorous keyword harmonization is applied (Dziuban et al., 2018; Corrin et al., 2022). Then, co-word relies on author-defined keywords and therefore can reflect authors' keyword selection choices rather than the field's conceptual architecture (Zupic & Čater, 2015). For instance, some list only content-specific term, such as flipped classroom, whereas others include methodological or contextual descriptors such as "case study" or "higher education" resulting in unstable clustering and inflated noise within co-word networks (Corrin et al., 2022). Furthermore, methodological choices (keyword frequency thresholds, normalization and similarity measures) strongly affect cluster solutions and are frequently underreported, undermining result reproducibility (Aria & Cuccurullo, 2017). Collectively, these limitations recommend that BLHE bibliometric studies explicitly report keyword cleaning protocols.

Building upon this existing body of research, the present study aims to contribute an updated perspective to the field's bibliometric analysis of BLHE. While recent reviews have made significant strides, this study differentiates itself in two key aspects. Firstly, while both Cruz-Cárdenas et al. (2023) and Hebebci and Ozer (2022) utilized VOSviewer for their analyses. Although VOSviewer is highly effective for generating static and stable network layouts and clustering large co-author or co-occurrence structures (van Eck & Waltman, 2010), it offers limited functions for visualizing the temporal evolution of a field. CiteSpace, by contrast, provides advanced analytical features such as burst detection, time-sliced co-citation analysis, and timeline visualizations that reveal developmental trajectories and turning points in scientific literature (Chen, 2006, Chen, 2016). Education research has seen a significant adoption of CiteSpace, as evidenced by studies like Chu et al. (2023) on STEM interventions and Geng (2024) on Chinese cultural integration in English education. This methodological variation offers an alternative approach to visualizing and analyzing the research landscape in BLHE. Secondly, this analysis extends the temporal scope to incorporate research conducted after the onset of the COVID-19 pandemic. This addresses a future research direction suggested by Hebebci and Ozer (2023), who proposed examining post-COVID-19 studies. By including this more recent data, the present study offers a more current perspective on BLHE, complementing the COVID-19 impact area identified by Cruz-Cárdenas et al. (2023). Through these approaches, this study aims to provide a comprehensive and up-to-date bibliometric analysis of BLHE, contributing to the ongoing development of this interdisciplinary field. Specifically, this CiteSpace-assisted review seeks to uncover prolific journals and conference proceedings, prominent researchers, significant institutions, and dynamic research issues, while creating a visual representation of related terms and dominant topics using keyword co-occurrence analysis. To achieve these objectives, the following research questions are proposed:

RQ1: What are the key trends and patterns in the development of blended learning research in higher education over the past two decades?

RQ2: In what ways can the temporal and geospatial analysis of research output contribute to our understanding of the global diffusion and adoption of blended learning practices in higher education?

RQ3: To what extent can the cluster analysis of keywords and research topics identify critical research features and potential gaps in the current body of knowledge on BLHE?

Based on these research questions, it is hypothesized that the bibliometric analysis will reveal significant evolution in BLHE research, shifting from technological implementation to more nuanced explorations of pedagogical strategies and student outcomes. The study anticipates uncovering distinct patterns of global diffusion and identifying critical research features and potential gaps, particularly in areas related to faculty development and institutional policy-making.

2. Methodology

2.1 Data Collection

This study employed a comprehensive bibliometric analysis approach to examine the landscape of blended learning research in higher education. To ensure a robust and representative dataset, an advanced search was conducted in the Web of Science (WoS) Core Collection of Thomson Reuters. This database was selected due to its extensive coverage, rigorous indexing process, and compatibility with the chosen bibliometric analysis tools. The search encompassed multiple citation indices, including the Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (AHCI), Conference Proceedings Citation Index (CPCI), and Emerging Sources Citation Index (ESCI). This multi-index approach allowed for a broad and interdisciplinary collection of literature pertinent to the research focus.

To capture the full spectrum of research on BLHE from 2001 to 2024, a comprehensive literature search was conducted. This time frame was chosen to encompass the early stages of blended learning adoption in higher education through to its current state, allowing for a thorough analysis of trends and developments over more than two decades. Prior research has shown that authors use several overlapping terms, including ’blended learning’, ‘hybrid learning’ and ‘technology-supported learning’, often interchangeably in empirical and bibliometic work (Dziuban et al., 2018). Based on this review, the search strategy adopted controlled keyword variants that refer to comparable instructional formats combining online and face-to-face components. Therefore, a set of key search terms was carefully selected to ensure comprehensive coverage: ‘blended learning’, ‘blended education’, ‘blended courses’, ‘integrated learning’, ‘hybrid learning’, and ‘higher education’. This selection was based on common terminology used in the field (Hrastinski, 2019). To ensure consistency, variant spellings and closely related expressions were consolidated under the most commonly used forms. For instance, earlier labels such as ‘integrated learning’ that appeared in pre-2010 literature were treated as conceptually aligned with ‘blended learning’ and were therefore included. Conversely, terms with broader or different meanings, such as ‘technology-enhanced learning’ or ‘online learning’ were excluded because they do not necessarily indicate a mixed-mode instructional design.

On July 22, 2024, an advanced search was executed in the Web of Science (WoS) database using the following search string: TS= (blended learning* OR blended education* OR blended course* OR integrated learning* OR hybrid learning*) AND (higher education). This strategy ensured the retrieval of articles containing the specified terms in their title, abstract, or keywords. The search was limited to research articles, specially systematic reviews and bibliometric analyses, to focus on original research and comprehensive syntheses of the field, a common practice in bibliometric studies (Zupic & Čater, 2015). Importantly, no language restrictions were applied, recognizing that valuable contributions might exist in non-English publications. Although no language restrictions were intentionally applied during the screen process, it must be acknowledged that the Web of Science (WoS) databases predominantly index English-language journals. As a result, publications in other language may still be underrepresented despite the inclusive search criteria. Furthermore, the exclusive use of WoS - despite its strong coverage and compatibility with scientometric tools - may have resulted in the omission if relevant literature available only in Scopus, ERIC, or Google Scholar. These limitations should be considered when interpreting the findings.

The initial search yielded 2144 results from WoS. A meticulous screening process was then undertaken to refine the dataset. Book reviews, book chapters, editorial materials, letters, and retracted publications were excluded from the analysis, following standard bibliometric practices (Aria & Cuccurullo, 2017). This screening process resulted in a final dataset of 2125 research articles and review articles. A PRISMA flow diagram (Figure 1) illustrate the identification, screening, and inclusion process. These documents spanned various WoS categories, predominantly including 'Education', 'Computer Science', 'Social Sciences', and 'Linguistics', reflecting the interdisciplinary nature of BLHE research. This refined dataset formed the basis for subsequent bibliometric analysis, providing a comprehensive overview of the field's development, key trends, and influential works in blended learning within higher education of more than two decades. The use of such a dataset for bibliometric analysis has been well-established in educational research (Chen, Zou & Xie, 2020).

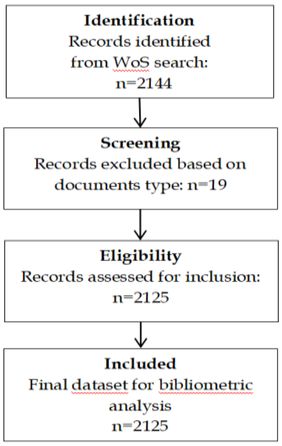

Figure 1: PRISMA flow diagram of study selection for bibliometric analysis of BLHE research

2.2 Descriptive Analysis

Prior to the in-depth bibliometric analysis, a comprehensive descriptive analysis of the dataset was conducted. This preliminary analysis aimed to provide an overview of publication trends and identify key contributors to the field of BLHE. The analysis began with an examination of the yearly publication trends from 2001 to 2024. This temporal analysis allowed for tracing the evolution of research interest in blended learning over time, identifying periods of rapid growth or potential plateaus in scholarly output. To visualize this trend, SPSS software was used to generate a bar graph depicting the number of publications per year.

The WoS website provided data on the number of publications for each journal, author, and institution. For journals and conference proceedings, we selected the top 5 for in-depth analysis, while for authors and institutions, we examined the top 10. These rankings offer insights into the key contributors and platforms driving research in this field. The analysis of the most productive journals and conference proceedings has revealed which publications have been most influential in disseminating research on BLHE. Similarly, identifying the most prolific authors has provided an understanding of the key thought leaders and researchers shaping the field. The examination of the most productive institutions highlighted the academic centers that have been at the forefront of blended learning research and implementation in higher education settings.

2.3 CiteSpace Analysis

While the descriptive analysis based on Web of Science (WoS) data has provided a valuable initial overview of the research field of BLHE, it has limitations in fully capturing the intellectual structure and emerging trends of this rapidly evolving domain (Zupic & Čater, 2015). The basic statistics on publication counts, top journals conference proceedings, authors, and institutions have offered a general picture but couldn't provide an exhaustive account of the field's development of the past more than two decades or identify the most recent directions for future research (Chen, 2006). Traditional literature reviews in the field of blended learning have often relied on researchers' prior knowledge and subjective (Halverson et al., 2014). This approach, while valuable, risks overlooking crucial information or emerging trends, particularly given the interdisciplinary nature and rapid technological advancements characteristic of blended learning research. The complex interplay between education, technology, and pedagogy in blended learning has made it challenging for individual researchers.

To move beyond the limitations of basic descriptive statistics and gain deeper insights into the intellectual structure and evolution of BLHE research, CiteSpace, an information visualization analysis software designed to present the structure and distribution of scientific knowledge through visualization (Chen, 2006; Kim, Zhu & Chen, 2016; Hou, Yang & Chen, 2020) has been employed for the bibliometric analysis. This approach allows us to examine the structures and characteristics of the existing knowledge regarding BLHE in a more systematic and data-driven manner (Chen, 2018). A key feature of CiteSpace is its ability to select a particular field based on a time sequence and link both together, enabling the deduction of developmental trends and changes within the area of BLHE (Chen et al., 2009). In our study, the bibliographic data files collected from WoS were in the field-tagged Institute for Scientific Information Export Format. We selected the 'full record and cited references' as the content, allowing CiteSpace to easily identify the files.

Once the files were loaded into CiteSpace, the following procedural operations were performed: time slicing, thresholding, modeling, merging, and mapping (Chen, 2004). To capture the longitudinal evolution of blended learning research in high education, we set the time span to 2001-2024. For the annual publication trend analysis, we used a one-year time slice to provide fine-grained temporal resolution. For both the document co-citation analysis and co-occurring terms analysis, we adopted a three-year time slice, which is commonly recommended for identifying stable intellectual structures within a developing research field. In constructing the co-citation network, we selected the top 50 most-cited references per slice, ensuring that the network retained the most influential scholarly works. Thresholding was performed using CiteSpace's default g-index scaling factor (k=25), which balances network density and and interpretability. For term-based analysis, we enabled the Look Back Years (LBY) parameter to include all previous years, allowing cumulative detection of emerging concepts. No network pruning algorithms (e.g., Pathfinder or Pruning Sliced Networks) were applied, in order to preserve the full structural connections among nodes and avoid the removal of potentially meaning but low-frequency links. These operations allowed for a comprehensive analysis of the blended learning literature. We conducted two separate visualizing analyses of the data:

- Document Co-citation Analysis: This analysis helped identify important documents in blended learning research. A co-cited reference was called a node, and when several nodes were strongly related to one another, they formed a cluster. This analysis revealed the intellectual structure and key influencers in the field of BLHE;
- Keyword Co-occurrence Analysis: The purpose of this analysis was to identify the most-discussed areas in research on BLHE. Keyword Co-occurrence identifies terms that frequently appear together across publications, indicating their thematic relatedness within the field. This helped in understanding the main themes and trends in the field over time.

3. Results

Publication years, journals and conference proceedings, productive authors, and institutions on BLHE. Figure 2 indicated the annual publications on BLHE research. In the web of Science core collection, this research field experienced a slow start from 2001 to 2006, with fewer than 20 publications per year. A noticeable increase began in 2007, with 22 publications, marking the beginning of more significant interest in the topic. Rapid growth was observed from 2010 onwards, with publications more than doubling from 67 in 2012 to 138 in 2015. The field reached its peak in terms of publications in 2018 and 2019, with 196 and 194 papers respectively. Interestingly, there was a slight dip in 2020 to 159 papers, possibly due to the disruptions caused by the COVID-19 pandemic. However, the field quickly rebounded in 2021 with 194 publications, suggesting a renewed interest in blended learning strategies as institutions adapted to new educational paradigms. The most recent years have shown a gradual decline in the number of publications, with 162 in 2022, 140 in 2023, and 101 in the partial year of 2024. This trend could indicate a maturation of the field or a shift in research focus within higher education.

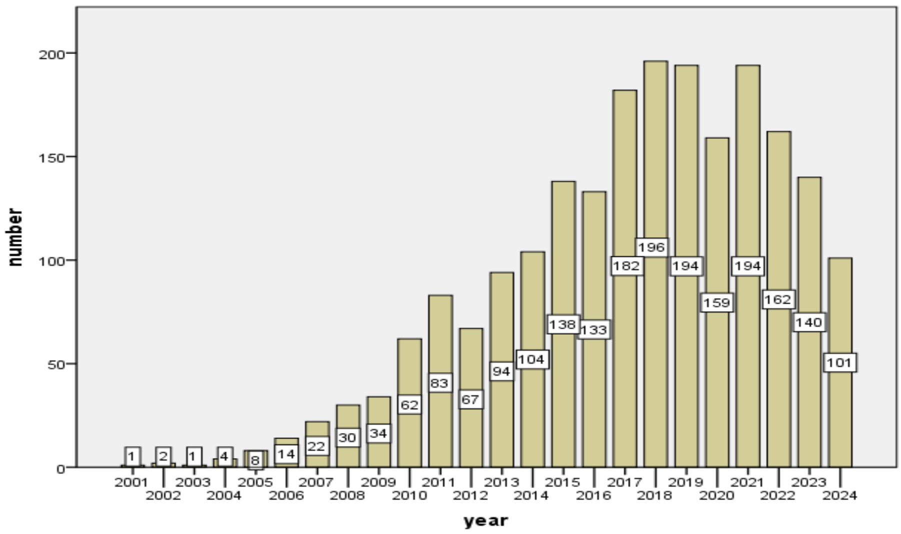

Figure 2: Annual publications on BLHE. The diagram reveals the publication number for each year and the general trend

Examining 2,125 articles and reviews revealed a diverse landscape of publication venues, encompassing both traditional journals and conference proceedings. Notably, conference proceedings dominated the upper echelons of this bibliometric analysis. At the forefront, *Edulearn Proceedings* stood out with an impressive 177 papers, closely followed by *Inted Proceedings* and *Iceri Proceedings*, contributing 138 and 87 publications respectively. Occupying the fourth position, *Lecture Notes in Computer Science*, a book series frequently utilized for conference proceedings, accounted for 63 publications. *Education and Information Technolog*ies emerged as the first traditional journal on the list, securing the fifth rank with 60 papers. Subsequently, another conference proceeding, *Proceedings of the European Conference on E-Learning*, claimed the sixth spot with 49 publications. Further down the list, two more journals make their appearance: *Higher Education Research Development* and *Procedia Social and Behavioral Sciences*, contributing 40 and 36 papers respectively. Rounding out the top ten were *Elearning and Software for Education*, a hybrid publication featuring both journal articles and conference proceedings, and the journal *Sustainability*, both tied at 34 publications each. A systematic summary of the top 10 most productive journals and conference proceedings in BLHE research is provided in Table 1.

Table 1: Top 10 most fruitful journals and conference proceedings for BLHE research

Ranking	Journals	The number of published papers
1	*Edulearn Proceedings*	177
2	*Inted Proceedings*	138
3	*Iceri Proceedings*	87
4	*Lecture Notes in Computer Science*	63
5	*Education And Information Technologies*	60
6	*Proceedings On the European Conference of E Learning*	49
7	*Higher Education Research Development*	40
8	*Procedia Social and Behavioral Sciences*	36
9	*Elearning And Software for Education*	34
10	*Sustainability*	34

Sources: Authors' analysis based on Web of Science Core Collection data (May, 2024)

Table 2 presented the top 10 most productive authors for BLHE research. The table ranked authors based on in this field. Jesús Sergio Artal-Sevil led the list with 19 publications, followed by Chang Zhu with 14 publications. Denise Jackson and Enrique Romero shared the third position, each with 10 publications. The remaining authors in the top 10 had between 7 and 9 publications each, with Yang Harrison Hao rounding out the list at 10th place with 7 published papers.

Table 2: Top 10 most productive authors for BLHE research

Ranking	Authors	The number of published papers
1	Artal-Sevil, Jesús Sergio	19
2	Zhu, Chang	14
3	Jackson, Denise	10
4	Romero, Enrique	10
5	Han, Feifei	9
6	Graham, Charles R.	9
7	Simonova, Ivana	9
8	Manuel Artacho, J.	9
9	Castro, Manuel	8
10	Yang, Harrison Hao	7

Sources: Authors' analysis based on Web of Science Core Collection data (May, 2024)

Turning to institutional productivity (Table 3), we noticed a landscape dominated by university systems rather than individual institutions. Griffith University topped the list with 29 published papers. Deakin University, Instituto Politécnico do Porto, and University of Zaragoza were tied for second place, each with 23 publications. The list included universities from various countries, including Australia, Portugal, Spain, Belgium, and China. Interestingly, the Ministry of Education and Science of Ukraine appeared in the 9th position with 16 publications, indicating significant governmental involvement in this research area. The number of published papers for these institutions ranged from 29 to 16, with the University of Granada completing the top 10 with 16 publications.

Table 3: Top 10 most productive institutions for BLHE research

Ranking	Institutions	The number of published papers
1	Griffith University	29
2	Deakin University	23
3	Instituto Politécnico do Porto	23
4	University of Zaragoza	23
5	Vrije Universiteit Brusse	18
6	Central China Normal University	17
7	Universidad Nacional de Educación a Distancia (UNED)	17
8	Hong Kong Polytechnic University	16
9	Ministry of Education and Science of Ukraine	16
10	University of Granada	16

Sources: Authors' analysis based on Web of Science Core Collection data (May, 2024)

Document co-citation analysis. The document co-citation analysis of 2125 publications on BLHE, spanning from 2001 to 2024, revealed a comprehensive picture of the field's intellectual structure. Using CiteSpace, we generated a visualization of the co-citation network, which comprised 674 nodes representing cited publications and 2801 links indicating co-citation relationships, as shown in Figure 3. The network was constructed by selecting the top 50 most-cited papers per 3-year time slice, allowing for a more granular view of the field's evolution over time. The resulting visualization presented a dense and intricate network structure with node sizes reflecting citation frequency and a color spectrum from cool to warm tones representing the temporal progression of publications. The modularity Q score of 0.8165 indicated a well-structured network with clearly defined communities, while the mean silhouette value of 0.3607 suggested reasonable clarity in the cluster divisions.

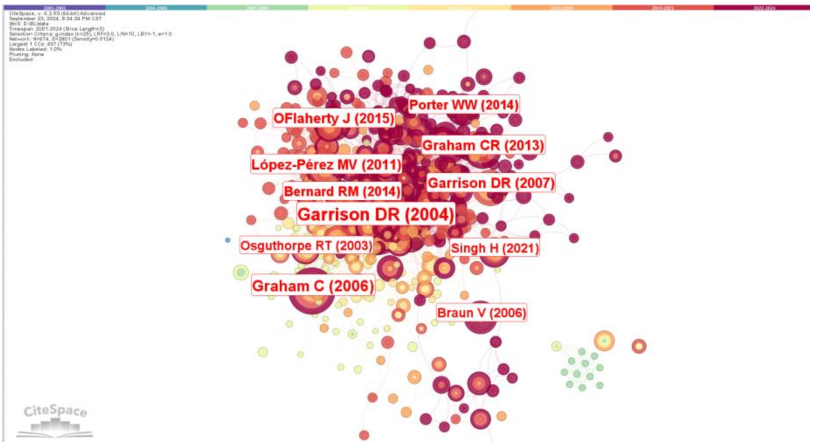

Figure 3: Crucial documents in BLHE study (2001-2024). Node size indicates citation frequency. High-frequency and central nodes such as Garrison (2004), Graham (2006) occupy prominent positions in the network

The diagram of document co-citations revealed the top 5 most cited articles among the 2125 publications collected from the WoS. The co-citation analysis identified the most frequently cited publications within the

BLHE dataset. Table 4 presents the top 5 cited works among the 2,125 articles and reviews. Citation counts ranged from 75 to 241.

Table 4: The top 10 most cited publications in BLHE research

Ranking	Citation count	Author(year)	Publication name	Journal or press	H-Index
1	241	Garrison and Kanuka (2004)	Blended learning: Uncovering its transformative potential in higher education	The Internet and Higher Education	41/32
2	116	Graham (2006)	The Handbook of Blended Learning: Global Perspectives, Local Designs	San Francisco: Pfeiffer Publishing	74
3	76	Garrison and Vaughan (2007)	Blended Learning in Higher Education: Framework, Principles, and Guidelines.	San Francisco: Jossey-Bass.	41/9
4	75	López-Pérez et al. (2011)	Blended Learning in Higher Education: Students' Perceptions and Their Relation to Outcomes	Computers & Education	23
5	75	Graham et al. (2013)	A framework for institutional adoption and implementation of blended learning in higher education	The Internet and Higher Education	74

Sources: Authors' analysis based on Web of Science Core Collection data (May, 2024)

The most cited work, Garrison and Kanuka's (2004) '*Blended learning: Uncovering its transformative potential in higher education*' (241 citations), stood as a cornerstone in the field. Its high citation count reflected its seminal role in introducing the Community of Inquiry (CoI) framework to blended learning contexts. This was followed by Graham (2006), '*The Handbook of Blended Learning: Global Perspectives, Local Designs*' , with 116 citations. While building on the theoretical foundations laid by Garrison and Kanuka (2004), Graham's work (2006) expanded the scope to include diverse global perspectives and implementation strategies. The next three works, all with similar citation counts (75-76), represented a diversification of research approaches in the field. Garrison and Vaughan's (2007) '*Blended Learning in Higher Education: Framework, Principles, and Guidelines*' (76 citations) further developed the CoI framework, providing more detailed guidance for practitioners. López-Pérez et al.'s (2011) '*Blended Learning in Higher Education: Students' Perceptions and Their Relation to Outcomes*' (75 citations) marked a crucial turn towards empirical validation. Graham et al.'s (2013) '*A framework for institutional adoption and implementation of blended learning in higher education*' (75 citations) represented another significant shift, focusing on the institutional level of blended learning adoption.

Co-occurring terms analysis. Keyword co-occurrence analysis is a powerful tool for identifying research areas and dominant topics within a field (Chen et al., 2016). This method leverages the principle that keywords in academic papers serve as concise summaries of the work's subject matter. When two or more keywords frequently appear together across multiple publications, it suggests a strong thematic relationship between these terms. In our analysis of blended learning literature, we examined keywords that co-occurred in at least two separate publications. We employed a three-year slice length and set the Look Back Years (LBY) parameter to all years to ensure a comprehensive view of the field's evolution. The network of related keywords is shown in Figure 4. This approach allowed for the identification of research hotspots, as terms with high frequency often indicated areas of intense scholarly interest. The results of our analysis revealed that the top five most frequently occurring terms were blended learning, higher education, students, (online) learning, and flipped classroom. These keywords provided insight into the central themes and preoccupations of blended learning research during the studied period. Additionally, all terms that appeared more than 30 times in the analyzed literature were listed in Table 5, providing a more comprehensive view of the field's vocabulary and research foci.

In Table 5, keyword frequency (count) and betweenness centrality (central) jointly characterize the prominence and structural positioning of terms within the BLHE co-occurring network. Frequency reflects the absolute occurrence of a keyword in the dataset, with blended learning (955), higher education (827), students (170), online (157), online learning (134), and flipped classroom (113) forming the core high-frequency terms that dominate the lexical composition of the field.

Betweenness centrality provides an additional topological indicator of each keyword's bridging function in the network. CiteSpace calculates centrality based on the extent to which a node lies on the shortest paths between other nodes, identifying terms that connect otherwise weakly linked thematic areas. Several keywords exhibit notable centrality values, including blended learning (0.26), higher education (0.13), collaborative learning (0.06), performance (0.05), technology (0.04), hybrid learning (0.04), achievement (0.04), and satisfaction (0.04). These nodes serve as structural intermediaries within the network and thus occupy more central positions in the overall knowledge structure.

Conversely, some terms appear with relatively high frequency but low centrality (e.g., education, learning analytics, distance education), indicating that they function as localized or domain-specific descriptors rather than cross-cutting connectors. The combined distribution of frequency and centrality therefore delineates both the dominant lexical patterns and the topological architecture of the BLHE keyword network.

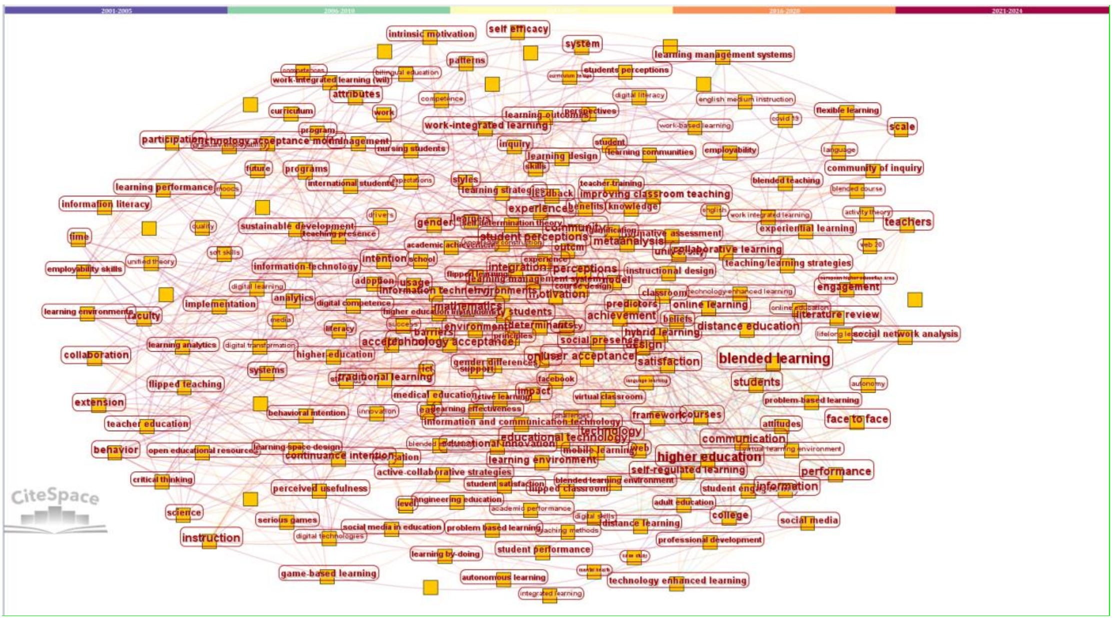

Figure 4: Keyword co-occurrence network. The keyword co-occurrence network diagram revealed the most popular keywords in BLHE research

Table 5: Co-occurring terms with high frequency

count	central	keyword	count	central	keyword	count	central	keyword
955	0.26	blended learning	74	0.02	design	43	0.02	outcome
827	0.13	higher education	74	0.04	satisfaction	43	0.03	teachers
170	0.03	students	74	0.04	work-integrated learning	41	0.00	learning analytics
157	0.04	online	65	0.04	hybrid learning	40	0.04	distance education
134	0.01	online learning	57	0.03	motivation	37	0.02	flipped learning
113	0.02	flipped classroom	57	0.04	achievemen t	37	0.02	distance learning
107	0.03	perceptions	55	0.02	engagemen t	35	0.03	acceptance

count	central	keyword	count	central	keyword	count	central	keyword
105	0.05	performance	55	0.02	university	34	0.01	adoption
92	0.04	technology	46	0.01	student engagement	34	0.03	instruction
89	0.01	education	46	0.01	classroom	33	0.00	challenges
79	0.01	impact	46	0.04	experiences	32	0.01	knowledge
78	0.03	model	45	0.06	collaborative learning	31	0.03	framework

Cluster interpretations. We utilized CiteSpace to conduct a cluster analysis based on keyword co-occurrences in the field of BLHE. The analysis, using a 3-year time slice, yielded a total of 674 nodes in the co-citation network, and 11 distinct clusters, providing a comprehensive overview of the research landscape in this field. Figure 5 illustrated these clusters, with warmer colors indicating more recent research topics and cooler colors representing older research themes. Table 6 presented the important clusters of keywords in BLHE research, including cluster size, silhouette value, and key terms associated with each cluster. The 11 clusters were named *blended learning, collaborative learning, continuance intention, self-regulated learning, curriculum design, work-integrated learning, teaching/ learning strategies, hybrid learning, game-based learning, learning communities, community of inquiry*.

The largest cluster (#0) is labeled 'blended learning,' representing the core concept of the field. This cluster's high silhouette value (0.903) indicates its coherence and distinctiveness. Key terms within this cluster, such as 'higher education,' 'flipped classroom,' 'online learning,' and 'student engagement,' suggest a focus on innovative pedagogical approaches within tertiary education settings. Blended learning, as the central concept, has been extensively studied in higher education contexts (Garrison & Kanuka, 2004). Closely related to this foundational cluster are 'hybrid learning' (#7) and 'collaborative learning' (#1). The hybrid learning cluster, with terms like 'digital competence,' 'distance learning,' and 'learning technologies,' reflects the evolving nature of blended learning as it incorporates more sophisticated digital elements. The collaborative learning cluster (#1), encompassing terms such as 'web 2.0,' 'English for academic purposes,' and 'bilingual education,' accentuates the value of interactive and participatory methodologies in blended environments. The prominence of this cluster signifies a paradigm shift from conventional, instructor-centric approaches towards more learner-oriented, dynamic models. The inclusion of language-specific terms (English for academic/specific purposes, bilingual education) in the collaborative learning cluster suggests that blended learning is being actively explored in language education contexts. This may be due to the unique advantages blended approaches offer for language learning, such as opportunities for authentic communication, access to diverse language resources, and the ability to practice language skills both synchronously and asynchronously (Ahmad, 2021).

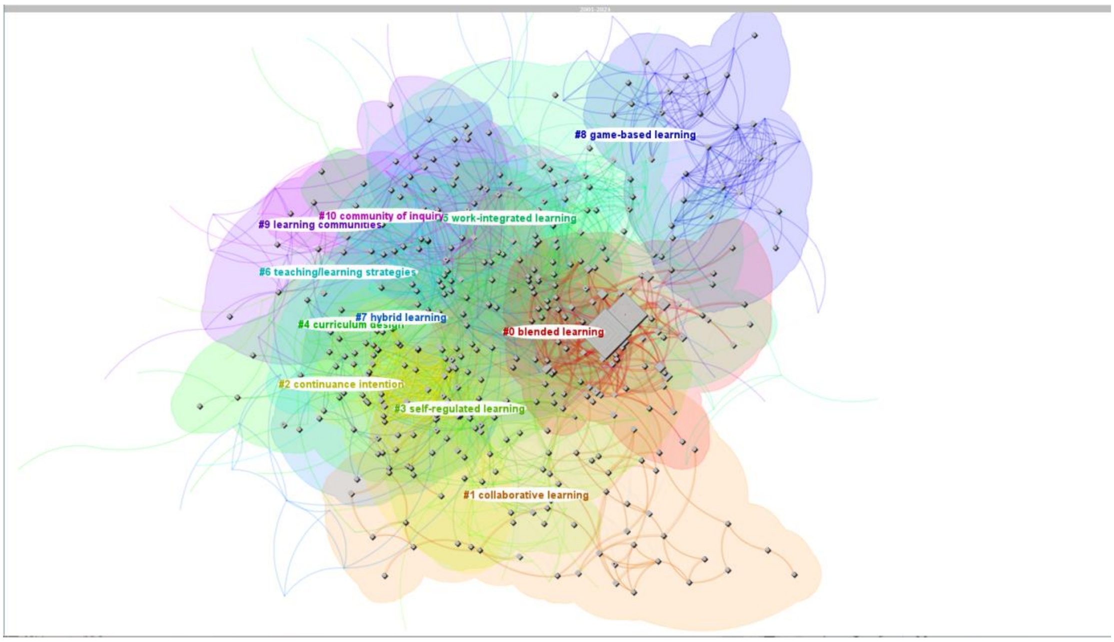

Figure 5: Cluster view of keyword co-occurrence for BLHE research

Several clusters focus on the theoretical underpinnings and learning processes in blended environments. These include 'self-regulated learning' (#3), 'community of inquiry' (#10), and 'learning communities' (#9). The self-regulated learning cluster (#3), with terms like 'mixed methods,' 'learning strategies,' and 'social network analysis,' highlights the importance of learner autonomy and metacognition in blended contexts. The community of inquiry framework (cluster #10), with its emphasis on teaching presence, social presence, and cognitive presence, has been particularly influential in blended learning research (Garrison, Anderson & Archer, 1999). Its appearance as a distinct cluster underscores its significance in understanding the dynamics of blended learning environments. The inclusion of terms like 'deep learning' and 'synchronous teaching model' within this cluster suggests ongoing research into how to foster meaningful, collaborative learning experiences in blended settings. The learning communities cluster (#9), featuring terms such as 'technology-enhanced learning,' 'undergraduate education,' and 'reflective practice,' reflects the growing recognition of social learning theories in blended education. This cluster emphasizes the importance of creating supportive, interactive learning environments that extend beyond the traditional classroom (Wenger, 1998). The inclusion of 'digital immigrants' and 'digital natives' in this cluster suggests that researchers are considering generational differences in technology use and learning preferences when designing blended learning communities.

Table 6: Important clusters of keywords in BLHE research

cluster ID	size	silhouette	cluster names (LLR)	LSI primary	LSI secondary	LLR
0	51	0.903	blended learning	blended learning; collaborative learning; teaching evaluations; instructional change; online education	online learning; student satisfaction; learning strategy; physical education; virtual learning	blended learning (133.65, 1.0E-4); higher education (68.21, 1.0E-4); flipped classroom (38.68, 1.0E-4); online learning (35.66, 1.0E-4); student engagement (17.75, 1.0E-4)
1	49	0.789	collaborative learning	blended learning; collaborative learning; continuous assessment; adaptive tests; technology quality	formative assessment; learning report; formative feedback; teaching bpm; distance learning education	collaborative learning (24.22, 1.0E-4); web 2.0 (23.61, 1.0E-4); English for academic purposes (23.36, 1.0E-4); English for specific purposes (18.68, 1.0E-4); bilingual education (18.68, 1.0E-4)

cluster ID	size	silhouette	cluster names (LLR)	LSI primary	LSI secondary	LLR
2	48	0.873	continuance intention	blended learning; mobile learning; technology adoption; mixed methods; new technologies	continuance intention; academic self-efficacy; intrinsic motivation; mandatory environments; success model	continuance intention (21.51, 1.0E-4); grounded theory (16.25, 1.0E-4); technology acceptance (16.25, 1.0E-4); utaut (15.3, 1.0E-4); technology acceptance model (12.53, 0.001)
3	47	0.759	self-regulated learning	blended learning; online learning; social capital; learning strategies; education	self-regulated learning; blended course designs: academic success; czech republic; self-reported measures	self-regulated learning (27.89, 1.0E-4); mixed methods (14.77, 0.001); learning strategies (13.85, 0.001); social network analysis (12.31, 0.001); critical thinking (10.37, 0.005)
4	47	0.731	curriculum design	blended learning: public health; educational modality; work-integrated learning; sustainability assessment	online learning; educational technology; hybrid learning; multi-criteria decision; decision making	curriculum design (14.38, 0.001); continuing professional development (14.38, 0.001); online and blended learning (14.38, 0.001); communities of practice (14.37, 0.001); professional development (12.18, 0.001)
5	41	0.854	work-integrated learning	work-integrated learning; scoping review; learning design; self-directed learning; study behaviors	blended learning; transparency assessment; research methods; descriptive review; work placements	work-integrated learning (100.14, 1.0E-4); blended learning (40, 1.0E-4); employability (30.82, 1.0E-4); online learning (17.18, 1.0E-4); work integrated learning (16.01, 1.0E-4)
6	31	0.866	teaching/learning strategies	blended learning; digital content; hybrid learning; management studies; student-generated media	learning strategies; pedagogical issues; improving classroom teaching; adult learning; digital content	teaching learning strategies (37.5, 1.0E-4); pedagogical issues (25.6, 1.0E-4); improving classroom teaching (20.84, 1.0E-4); distributed learning environments (20.33, 1.0E-4); lifelong learning (19.58, 1.0E-4)
7	29	0.86	hybrid learning	blended learning; online learning. social science; academic health; information technology	hybrid learning; engineering education; computer-aided design; linear auto-regression; data mining	hybrid learning (30 35, 1.0E-4); digital competence (24.71, 1.0E-4); distance learning (24.49, 1.0E-4); learning design (15.34, 1.0E-4); learning technologies (15.12, 0.001)
8	27	0.925	game-based learning	Blended learning; game-based learning; advanced classroom technology; interactive tools; traditional learning	Open educational resources; advanced classroom applications; learning space design; serious games; didactical innovations	Game-based learning (41.77, 1.0E-4); flipped learning (41.77, 1.0E-4); learning by-doing (36.33, 1.0E-4); serious games (36.53, 1.0E-4); learning space design (36.53, 1.0E-4)
9	24	0.834	learning communities	blended learning; reflective practice ; digital immigrants;	technology-enhanced learning ; undergraduate education ; gross anatomy	learning communities (15.39, 1.0E-4); technology-enhanced learning (13.42, 0.001); undergraduate education

cluster ID	size	silhouette	cluster names (LLR)	LSI primary	LSI secondary	LLR
				digital natives; digital storytelling	education: medical education; task-based language	(13.23, 0.001); community of practice (13.2, 0.001)
10	20	0.871	community of inquiry	blended learning ; learning style model ; learning level; deep learning: synchronous teaching model	teaching presence ; social presence; cognitive presence; blended learning contexts; inquiry framework	community of inquiry (25.79, 1.0E-4); teaching presence (25.09, 1.0E-4); social presence (17.17, 1.0E-4); cognitive presence (12.7, 0.001); adult education (9.84, 0.005)

Clusters related to technological aspects include 'game-based learning' (#8) and elements of 'continuance intention' (#2), which often deals with technology adoption. These clusters reflect the ongoing integration of innovative technologies in blended learning environments. Game-based learning's emergence as a distinct cluster (#8), with terms like 'serious games,' 'learning by-doing,' and 'learning space design,' suggests a growing interest in leveraging gamification and interactive technologies to enhance engagement and learning outcomes in blended settings (Tsay, Kofinas & Luo, 2018). The continuance intention cluster (#2), featuring terms such as 'technology acceptance,' 'UTAUT' (Unified Theory of Acceptance and Use of Technology), and 'grounded theory,' indicates researchers' interest in understanding factors that influence the sustained use of blended learning technologies. They are crucial for ensuring the long-term success and adoption of blended learning approaches (Bhattacherjee, 2001).

Clusters focused on design aspects include 'curriculum design' (#4), 'work-integrated learning' (#5), and elements of 'teaching/learning strategies' embedded in other clusters. These clusters highlight the importance of thoughtful design in blended learning implementations. The curriculum design cluster (#4), with terms like 'continuing professional development,' 'communities of practice,' and 'multi-criteria decision,' underscores the need for intentional and pedagogically sound approaches to blended learning. The work-integrated learning cluster (#5), featuring terms such as 'employability,' 'scoping review,' and 'self-directed learning,' suggests a trend towards aligning blended learning with professional and vocational education (Wuxue, 2023).

While not appearing as a distinct cluster, assessment and evaluation themes are present within several clusters, particularly in 'collaborative learning' (#1) and 'curriculum design' (#4). Terms like 'continuous assessment,' 'formative feedback,' and 'adaptive tests' within these clusters reflect the ongoing challenges and innovations in assessing student learning in blended environments (Gikandi, Morrow & Davis, 2011). The presence of 'adaptive tests' in the curriculum design cluster points to an interest in using technology to create more personalized assessment experiences. Adaptive testing, which adjusts the difficulty or content of questions based on a student's performance, could be particularly powerful in blended learning environments (Barla et al., 2010) where data on student performance can be collected and analyzed in real-time.

To provide a consolidated view of the thematic structure identified in the cluster analysis, Table 7 provides an overview of the 11 keyword clusters, including representative terms, cluster size, dominant periods, and example studies drawn from the dataset. This table complements the preceding description by presenting the major clusters in a comparable format, enabling a clearer overview of their relative scope and temporal distribution.

Table 7: Summary of major keywords clusters in BLHE research

cluster ID	size	cluster names (LLR)	Dominate period*	Representative keywords	Example studies
0	51	blended learning	2004-2008	Higher education; online education; instructional change; flipped classroom	Garrison & Kanuka (2004); Graham (2006)

cluster ID	size	cluster names (LLR)	Dominate period*	Representative keywords	Example studies
1	49	collaborative learning	2012-2020	collaborative learning; continuous assessment; adaptive tests	Szeto & Cheng (2016); Ahmad (2021)
2	48	continuance intention	2013-2024	technology adoption; mixed methods; new technologies;	Bhattacherjee (2001)
3	47	self-regulated learning	2015-2024	self-regulated learning; learning strategies; social capital	Garrison & Kanuka (2004)
4	47	curriculum design	2010-2020	educational modality; sustainability assessment; curriculum design	Graham et al. (2013)
5	41	work-integrated learning	2014-2024	work-integrated learning; learning design; study behaviors	Wuxue (2023)
6	31	teaching/learning strategies	2011-2020	digital content; management studies; digital content; student-generated media	Halverson & Graham (2019); Garrison & Kanuka (2004)
7	29	hybrid learning	2015-2023	online learning; social science; academic health	Garrison & Kanuka (2004)
8	27	game-based learning	2016-2023	interactive tools; advanced classroom technology; traditional learning	Tsay et al. (2018); Moreno-Ger et al. (2008)
9	24	learning communities	2008-2018	reflective practice；digital natives; digital storytelling; digital immigrants	Wenger (1998)
10	20	community of inquiry	2004-2015	learning style model； learning level; deep learning: synchronous teaching model	Garrison et al. (1999)

As shown in Table 7, the identified clusters collectively outline the thematic breadth and chronological development of BLHE research over the past two decades.

4. Discussion and Implications for Future Studies

The bibliometric analysis of BLHE research from 2001 to 2024 revealed a field that has undergone significant evolution, characterized by the development of robust theoretical frameworks, methodological diversification, and an increasing focus on practical applications. This study addressed three key research questions, providing insights into the intellectual structure, global diffusion, and critical research features of BLHE.

The document co-citation analysis revealed a clear progression in the intellectual structure of blended learning research of the past more than two decades. The field's foundation was laid by Garrison and Kanuka's (2004) seminal work, which introduced the Community of Inquiry (CoI) framework to blended learning contexts. The CoI framework offered an integrated conceptual lens for understanding learning in blended environments through the interaction of cognitive, social, and teaching presence, addressing an urgent theoretical need during the field’s formative stage. The CoI framework's dominance in blended learning research aligned with broader trends in educational theory that emphasized the social nature of learning. As Garrison and Arbaugh (2007) noted, the CoI framework provided a valuable lens for understanding the complex interactions that occured in blended learning environments (Garrison & Arbaugh, 2007). However, as Rourke and Kanuka (2009) pointed out, there was a need for more research on how the CoI framework translated into measurable learning outcomes, suggesting a potential area for future investigation (Rourke & Kanuka, 2009). The progression of highly cited works demonstrated a clear evolution in the field's focus. Graham's (2006) ‘*The Handbook of Blended Learning: Global Perspectives, Local Designs*’ marked a shift towards contextual considerations in blended learning design. This work bridged the gap between theoretical frameworks and practical implementation, a theme that became increasingly prominent in later works. The emphasis on global perspectives and local designs resonated with calls from researchers like Uzuner (2009) for more cross-cultural studies in online and blended learning environments. Subsequent highly cited works by Garrison and Vaughan (2007), López-Pérez et al. (2011), and Graham, Woodfield and Harrison (2013) demonstrated a progression from theoretical foundations to empirical validation and institutional adoption strategies. This evolution mirrored the typical development pattern of maturing fields of study, as described by Kuhn (1962), in his work on the structure of scientific revolutions.

Methodologically, these works demonstrated a clear evolution in research approaches. Garrison and Kanuka (2004) as well as Graham (2006) primarily employed theoretical and conceptual analyses, laying the groundwork for the field. Garrison and Vaughan (2007) introduced more practical, design-based research approaches, bridging theory and practice. López-Pérez et al. (2011) marked a shift towards empirical, quantitative methods, using statistical analyses to correlate student perceptions with learning outcomes. This methodological diversity reflected the field's maturation and the growing recognition of the need for multiple research approaches to fully understand the complexities of blended learning.

Theoretically, while the CoI framework dominates, particularly in the earlier works, there's a notable trend towards theoretical pluralism. None of these highly cited works adhered exclusively to a single learning theory. Instead, they drew from various constructivist and social learning principles, reflecting the inherently hybrid nature of blended learning. This theoretical eclecticism suggested that the field recognized the need for flexible, adaptable frameworks to accommodate the diverse contexts in which blended learning was implemented.

Thematically, all five works emphasized the transformative potential of blended learning in higher education, but approached this potential from different angles. Garrison and Kanuka (2004) and Garrison and Vaughan (2007) focused on pedagogical transformation through the CoI framework. Graham (2006) emphasized the importance of contextual adaptation and cultural sensitivity in blended learning design. López-Pérez et al. (2011) highlighted the potential for improved student outcomes, while Graham, Woodfield and Harrison (2013) addressed the broader institutional transformations necessary for successful blended learning adoption. The evolution of these themes over time reflected the field's growing sophistication. Early works focused on defining blended learning and establishing theoretical frameworks. Later works moved towards providing practical implementation guidelines, empirical evidence of effectiveness, and strategies for institutional adoption. This progression mirrored the typical development of a maturing field of study, moving from conceptual foundations to practical applications and empirical validation.

Interestingly, the balanced citation counts across the later works suggested that the field valued theoretical development, practical implementation, and empirical research equally. This balance indicated a holistic approach to understanding blended learning, recognizing that effective implementation required a combination of strong theoretical grounding, practical know-how, and evidence-based practice.

This analysis examined the implications of the observed publication trends for the global diffusion and adoption of blended learning practices in higher education. This trend alignd with broader patterns of educational technology adoption and the increasing digitalization of higher education (Zawacki-Richter & Latchem, 2018). The slight dip in publications in 2020, followed by a quick rebound in 2021, likely reflected the impact of the COVID-19 pandemic and subsequent renewed interest in blended learning strategies. This observation was consistent with findings from other educational technology research areas, where the pandemic acted as a catalyst for increased interest and adoption of online and blended learning approaches (Ferdig et al., 2020).

The geographic diversity of top institutions, spanning countries such as Australia, Portugal, Spain, and China, indicated that blended learning research is indeed a global endeavor. This diversity was crucial for developing a comprehensive understanding of blended learning, as it allowed for the exploration of cultural and contextual factors that may influence the effectiveness of blended learning approaches (Tarhini, Hone & Liu, 2015). However, the dominance of English-language publications from Western institutions also pointed to potential gaps in the literature, particularly regarding blended learning implementation in other cultural contexts. This observation aligned with concerns raised by Zawacki-Richter and Latchem (2018) about the need for more diverse perspectives in educational technology research. The prominence of conference proceedings among the most productive outlets suggested a field that valued rapid dissemination of ideas and practices. This was congruent with observations by Halverson et al. (2014), who noted the importance of conferences in disseminating emerging educational technology research. The preference for conference proceedings may be particularly beneficial in a fast-evolving area like blended learning, where practitioners and researchers alike benefited from timely access to new insights and best practices. This aligned with observations by Martin et al., (2018), who noted the importance of conferences in disseminating emerging educational technology research.

The cluster analysis revealed a rich tapestry of research areas within blended learning, providing a nuanced picture of the field's current focus. The emergence of distinct clusters around foundational concepts, theoretical frameworks, technological integration, curriculum design, and assessment methods reflected the multifaceted nature of blended learning research. These clusters suggest that the transformative potential of blended learning lies in its ability to integrate the complementary strengths of face-to-face and online learning modalities. The largest cluster, labeled 'blended learning,' encompassed core concepts such as 'higher education,' 'flipped classroom,' and 'student engagement.' The prominence of the 'flipped classroom' within this cluster reflected a growing interest in pedagogical models that leveraged technology to restructure traditional learning environments. As Bergmann and Sams (2012) argued, the flipped classroom model represented a specific implementation of blended learning that aimed to enhance face-to-face interactions by shifting content delivery to online platforms. The presence of 'student engagement' in this cluster underscores the potential of blended learning to increase student participation and motivation. Research has shown that well-designed blended learning environments could lead to higher levels of student engagement compared to traditional face-to-face or fully online courses (Halverson & Graham, 2019). This engagement is often attributed to the flexibility and interactivity offered by blended approaches.

Closely related lines of research further extend this pedagogical focus by examining how blended learning evolves through more nuanced integrations of technology and interaction. The emergence of 'hybrid learning' as a distinct cluster suggests a nuanced approach to integrating face-to-face and online learning, potentially incorporating more advanced technologies and pedagogies. Within this cluster, the emphasis on digital competence underscores the significance of cultivating students' technological prowess alongside domain-specific knowledge, thus equipping them for a digitally-driven workforce. Similarly, the cluster of 'collaborative learning' foregrounds the interactive and participatory dimensions of blended environments. The prominence of this cluster signifies a paradigm shift from conventional, instructor-centric approaches towards more learner-oriented, dynamic models. This transition resonates with constructivist learning theories and illustrated the capacity of blended environments to nurture meaningful interactions among peers and between students and instructors (Szeto & Cheng, 2016). However, the concentration of research on this particular model raised questions about whether other innovative blended learning approaches were being overlooked.

The clusters focused on theoretical frameworks and learning processes, including 'self-regulated learning,' 'community of inquiry,' and 'learning communities,' underscore the field's strong theoretical grounding. The emergence of self-regulated learning as a distinct cluster resonated with findings from Broadbent and Poon (2015), who highlighted the importance of self-regulation skills in online and blended learning environments. This focus suggested that successful blended learning required students to develop skills in managing their own learning processes, a crucial competency in increasingly flexible and personalized learning environments (Schunk & Zimmerman, 2011). This reflects a growing recognition that successful blended learning requires students to develop skills in managing their own learning processes (Garrison & Kanuka, 2004). The inclusion of 'social network analysis' in this cluster is intriguing, suggesting that researchers are exploring the social aspects of self-regulated learning in blended environments, perhaps examining how students' social connections influence their self-regulation strategies. The presence of 'critical thinking' in this cluster aligns with the idea that self-regulated learning could foster higher-order thinking skills. Blended learning environments, by their nature, often require students to navigate complex information landscapes, make decisions about their learning paths, and reflect on their progress – all activities that could promote critical thinking (Garrison & Kanuka, 2004).

However, the emphasis on self-regulated learning also raised important questions about equity and access in blended learning environments. Students with well-developed self-regulation skills may thrive in these settings, while those who struggled with self-regulation may be at a disadvantage. This concern echoed broader issues of educational equity in digital learning environments, as highlighted by Broadbent and Poon (2015). Future research could explore interventions to support the development of self-regulation skills in blended learning contexts, particularly for students from diverse educational backgrounds.

The persistence of the Community of Inquiry (CoI) framework, nearly two decades after its introduction, speaks to its robustness and applicability in understanding the complex interactions that occur in blended learning environments. However, as Rourke and Kanuka (2009) pointed out, there was a need for more research on how the CoI framework translated into measurable learning outcomes. This gap suggests a potential area for future research that could bridge theoretical understanding with practical outcomes.

Clusters related to technological integration and innovation, such as ‘game-based learning’ and ‘continuance intention,’ reflect the ongoing integration of innovative technologies in blended learning environments. The game-based learning cluster, with terms like ‘serious games’ and ‘learning by-doing,’ aligns with findings from Dicheva et al. (2015), who identified positive effects of gamification on student engagement and motivation in various educational contexts, including blended learning. From a pedagogical perspective, game-based approaches in blended learning are often valued for their capacity to create immersive and motivating learning experiences that complement, rather than replace, traditional instructional methods. The integration of game-based learning can provide immediate feedback, allow learners to experiment and fail in low-risk environments, and incorporate elements of storytelling and problem-solving, all of which have been shown to support engagement and knowledge retention (Tsay, Kofinas & Luo, 2018). Moreover, the emphasis on learning by doing inherent in many game-based designs aligns closely with constructivist learning theories that underpin much of blended learning pedagogy (Moreno-Ger et al., 2008). However, the enthusiasm for game-based learning and other technological innovations in blended environments should be tempered with critical consideration of their long-term effectiveness and potential drawbacks, as it was stressed by Meoreno-Ger et al. (2008) in his study.

The continuance intention cluster, featuring terms such as ‘technology acceptance’ and ‘UTAUT’ (Unified Theory of Acceptance and Use of Technology), indicates ongoing interest in understanding the factors that influence the adoption and sustained use of blended learning technologies. This research stream, building on the work of Venkatesh et al. (2003), is crucial for ensuring the long-term success and sustainability of blended learning initiatives. The focus on technology acceptance and continuance intention also highlights a potential blind spot in the field. While understanding the factors that influence adoption is important, there is a risk of technological determinism – the assumption that technological innovation alone can drive educational improvement.

Clusters focused on ‘curriculum design’ and ‘work-integrated learning’ highlight the importance of thoughtful design in blended learning implementations. The cluster of ‘curriculum design’ suggests a focus on designing blended learning experiences that are aligned with professional development needs and foster ongoing learning communities. The inclusion of ‘multi-criteria decision’ in this cluster is particularly interesting, as it suggests that researchers are exploring complex decision-making processes in curriculum design for blended learning. This could involve balancing various factors such as learning objectives, technological constraints, student preferences, and institutional resources when designing blended curricula.

The emergence of work-integrated learning as a distinct cluster suggests a trend towards aligning blended learning with professional and vocational education, reflecting broader trends in higher education towards more career-focused curricula (Bonk & Graham, 2012). This cluster highlights the potential of blended approaches to bridge the gap between academic learning and workplace requirements, potentially enhancing students' employability and career readiness. The emphasis on ‘self-directed learning’ within this cluster aligns well with the demands of many modern workplaces, where employees are often expected to take initiative in their own learning and professional development. Blended learning approaches, by offering flexibility and promoting self-regulation, may be particularly well-suited to preparing students for these workplace expectations. While this trend is promising, it also raises questions about the broader purpose of higher education. There is a risk that an overemphasis on vocational skills could come at the expense of critical thinking, creativity, and other transferable skills that are crucial for long-term career success and civic engagement.

The cross-cutting theme of assessment, evident across multiple clusters, reflected the ongoing challenges and innovations in evaluating student learning in blended environments. Terms like ‘continuous assessment,’ ‘formative feedback,’ and ‘adaptive tests’ suggested that researchers have been exploring ways to leverage both online and face-to-face components of blended learning for more effective and diverse assessment strategies. This aligns with the findings of Gikandi, Morrow and Davis (2011), who highlighted the potential of online formative assessment in blended and online learning contexts. However, the integration of these assessment strategies with traditional evaluation methods remains a challenge, particularly in institutional contexts where established assessment practices are deeply entrenched. Despite the rich insights provided by this analysis, several significant gaps and potential areas for future research emerge. Despite the rich insights provided by this analysis, several significant gaps and potential areas for future research emerge. For example, existing evidence suggests that the adoption and implementation of blended learning may differ substantially across regions such as East Asia, Africa, and Latin America, due to variations in technological infrastructure, institutional autonomy, pedagogical traditions, and cultural attitudes toward teacher–student interaction. Future research could explore how cultural factors influence the design, implementation, and effectiveness of blended learning approaches in different global contexts. Moreover, while the field has made significant progress in understanding the implementation of blended learning, there is still a critical need for more longitudinal studies that examine the long-term impacts on student outcomes and institutional transformation. Most of the highly cited works focus on short-term outcomes or implementation processes, leaving questions about the sustained effects of blended learning initiatives largely unanswered. This gap aligns with observations by Halverson and Graham (2019) about the need for more rigorous, long-term studies of blended learning effectiveness. Future research could adopt longitudinal cohort designs that track student learning trajectories across multiple semesters, or institutional case studies that examine how blended learning initiatives evolve over time within specific policy and organizational contexts. The analysis also reveals potential methodological gaps in the field. While there is a mix of theoretical, quantitative, and qualitative approaches represented in the highly cited works, there appears to be a lack of large-scale, mixed-methods studies that combine the depth of qualitative insights with the breadth of quantitative data. Future research could benefit from more integrated methodological approaches, as suggested by Creswell and Plano (2017), to provide a more comprehensive understanding of blended learning phenomena. As blended learning continues to evolve, the integration of emerging technologies such as artificial intelligence and virtual reality presents both opportunities and challenges. While these technologies have the potential to significantly reshape blended learning practices, their integration must be approached thoughtfully, with careful consideration of both pedagogical implications and ethical concerns.

Implications for future studies. Based on the discussion, two critical issues that deserve more consideration in future studies on BLHE. Future research should focus on exploring how cultural factors influence the design, implementation, and effectiveness of blended learning approaches in diverse global contexts. The current literature is dominated by Western perspectives, leaving a significant gap in our understanding of how blended learning can be effectively adapted and implemented in non-Western educational systems. This line of inquiry is crucial as higher education becomes increasingly globalized. As Shadiev et al. (2024) points out, there is a pressing need for more cross-cultural studies in online and blended learning environments. Such research could investigate how different cultural values, learning styles, and educational traditions impact the acceptance and effectiveness of blended learning models. For instance, studies could explore how the Community of Inquiry (CoI) framework, which has been primarily developed and tested in Western contexts, translates to educational settings in Asia, Africa, or the Middle East. This research could build on the work of Garrison and Arbaugh (2007) but extend it to diverse cultural contexts, potentially leading to refinements or adaptations of the framework. Moreover, as Nistor, Göğüş and Lerche (2013) demonstrated in their cross-cultural examination of educational technology acceptance, factors influencing technology adoption can vary significantly across cultures. Future studies could extend this work to blended learning specifically, examining how cultural factors impact not just technology acceptance, but also engagement with different aspects of blended learning, such as online discussions, collaborative projects, or flipped classroom approaches.

There is a critical need for more longitudinal studies that examine the long-term impacts of blended learning on student outcomes, skill development, and institutional transformation. As Versteijlen and Wals (2023) observed, much of the existing research focuses on short-term outcomes or implementation processes, leaving questions about the sustained effects of blended learning initiatives largely unanswered. Future research should aim to track cohorts of students through blended learning programs and into their early career stages, examining not only academic outcomes but also the development of lifelong learning skills, digital literacy, and career readiness. Such studies could build on the work of Ingkavara et al. (2022) on self-regulated learning in online environments, extending it to long-term outcomes in blended learning contexts. Additionally, research should investigate the institutional factors that contribute to the sustainability of blended learning initiatives over time. This could involve examining how institutions successfully embed blended learning into their long-term strategic plans, adapt to evolving technologies, and maintain faculty engagement and development. The framework for institutional adoption proposed by Graham, Woodfield and Harrison (2013) could serve as a starting point for such investigations, but with a focus on long-term sustainability rather than initial adoption. Furthermore, as the educational technology landscape continues to evolve rapidly, longitudinal studies could explore how institutions successfully integrate emerging technologies like artificial intelligence and virtual reality into their blended learning models over time. This research could build on the work of Zawacki-Richter et al. (2019) on AI in higher education (Zawacki-Richter et al., 2019), but with a specific focus on its long-term integration and impact in blended learning environments. By addressing these two critical areas, future research can contribute to a more comprehensive and nuanced understanding of BLHE, informing both policy and practice in an increasingly diverse and technology-driven educational landscape.

5. Conclusion

Blended learning has emerged as a significant area of research in higher education over the past two decades. This study aimed to systematically review the literature on BLHE using bibliometric tools, specifically CiteSpace. Our analysis of 2,125 publications from the Web of Science Core Collection spanning from 2001 to 2024 provides a comprehensive overview of the field's evolution, intellectual structure, and emerging trends. The descriptive analysis indicates a sustained growth of blended learning research in higher education over the past two decades, reflecting increasing and continuing scholarly interest in BLHE. Our findings highlight the dominance of conference proceedings in disseminating blended learning research, with Edulearn Proceedings, Inted Proceedings, and Iceri Proceedings leading in publication output. This trend underscores the field's dynamic nature and the need for rapid knowledge exchange, as noted by Martin, Sun and Westine (2020) in their recent review of educational technology research dissemination. And the Community of Inquiry framework remains the most influential theoretical foundation shaping the field. Overall, the evolution of influential publications and the cluster analysis indicate that BLHE has matured into a thematically diverse field, encompassing a wide range of pedagogical and technological perspectives. The prominence of self-regulated learning and technology acceptance models in these clusters resonated with recent findings by Junaštíková (2024) on the importance of learner autonomy and technology integration in successful blended learning implementations. At the same time, this finding raises important implications for equity and access, as disparities in digital literacy, learning support, and technological resources may shape students' capacity to benefit from BLHE.

Our analysis also revealed several gaps and potential areas for future research. Firstly, there is a pressing need for more diverse cultural perspectives on blended learning, particularly from non-Western contexts. As Serradell-Lopez, Lara-Navarra and Casado-Lumbreras (2012) argued, understanding the cultural dimensions of blended learning is crucial for its effective global implementation. Secondly, longitudinal studies examining the long-term impacts of blended learning on student outcomes and institutional transformation are scarce (Ashraf et al., 2021). Future research should address this gap to provide insights into the sustained effects of blended learning initiatives. Furthermore, the integration of emerging technologies such as artificial intelligence and virtual reality in blended learning environments presents both opportunities and challenges that warrant further investigation (Zawacki-Richter et al., 2019). Additionally, as blended learning continues to evolve, research on innovative assessment strategies that leverage both online and face-to-face components will be crucial (Buhl-Wiggers, Kjærgaard & Munk, 2023). While this study aimed to provide a comprehensive review of blended learning research in higher education, it has some limitations. The analysis was limited to publications in the Web of Science Core Collection, potentially excluding relevant studies from other databases. Additionally, the rapid pace of technological advancements and the recent impact of the COVID-19 pandemic may not be fully reflected in the analyzed literature due to publication time lags.

Despite these limitations, this bibliometric review provides a comprehensive synthesis of global research on BLHE and clarifies the field's intellectual structure and developmental trajectory. It provides researchers, educators, and policymakers with insights into the field's intellectual structure, emerging trends, and future directions. As blended learning continues to play a crucial role in shaping the future of higher education, addressing the identified research gaps and embracing new challenges will be essential for developing more effective, inclusive, and transformative learning experiences. The findings of this review have significant implications for both theory and practice in blended learning. They highlight the need for more integrated theoretical frameworks that can account for the complex interplay of pedagogical, technological, and institutional factors in blended learning environments. Practically, they underscore the importance of thoughtful design, ongoing assessment, and institutional support in successful blended learning implementations. For educators, it highlights the importance of designing blended learning environments that explicitly support students' self-regulation, engagement, and assessment literacy. For institutional leaders, the results underscore the need for sustained professional development, digital infrastructure investment, and coherent institutional strategies to support blended learning implementation. At the policy level, the findings point to the importance of addressing equity and access by ensuring that digital resources and support mechanisms are available to diverse student populations. Together, these insights contribute to a more informed understanding of how blended learning can be effectively and inclusively implemented as higher education systems continue to adapt to digital transformation.

AI Statement: The authors declare that AI-assisted tools (ChatGPT) were used solely for language polishing, including spelling and grammar checking, adhering to ethical guideline. No AI tools were used for any data collection, interpretation of results, or the generation of scientific or academic content. All intellectual contributions and academic content presented in this manuscript are the sole responsibility of the authors.

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