Article

Journal of Interdisciplinary Studies in Education

Volume 15, Issue 2 (2026), pp. 85-108
Journal of Interdisciplinary Studies in Education
ISSN: 2166-2681Print 2690-0408 Online | https://ojed.org/jise
https://doi.org/10.32674/whffna77

Enhancing Critical Thinking and Self-Directed Learning through Integration of Digital Competence and Didactic Strategy in Higher Education

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ABSTRACT

The rapid digital transformation of higher education, accelerated by the COVID-19 pandemic, has exposed a persistent misalignment between digital competence and pedagogical practice, limiting the development of critical thinking and self-directed learning. This qualitative descriptive study investigates how digital technologies and didactic strategies are integrated in practice. Data were collected through interviews, observations, and document analysis involving lecturers and students, and analyzed thematically. Findings reveal disparities in digital proficiency, limited use of advanced tools, and inconsistent implementation of learner-centered approaches. However, integrating digital technologies with project-based learning and peer assessment enhances problem-solving, communication, and metacognitive skills. The study highlights the importance of digital–didactic alignment, emphasizing the need for continuous professional development, institutional support, and curriculum redesign to foster effective, learner-centered digital learning environments.

Keywords: adaptive learning, digital transformation, instructional design, learner-centered, peer assessment.

INTRODUCTION

The COVID-19 pandemic has catalyzed a significant transformation in global higher education, compelling institutions to rapidly adopt online and hybrid learning models (Romero-Tena et al., 2025). This study argues that a persistent misalignment between digital competence and pedagogical practice remains a critical barrier to achieving meaningful learning outcomes in these transformed environments. While this shift ensured instructional continuity, it also exposed structural deficiencies—particularly in aligning digital technologies with pedagogical frameworks. Reports from networks such as tropEd indicate that over 75% of institutions encountered difficulties related to infrastructure and digital teaching preparedness (Chereguini & Gea, 2021). Concurrently, global educational bodies like UNESCO emphasize the urgency of equipping students with 21st-century competencies, including critical thinking, digital literacy, collaboration, and self-directed learning (Bazán-Ramírez et al., 2023).

Despite this contextual urgency, the specific research problem lies in the insufficient integration between digital competence and pedagogical design, which limits the effective development of these competencies. Despite widespread access to digital platforms, the pedagogical application of these tools often remains fragmented. Studies reveal a lack of synergy between digital competencies and learner-centered instructional strategies, especially in developing regions (Membrillo-Hernández et al., 2023; Zambrana-Tévar et al., 2025). This misalignment between digital competence and pedagogy—referred to in this study as digital–didactic misalignment—emerges as a central challenge that requires systematic investigation.

To analytically frame this issue, the study draws on the Technological Pedagogical Content Knowledge (TPACK) framework, which conceptualizes the integration of technology, pedagogy, and content knowledge. However, rather than treating TPACK as a general reference, this study unpacks its dimensions by examining specific areas of integration challenge, including technological–pedagogical alignment, content adaptation in digital environments, and the enactment of learner-centered strategies through digital tools. While conceptual models such as TPACK offer theoretical guidance for integration, their practical adoption in curriculum design remains limited. Moreover, many professional development programs emphasize operational skills rather than didactic transformation (Antón-Sancho et al., 2023; Kholid et al., 2024).

Existing research tends to either address digital infrastructure or isolate pedagogical methods without exploring their interactive effects on learning outcomes (Nilsson & Lund, 2023). Furthermore, few studies foreground the combined perspectives of lecturers and students in understanding how digital and pedagogical elements interact in practice. There is also limited exploration of the dual perspectives of lecturers and students in the context of digital–didactic

integration. Accordingly, this study investigates how digital competence and pedagogical strategies converge in practice, with a particular focus on their role in fostering critical thinking, collaboration, and autonomous learning.

Rather than assuming the transformative potential of digital learning, this study critically examines the conditions under which such transformation may or may not occur. This research is grounded in the premise that without coherent digital–didactic integration, higher education risks fostering superficial engagement with technology. In such a scenario, the transformative potential of digital learning environments remains unrealized, ultimately impairing graduate readiness in digitally mediated workplaces (Marín León et al., 2026). By providing empirically grounded insights from the lived experiences of educators and students, this study seeks to contribute evidence-based recommendations for strengthening digitally mediated pedagogy.

Given the ongoing digitalization of higher education, this study responds to a timely need to better understand how digital tools and pedagogical strategies interact in real-world academic contexts. Without sufficient empirical evidence, institutions may continue to adopt digital technologies without achieving meaningful improvements in learning outcomes (D.S. et al., 2025; Prasetyo et al., 2023). Therefore, this research aims to offer a more measured and evidence-based contribution to discussions on post-pandemic educational transformation, particularly in supporting the development of resilient and pedagogically aligned learning ecosystems.

LITERATURE REVIEW

Researchers have reviewed studies on digital competence and didactic strategies in higher education and grouped them into three categories: (1) integration of digital tools and pedagogy, (2) development of 21st-century skills (critical thinking, collaboration, and self-directed learning), and (3) empirical studies on lecturer–student digital learning experiences. This categorization follows a thematic synthesis approach, grouping studies based on their primary focus: technology–pedagogy integration, targeted learning outcomes, and analytical perspective (student, lecturer, or both).

In the first category, studies show that digital tools are widely adopted but insufficiently integrated with pedagogy. Technologies are often used to replicate traditional teaching rather than transform it. The TPACK model is rarely implemented holistically, with its components (TK, PK, CK) often treated separately, weakening their intersection. Faculty development programs also tend to emphasize technical skills over pedagogical integration, reinforcing the gap between digital competence and instructional practice.

In the second category, digital strategies are associated with improved critical thinking, collaboration, and self-directed learning. However, their

effectiveness depends on pedagogical alignment. Approaches such as project-based learning, peer assessment, and structured asynchronous tasks support higher-order skills, yet adaptive learning technologies remain underutilized, indicating a gap between technological potential and practice.

The third category highlights differences between student and lecturer experiences. Students are often more digitally fluent, while lecturers face challenges in integrating technology effectively. Most studies adopt a single perspective, with limited research capturing both lecturer and student views simultaneously, constraining a comprehensive understanding of digital–didactic interaction.

Figure 1: Research Position

Figure 1 illustrates prior research, identified gaps, and the focus of this study.

RESEARCH METHOD

This study employed a descriptive qualitative design to explore the integration of digital competence and didactic strategies in higher education. This approach enables researchers to capture complex social and instructional phenomena in their natural context and to generate rich, contextualized interpretations of participants' experiences (Creswell & Poth, 2018; Nurmeidina et al., 2025; Younas et al., 2023). Qualitative description was chosen specifically for its pragmatic orientation, which is well-suited to investigating underexplored yet practice-relevant issues, such as digital–didactic integration in Indonesian universities.

Participants

The study involved 70 participants, comprising 35 lecturers and 35 students from five higher education institutions in Indonesia: Universitas Muhammadiyah Surakarta (UMS), Universitas Sebelas Maret (UNS), UIN Raden Mas Said Surakarta, Universitas Negeri Yogyakarta (UNY), and Universitas Muhammadiyah Yogyakarta (UMY). These institutions were selected due to their adoption of digital learning innovations and their formal commitment to integrating 21st-century skills into their academic programs. Lecturers were purposively selected based on their active involvement in the design, implementation, or evaluation of digitally supported instructional practices. Students were chosen from academic programs that emphasize collaborative, project-based, or technology-integrated learning environments.

Lecturers were eligible if they had at least 2 years of higher-education teaching experience, actively used digital tools in instruction, and taught courses that integrated 21st-century skills. Students qualified if they were enrolled in digitally supported courses, had experience with collaborative or project-based learning, and were in at least their second year to ensure adequate exposure to university learning environments. Individuals not meeting these criteria or with limited engagement in digital learning were excluded.

Participants were recruited through institutional coordination and direct invitations. Faculty representatives identified eligible candidates, followed by purposive sampling to ensure disciplinary and contextual diversity. Invitations were disseminated via email and academic channels, and participation was voluntary, ensuring both relevance of experience and diversity across institutional and pedagogical contexts. Purposive sampling was employed to ensure the inclusion of participants with relevant and diverse experiences aligned with the study's focus. This diversity across institutional types and learning models allowed for a more comprehensive understanding of digital–didactic integration within varied pedagogical and organizational contexts.

Indicators of 21st-Century Skills Development

To assess the extent to which digital–didactic integration supports the development of 21st-century competencies, this study adopted three core skill dimensions as analytical indicators: critical thinking, collaboration, and self-directed learning. These indicators were adapted from existing educational competency frameworks (Emad & Ghosh, 2023), and were used to guide both data coding and thematic synthesis.

Table 1: Indicators for 21st-Century Skills Development

Skill Dimension	Observable Behaviors or Evidence	Code
Critical Thinking	1. Justifies opinions in discussions	G1
	2. Uses evidence-based reasoning	G2
	3. Reflective journal entries showing analysis	G3
Collaboration	1. Active participation in group tasks	N1
	2. Uses collaborative tools (e.g., shared docs)	N2
	3. Gives/receives peer feedback	N3
Self-Directed Learning (SDL)	1. Completes tasks independently	L1
	2. Seeks out resources	L2
	3. Reflective reports on learning process	L3

Instruments

The data collection instruments used in this study consisted of a semi-structured interview guide, classroom observation checklists, and document analysis forms. These tools were developed based on a literature review related to digital–didactic strategies, the TPACK framework, and 21st-century skill indicators such as critical thinking, collaboration, and self-directed learning. The development of these instruments followed a multi-step process. First, the initial drafts were constructed using indicators drawn from existing competency frameworks and relevant studies. Second, the draft instruments were validated by three experts—senior lecturers with expertise in educational technology and learning evaluation. The experts provided feedback on item clarity, alignment with the research objectives, and the suitability of the observation format for digital learning environments.

To strengthen methodological rigor, inter-expert agreement was assessed using a structured validation rubric. Each item was rated on relevance, clarity, and alignment using a 4-point scale. Items achieving a minimum agreement level of 0.80 (content validity index) were retained, while those below the threshold were revised or removed. This process ensured that the instruments met established content validity criteria.

Based on the validation input, the instruments were revised in terms of both content and structure. For example, several interview questions were rephrased to be more exploratory and less leading, while observation checklist indicators were refined to help observers systematically identify digital engagement and instructional strategies (Ishartono et al., 2025). Prior to full deployment, the instruments were pilot-tested at one institution outside of the main sample. This pilot aimed to identify any ambiguities and assess the effectiveness of the tools in capturing relevant data. The pilot test revealed the need for minor adjustments, such as adding an open comment section to the observation checklist and reordering interview questions for better logical flow (Schmid et al., 2024). Feedback from the pilot phase was also used as an additional validation step to confirm the clarity, usability, and contextual relevance of the instruments, thereby enhancing their overall reliability and applicability in real-world settings.

Data Collection Methods

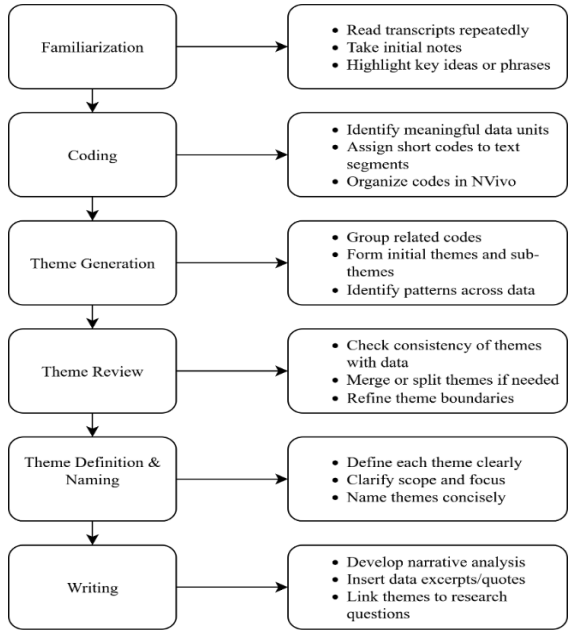
Data were collected through three primary techniques: (1) semi-structured in-depth interviews, (2) classroom observations (both synchronous and asynchronous sessions), and (3) document analysis. The interviews aimed to uncover perceptions, challenges, and instructional strategies related to digital competence (Aristovnik et al., 2024; Prasetyo et al., 2023). Observations were used to triangulate interview data and to examine real-time instructional practices (Prayitno et al., 2022; Suprapto et al., 2021). Institutional documents—such as syllabi, e-learning policies, and training manuals—were reviewed to contextualize findings within broader institutional strategies.

Data Analysis

Data analysis followed a thematic analysis approach as outlined by Braun and Clarke (2006), involving six iterative steps: familiarization, coding, theme generation, review, definition, and writing (Dunwoodie et al., 2023; Ravn, 2023). NVivo 12 software was used to manage data coding and to support systematic pattern identification (Limna, 2023). Themes were derived inductively but guided by theoretical constructs such as TPACK framework. Trustworthiness of the analysis was strengthened through triangulation of sources and methods, peer debriefing with senior researchers, and member checking with selected participants.

To enhance coding reliability, an intercoder agreement procedure was implemented. Two independent coders were involved in the coding process, each analyzing a subset of the data using the same coding framework. The level of agreement between coders was assessed using Cohen's kappa coefficient, achieving a value of 0.82, which indicates strong agreement. Discrepancies in coding were discussed and resolved through iterative consensus, leading to refinement of the coding scheme and improved consistency across the dataset.

Figure 2: Data analysis process



RESULTS

The research findings indicate variations in digital competence levels among lecturers and students, as well as differences in the intensity of digital media use for learning activities. The digital competence distribution chart shows that most lecturers are at a moderate level (18 respondents), with only 12 at a high level and 5 at a low level. In contrast, students tend to have higher digital competence, with 20 students categorized as high, 10 as moderate, and 5 as low.

In-depth interviews with lecturers revealed that they felt relatively comfortable using platforms such as LMS and Zoom but acknowledged limitations in designing interactive materials or utilizing learning analytics. One lecturer stated, *"I am familiar with basic platforms like Moodle and Google Classroom, but I have never used features such as automated student performance analysis."* On the other hand, students demonstrated a quicker adaptation to using digital tools. During observations of online learning activities, students were observed actively using Google Docs for collaboration and LMS forums for discussion, although some remained passive when faced with more advanced technology-based assignments.

The digital media usage chart reinforces these findings**.** Both lecturers and students reported high levels of usage for LMS platforms (28 lecturers and 30

students) and video conferencing tools such as Zoom or MS Teams (30 users in each group). However, differences begin to emerge in the use of collaborative tools such as Google Docs, which were used more frequently by students (25 respondents) than by lecturers (18 respondents). The use of virtual or augmented reality (VR/AR) tools remains very limited, with only 5 lecturers and 3 students reporting usage—indicating that this technology has yet to be widely integrated into the learning process.

Figure 3: Digital Competence Levels of Lecturers and Students

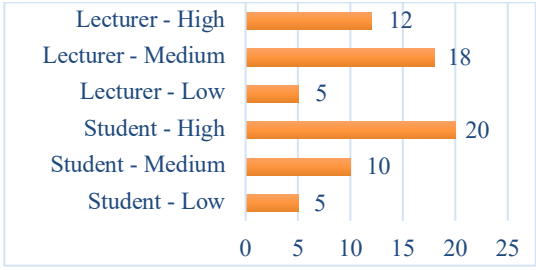
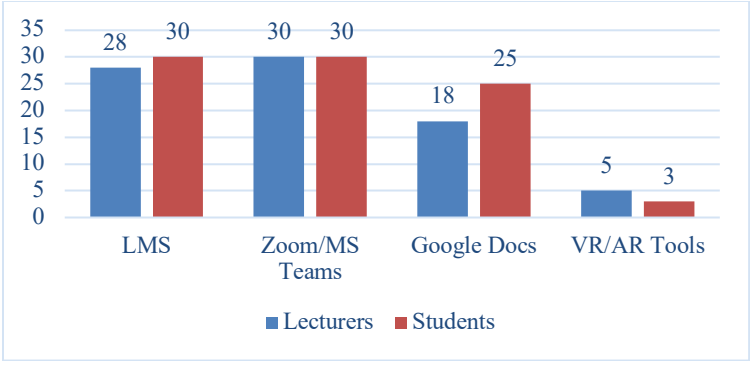


Figure 4: Use of Digital Media in Learning Activities



From observations of online classes, the most frequently implemented didactic strategies by lecturers included project-based collaborative learning, peer assessment via LMS forums, and weekly reflective assignments. Students responded positively to these methods, and in interviews, several reported that such experiences helped them develop communication, time management, and problem-solving skills. One student commented, *"I feel more prepared for the workforce because this kind of learning trains me to think critically and collaborate in teams online."*

Overall, these findings affirm that although a minor gap exists in technological proficiency between lecturers and students, the integration of digital technologies and collaborative didactic strategies has significantly contributed to the development of 21st-century skills in higher education settings. Table 2 provides a summary of the didactic strategies most frequently observed during instruction, along with student responses reflecting their perceived impact.

Table 2: Didactic Strategies Observed and Student Responses

Didactic Strategy	Frequency of Implementation	Effect on Students
Project-based learning	High	Enhanced collaboration and problem-solving
Peer assessment	Moderate	Improved reflection and metacognitive skills
Weekly reflection tasks	Moderate	Better self-awareness and time management

The integration of digital competence and didactic strategies in higher education has shown a notable influence on the development of key 21st-century skills—namely collaboration, critical thinking, and self-directed learning—among students, as perceived by both learners and lecturers. Among the three critical thinking indicators, justifying opinions in discussions (G1) was the most frequently observed, at 70%. This was especially visible in case-based discussions and problem-solving tasks where students were encouraged to explain their reasoning. One student remarked, *"When we debate in class, I try to explain my position clearly and give examples from the readings."*

Evidence-based reasoning (G2) followed with 60%, appearing in written tasks or structured assignments. However, some students tended to provide assertions without supporting data. Lecturers noted that *"students often state their opinions but forget to back them up with solid evidence."*

The least observed was reflective journal analysis (G3) at 45%. Although reflection activities were assigned in some courses, they lacked depth and feedback. Students admitted to writing surface-level reflections, often just summarizing what they had done. One shared, *"I just wrote down what I did, because we never got comments back."*

In contrast to the previous dimension, collaboration indicators presented a less uniform pattern. Active participation in group tasks (N1) was observed in 65% of cases. Group activities such as presentations and team assignments were common, and students often assumed distinct roles. A student stated, *"In our group, I handled the slides while others prepared the content. We worked well together."* Interestingly, peer feedback exchange (N3) reached 55%, overtaking

collaborative tool use. In several courses, peer review sessions were facilitated using rubrics or feedback forms. Some students appreciated this structure: *"We gave each other comments after the presentations. It helped me see what to fix."*

Conversely, the use of collaborative digital tools (N2) was the least observed, at only 40%. While tools like Google Docs or Padlet were introduced, their use was often superficial. Lecturers reported that *"students mostly divided the task offline and then just uploaded the parts, not really collaborating through the tools."*

Figure 5: Percentage of Critical Thinking Indicators Observed

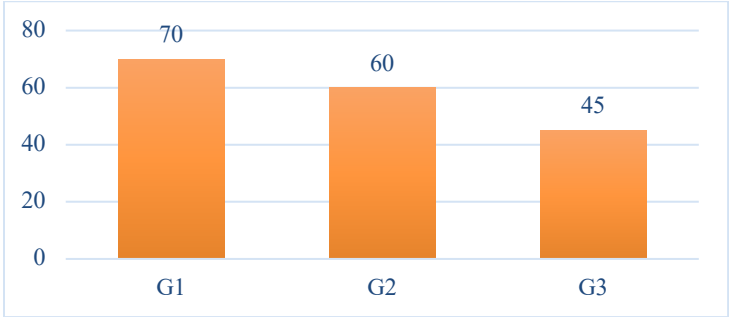
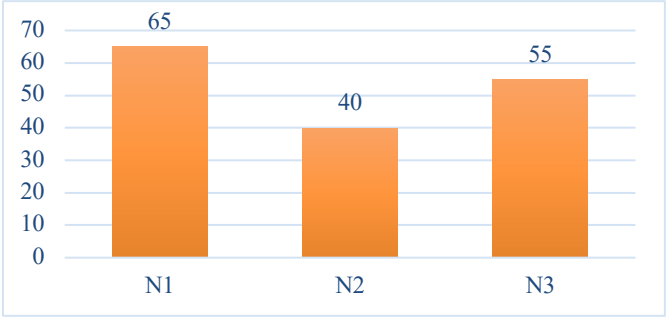


Figure 6: Percentage of Collaboration Indicators Observed



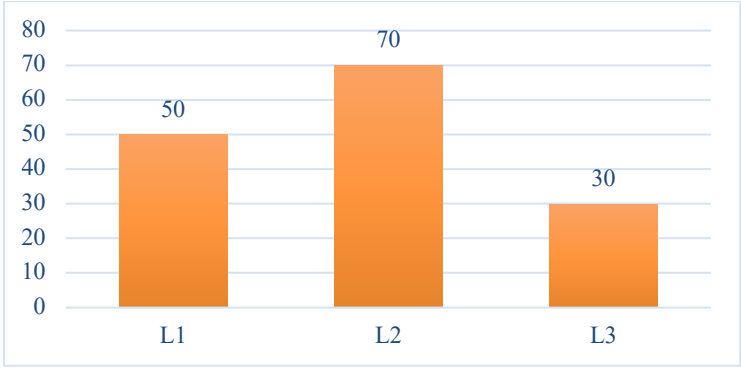
The self-directed learning (SDL) dimension revealed an unexpected trend, with seeking out resources (L2) being the most frequent behavior, observed in 70% of students. Many accessed additional materials—such as YouTube videos, blogs, and online tutorials—when they felt lecture materials were insufficient. A student noted, *"I searched for extra examples when I didn't understand the teacher's explanation."*

Completing tasks independently (L1) followed with 50%. While many students managed their responsibilities well in asynchronous learning contexts,

others showed dependence on reminders or peer direction. A lecturer mentioned, *"Some students still waited for instructions, even when the task was already clear on the LMS."*

Reflective reports on learning process (L3) were the least evident, at 30%. Although a few lecturers assigned learning journals or reflective essays, students often submitted brief, descriptive accounts. The lack of modeling and feedback seemed to discourage deeper metacognitive engagement. As one student explained, *"We didn't really know how to reflect—we just wrote what we did."*

Figure 7: Percentage of Self-Directed Learning Indicators Observed



DISCUSSION AND CONCLUSIONS

Interpretation of Findings

The findings of this study indicate that the integration of digital competence and didactic approaches in higher education learning has taken place, yet remains suboptimal. These results are consistent with previous studies showing that professional digital competence has not been fully incorporated into higher education policy frameworks. Generic and subject-specific digital competencies continue to dominate, while transformational and contextual competencies—particularly those relevant to the workplace and lifelong learning—are still minimally represented in policy documents (Barrios-Rubio, 2024; Boyarintseva et al., 2023).

In instructional practice, the use of digital technologies such as Moodle, Google Classroom, and various video conferencing platforms has become widespread (Kühl et al., 2024). However, the application of advanced features such as learning analytics, adaptive learning design, and the integration of interactive media remains inconsistent and infrequent (Martínez-Hernández et al., 2023). Table 3 outlines the key institutional and pedagogical barriers identified in the

integration of digital competencies, based on data from interviews and policy document analysis.

Table 3: Institutional and Pedagogical Barriers in Digital Integration

Type of Barrier	Description
Infrastructure disparities	Unequal access to technology across faculties
Lack of curriculum integration	Absence of TPACK in formal curriculum design
Technical-focused training only	Short-term workshops with limited pedagogical depth
Traditional assessment models	Limited use of learning analytics and authentic LMS-based evaluation

Beyond their categorization, these barriers demonstrate varying levels of impact and are structurally interrelated. Infrastructure disparities function as a foundational constraint, limiting access to digital tools and thereby constraining the implementation of more advanced pedagogical practices. In contrast, curriculum-related barriers—particularly the absence of TPACK integration—have a more direct influence on instructional design, shaping how technology is pedagogically enacted in the classroom. Moreover, these barriers interact in a reinforcing cycle. For instance, technical-focused training programs that lack pedagogical depth contribute to the persistence of traditional assessment models, which in turn discourage the adoption of data-driven approaches such as learning analytics. Similarly, inadequate infrastructure can limit opportunities for meaningful professional development, further widening the gap between digital competence and its pedagogical application.

From an analytical perspective, curriculum integration and pedagogical design emerge as higher-impact factors, as they directly mediate the translation of digital competence into learning outcomes. Meanwhile, infrastructure and training serve as enabling or constraining conditions that indirectly shape this process. This layered interaction suggests that addressing digital–didactic misalignment requires systemic interventions rather than isolated improvements in individual components.

Other studies suggest that learning approaches emphasizing self-regulated learning and peer feedback can significantly enhance students' metacognitive awareness and capacity for independent learning (Membrillo-Hernández et al., 2023). This aligns with the current study's findings, in which students reported feeling more engaged and responsible in the learning process when provided with opportunities for peer evaluation and self-reflection (Wijaya & Nizam, 2026). Meanwhile, innovative technologies such as virtual reality (VR), although widely recognized for their potential as experiential learning tools, are still underutilized

due to limited training, faculty competence, and infrastructure availability (Arancibia-Herrera et al., 2024).

Competency models such as TPACK have been proposed as conceptual frameworks to unify the technological, pedagogical, and content dimensions of digital learning. However, these models have not yet been systematically implemented in curricula or adopted as references for instructional design in many institutions (Trabelsi et al., 2022). The absence of evaluation systems that support competency-based learning further hampers efforts to assess the effectiveness of such integration (Llerena et al., 2026).

Within the institutional context of this study, it is important to distinguish between enabling factors and structural constraints shaping digital–didactic integration. The successful integration of digital competence was supported by several key enablers, including the availability of familiar digital platforms, students' readiness to use collaborative applications, and the commitment of some lecturers to design project-based and discussion-oriented learning activities (Ripsam & Nerdel, 2023). These enablers primarily facilitate the adoption and initial implementation of digitally supported pedagogical practices.

However, this enabling environment is counterbalanced by a set of persistent institutional constraints. These include varying levels of digital competence among lecturers, a lack of continuous and pedagogically oriented training, and insufficient institutional policy support. Several lecturers reported that although they were comfortable using basic technologies, they struggled to manage advanced features such as performance analytics or personalized learning materials (Soboleva & Karavaev, 2020). These constraints not only limit the depth of technology integration but also hinder the transition from basic usage to more advanced, data-informed pedagogical practices.

On the other hand, students expressed that learning approaches emphasizing online collaboration and reflection provided a deeper and more relevant educational experience aligned with future needs (Lo Presti, 2023). This contrast suggests that while student readiness acts as a strong enabling factor, its potential is not fully realized due to institutional and pedagogical limitations. Overall, the findings indicate a misalignment between enabling conditions at the student level and constraints at the institutional and instructional levels, reinforcing the need for more coherent and systemic support structures.

Didactic Implications

The findings of this study have significant implications for pedagogical practice in higher education, particularly for redefining the role of lecturers and designing learning that is aligned with 21st-century demands. In the context of digital learning, the role of the lecturer has undergone a paradigm shift—from merely a transmitter of information to an active facilitator of contextual, reflective, and competency-based learning experiences (Aydin et al., 2026; Z.-J. Liu et al., 2020).

This shift is not simply a methodological change but a transformation of didactic functions encompassing curriculum design, management of learning interactions, and monitoring of competency achievement through technology (Salim et al., 2026).

As facilitators, lecturers are expected to create a learning ecosystem that enables students not only to access information but also to construct knowledge through collaborative, exploratory, and reflective activities (Z. Liu et al., 2026; Vázquez-Cano et al., 2020). This reflects the lecturer's function as a guide of both cognitive and social processes—simultaneously supporting individual learning paths and managing group dynamics. In practice, this role is embodied through the use of tools such as online discussion forums, peer assessment, automated and qualitative feedback via LMS platforms, and the development of real-world, problem-based projects that challenge students to think critically and collaborate across disciplines (Candel et al., 2021; Nagovitsyn et al., 2021).

This transformation requires lecturers to be proficient in three key dimensions: technological literacy, pedagogical understanding rooted in learner-centered approaches, and sensitivity to the social dynamics of online learning environments (Mynaříková & Novotnỳ, 2020). Unfortunately, not all lecturers possess adequate competence or institutional support to adopt this new role. Previous studies have revealed that many lecturers remain at an intermediate level in terms of educational technology mastery and often continue to employ conventional approaches, even within digital learning formats. Therefore, institutional support is crucial in developing continuous training and mentoring systems that go beyond technical skill development and foster a pedagogical mindset shift (Husna et al., 2026). However, the effective enactment of these competencies is not solely dependent on individual lecturer capacity but is significantly mediated by institutional conditions. Institutional policies, curriculum structures, and the availability of professional development programs play a critical role in shaping how these competencies are interpreted and implemented in practice. Without coherent institutional support, lecturers may struggle to move beyond basic facilitation toward more advanced, data-informed, and adaptive pedagogical practices.

In this regard, institutions act as both enablers and regulators of didactic innovation. Supportive environments—characterized by sustained training, integrated digital pedagogy frameworks, and access to advanced technological tools—can enhance lecturers' ability to operationalize competencies such as collaborative learning design, formative assessment, and learning analytics. Conversely, fragmented policies and limited institutional guidance may constrain these practices, leading to inconsistent implementation across courses and programs. Therefore, the development of digital–didactic competence should be understood as a systemic process, where individual capabilities are continuously shaped, supported, and constrained by institutional structures. This highlights the

need for alignment between competency expectations at the instructional level and strategic support at the institutional level to ensure meaningful and sustainable pedagogical transformation.

On the other hand, adaptive and collaborative learning designs have emerged as strategic approaches that are demonstrably effective in supporting the development of 21st-century skills. Adaptive learning leverages data gathered through digital platforms to personalize learning pathways for each student (Nothacker & Lavicza, 2020). This results in a more meaningful and tailored learning experience that meets students' individual needs. Adaptivity allows learners to proceed at their own pace and according to their preferences without losing sight of core competency goals. Moreover, it enables lecturers to design evidence-based pedagogical interventions—for example, through analysis of assignment performance and LMS engagement data—which in turn enhances instructional efficiency.

Meanwhile, collaborative learning serves as a socio-cognitive framework that integrates interpersonal interaction with knowledge construction (Kholid et al., 2024). Students learn not only from lecturers but also from their peers through discussions, teamwork, and peer evaluations (Villalustre-Martínez, 2024). This process cultivates academic empathy, argumentative competence, and resilience in collaborative settings—all of which are essential competencies in the modern workforce. Recent studies affirm that using technology to support collaborative interaction increases student engagement and provides a richer space for evaluative and reflective practices (Mahmood, 2025).

Table 4: Evolving Roles of Lecturers in Digital Learning Environments

Lecturer Role Dimension	Function in Digital Learning
Learning Facilitator	Guiding discussions, collaboration, and student reflection
Instructional Designer	Creating project-based and adaptive, data-driven learning
Manager of Digital-Social Interaction	Orchestrating online class dynamics and student engagement
Data-informed Evaluator	Using LMS analytics to personalize instruction and feedback

The deeper implication of this integration is that learning can no longer be viewed as a linear or uniform activity. Contemporary instructional design demands a dynamic, interactive, and responsive approach to complex learning needs (Afif & Musyaffa, 2025). Lecturers must utilize technology not merely as a support tool, but as an integral component of a competency-based instructional strategy. Beyond this, integration also opens up space for *assessment for learning*—ongoing and

contextual evaluation (Laila et al., 2023; Nevrelova et al., 2024). Technology enables the creation of authentic, flexible, and process-based assessment systems that measure not only learning outcomes but also students' learning journeys.

Structural Challenges and Institutional Support in the Integration of Digital Competence

Digital transformation in higher education—particularly the integration of digital competencies into pedagogical practices—faces challenges that are not merely technical but also systemic and structural (Pinto-Santos et al., 2024). Although both faculty members and students have demonstrated a significant level of technology adoption, this transformation cannot develop optimally without a strong institutional foundation. One of the most prominent challenges is the disparity in the provision of digital infrastructure across departments or academic programs within the same institution (Issa & Castulo, 2026). Some faculties, equipped with sufficient budgetary support and access to cutting-edge technology, are able to comprehensively implement learning through Learning Management Systems (LMS), video conferencing, and collaborative digital applications. However, other faculties still struggle with basic infrastructure such as computers, stable internet connectivity, or digital spaces for academic interaction. This disparity not only creates a gap in the quality of teaching and learning but also exacerbates inequality in students' achievement of digital competencies in the current era (Cabero-Almenara et al., 2020).

Additionally, there is a lack of institutional policy that guides the integration of digital pedagogy into the learning system. Higher education curricula generally remain content-oriented rather than focused on the development of transformative competencies such as digital literacy, critical thinking, and cross-platform collaboration (Soboleva et al., 2022). Even well-established model such as TPACK (which integrates content, pedagogy, and technology) have yet to be formally adopted as references in curriculum development or faculty training. The absence of regulations or guidelines that promote or mandate this integration results in the use of technology as a mere supplement—an add-on—rather than as a core framework for learning development. As a result, the use of technology is often driven by enthusiastic individual lecturers rather than being part of a systemic institutional design. Without clear policy direction, the integration of technology remains unsustainable and tends to be sporadic (Chereguini & Gea, 2021).

Another issue lies in the limited availability of faculty development programs that are continuous, reflective, and practically oriented (Opesemowo & Adekomaya, 2024). Current training programs are mostly technical and short-term, focusing solely on the use of specific software or platforms without connecting them to the transformation of teaching roles or the redesign of instructional strategies. These programs often do not provide opportunities for lecturers to

understand the pedagogical dynamics of digital learning, data-driven instructional design, or the effective management of online interactions. Moreover, they frequently lack long-term mentoring processes, reflective practice, or learning communities that support pedagogical innovation. Consequently, many lecturers experience digital fatigue and innovation stagnation due to the absence of sustained institutional support (Z.-J. Liu et al., 2020).

Furthermore, internal campus regulations remain limited in adopting technology-based learning assessment approaches. Evaluation still tends to rely on traditional summative formats such as final exams and end-of-semester assignments, leaving little room for continuous, personalized formative learning (Lo Presti, 2023). In contrast, approaches such as learning analytics, personalized feedback, and authentic assessment integrated within LMS platforms can provide rich data for faculty to monitor student progress and design appropriate instructional interventions (Sosnovskaya et al., 2021). The lack of policies encouraging the use of digital data as the basis for evaluation renders instructional decision-making less informative and insufficiently adaptive.

In addressing these complexities, transformational strategies at the institutional level must be systematically and long-term oriented (Vaterlaus et al., 2025). Higher education institutions need to develop a digital pedagogy roadmap that outlines a comprehensive vision, stages, and targets for the development of digital competence-based learning (Villalustre-Martínez, 2024). This roadmap should be integrated into the university's strategic planning documents—not merely as part of information technology initiatives, but as a core educational strategy. Complementing this, a long-term faculty support system must be established, one that not only builds technical skills but also fosters instructional design capacity, leadership in digital learning, and the ability to engage in pedagogical reflection and innovation (Ángel-Uribe et al., 2024). This support may be implemented through mentoring, peer learning groups, or co-teaching arrangements in digital learning contexts.

In conclusion, the integration of digital competence and didactic strategies in higher education, exemplified through practices such as project-based learning, peer assessment, and reflective activities, demonstrates meaningful contributions to the development of 21st-century skills, including critical thinking, collaboration, and self-directed learning. While disparities in digital proficiency between lecturers and students persist, effective alignment between technology use and adaptive, collaborative instructional design enhances learning outcomes, contingent upon strong institutional support and contextual readiness. This study advances scholarly understanding by conceptualizing digital–didactic alignment as an interactive process, extending the practical application of the TPACK framework through empirical insights from both lecturers and students. To ensure sustainable impact, higher education institutions must invest in continuous professional development, competency-based curricula, and adaptive learning

systems, fostering coherent integration that prepares graduates for the complexities of the modern workforce.

REFERENCES

Afif, F. N. H., & Musyaffa, Z. H. (2025). Inclusive Digital Technology and Islamic Education: Promoting Social Equity for Persons with Disabilities in the Digital Age. *Multicultural Islamic Education Review*, *3*(1), 25–35. https://doi.org/10.23917/mier.v3i1.9913

Ángel-Uribe, I., Cano-Vásquez, L., & López-Molina, G. (2024). Characteristics of Educational Experiences In Stem Education In Medellin. *Journal of Technology and Science Education*, *14*(4), 1073–1098. https://doi.org/10.3926/JOTSE.2199

Antón-Sancho, Á., Vergara, D., & Fernández-Arias, P. (2023). Impact of the Digitalization Level on the Assessment of Virtual Reality in Higher Education. *International Journal of Online Pedagogy and Course Design*, *13*(1), 1–19. https://doi.org/10.4018/IJOPCD.314153

Arancibia-Herrera, M., Castro-Appelhanz, M.-J., & Sigerson, A. (2024). Relations between ICT conceptions and competencies: A study of the didactic sequences of nine Chilean teachers. *Educacao e Pesquisa*, *50*. https://doi.org/10.1590/S1678-4634202450260125ES

Aristovnik, A., Umek, L., Brezovar, N., Keržič, D., & Ravšelj, D. (2024). The Role of ChatGPT in Higher Education: Some Reflections from Public Administration Students. In C. S.K.S., W. F.L., L. K.C., P. N., C. P., & P. K. (Eds.), *Communications in Computer and Information Science: Vol. 1974 CCIS* (pp. 254–263). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-981-99-8255-4_22

Aydin, S., Raihan, F., Corliss, T., & Alwyn, S. (2026). Governance-Embedded Character Education: Institutionalizing Adab in Islamic School-Based Management. *Islamic Pedagogy Evaluation Journal*, *1*(1 SE-Articles), 1–16.

Barrios-Rubio, A. (2024). Training communicators in inter-and trans-disciplinarity to operate in a digitalised world. *Doxa Comunicacion*, *2024-July*-(39), 19–36. https://doi.org/10.31921/doxacom.n39a2009

Bazán-Ramírez, A., Ango-Aguilar, H., Cárdenas-López, V., Anaya-González, R. B., Capa-Luque, W., & Bazán-Ramírez, M. A. (2023). Self-Reporting of Teacher–Student Performance in Virtual Class Interactions in Biological Sciences during the SARS-CoV-2/COVID-19 Pandemic. *Sustainability (Switzerland)*, *15*(23). https://doi.org/10.3390/su152316198

Boyarintseva, N. A., Soboleva, E. V, Shilova, Z. V, & Zhuravleva, L. A. (2023). Developing the communicative competence of future cultural sector specialists when designing and applying didactic web-quests. *Perspektivy Nauki i Obrazovania*, *63*(3), 619–636. https://doi.org/10.32744/pse.2023.3.37

Cabero-Almenara, J., Gutiérrez-Castillo, J.-J., Palacios-Rodríguez, A., & Barroso-

Osuna, J. (2020). Development of the teacher digital competence validation of DigCompEdu check-in questionnaire in the University context of Andalusia (Spain). *Sustainability (Switzerland)*, *12*(15). https://doi.org/10.3390/su12156094

Candel, E. C., Agustín, M. P., & de Ory, E. G. (2021). ICT and gamification experiences with CLIL methodology as innovative resources for the development of competencies in compulsory secondary education. *Digital Education Review*, *39*, 238–256. https://doi.org/10.1344/DER.2021.39.238-256

Chereguini, C. D. P., & Gea, A. I. P. (2021). Model for the evaluation of teaching competences in teaching–learning situations. *Societies*, *11*(2), 1–17. https://doi.org/10.3390/soc11020056

Creswell, J. W., & Poth, C. N. (2018). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches* (4th ed.). SAGE Publications Inc.

D.S., S., Sutama, S., Fauziati, E., & Markhamah, M. (2025). Increasing students' higher-order thinking skills: The power of project-based STEM in Ethnomathematics Learning. *International Journal of Innovative Research and Scientific Studies*, *8*(3), 1933–1943. https://doi.org/10.53894/ijirss.v8i3.6903

Dunwoodie, K., Macaulay, L., & Newman, A. (2023). Qualitative interviewing in the field of work and organisational psychology: Benefits, challenges and guidelines for researchers and reviewers. *Applied Psychology*, *72*(2), 863–889. https://doi.org/10.1111/apps.12414

Emad, G. R., & Ghosh, S. (2023). Identifying essential skills and competencies towards building a training framework for future operators of autonomous ships: a qualitative study. *WMU Journal of Maritime Affairs*, *22*(4), 427–445. https://doi.org/10.1007/s13437-023-00310-9

Husna, S. F. N., Prasanti, R. R., Amaliah, N., Husniyah, F. N., & Qameer, N. (2026). Assessing Digital Technology Integration in Islamic Religious Education: A CIPP Model Evaluation. *Islamic Pedagogy Evaluation Journal*, *1*(1 SE-Articles), 17–32.

Ishartono, N., Halili, S. H. binti, & Razak, R. binti A. (2025). Exploring factors affecting the preservice mathematics teachers' use of digital mathematics learning media during online teaching practice. *Interactive Learning Environments*, 1–23. https://doi.org/10.1080/10494820.2024.2444532

Issa, H. M., & Castulo, N. J. (2026). Investigating teaching practices in large classes: A case study of public primary schools in Tanzania. *Journal of Interdisciplinary Studies in Education*, *15*(1 SE-Articles), 1–28. https://doi.org/10.32674/zr9wew97

Kholid, M. N., Mahmudah, M. H., Ishartono, N., Putra, F. G., & Forthmann, B. (2024). Classification of students' creative thinking for non-routine mathematical problems. *Cogent Education*, *11*(1). https://doi.org/10.1080/2331186X.2024.2394738

Kühl, L. M., Zerban, N. L., Tiedemann, E., & König, S. (2024). Development of a strategy for the expansion of online teaching at the University of Würzburg based on the experiences of lecturers and students in the pandemic years

2020/21. *GMS Journal for Medical Education*, *41*(1). https://doi.org/10.3205/zma001667

Laila, M., Haryanti, D., Haryanto, S., Tedjani, M. F., Allami, H., & Rahmatika, L. (2023). The Use of Repair Strategies in the EFL University Classroom During the COVID-19 Pandemic in Indonesia, Algeria, and Iran. *Journal of Language Teaching and Research*, *14*(4), 1083–1093. https://doi.org/10.17507/jltr.1404.27

Limna, P. (2023). The impact of NVivo in qualitative research: Perspectives from graduate students. *Journal of Applied Learning and Teaching*, *6*(2), 271–282. https://doi.org/10.37074/jalt.2023.6.2.17

Liu, Z.-J., Tretyakova, N., Fedorov, V., & Kharakhordina, M. (2020). Digital literacy and digital didactics as the basis for new learning models development. *International Journal of Emerging Technologies in Learning*, *15*(14), 4–18. https://doi.org/10.3991/ijet.v15i14.14669

Liu, Z., Gura, A., Pavlovskaya, O., & Antonova, N. (2026). The role of digital technologies in the transformation of ethical norms in the educational process. *International Journal of Evaluation and Research in Education*, *15*(1), 943–954. https://doi.org/10.11591/ijere.v15i1.32497

Llerena, L., Castro, J. W., & Rodriguez, N. (2026). Evaluating the usability of open source software tools in e-learning: a systematic mapping study and case study. *Journal of Computers in Education*, *13*(1), 355–388. https://doi.org/10.1007/s40692-025-00360-3

Lo Presti, V. (2023). The social impact of distance learning in Roman schools: "Success," social innovation, teaching practices. *Frontiers in Sociology*, *8*. https://doi.org/10.3389/fsoc.2023.1141435

Mahmood, R. Q. (2025). Exploring pedagogical effectiveness in teacher education: Insights and challenges from Kurdish EFL university lecturers. *Journal of Interdisciplinary Studies in Education*, *14*(4 SE-Articles), 1–26. https://doi.org/10.32674/tm4f3a78

Marín León, J. A., Castillo, E. R., Sigüeñas Fernández, R. L., Jara Alarcón, T. J., & Aguilar, D. D. (2026). Development of Research Competencies in University Students: A Systematic Review. *International Journal of Interdisciplinary Educational Studies*, *21*(1), 1–21. https://doi.org/10.18848/2327-011X/CGP/v21i01/1-21

Martínez-Hernández, C., Piskorski, R., & Stoffelen, A. (2023). Designing Online Workshops for Teacher Trainees: Heritage Mapping with Web GIS Story Maps. *European Journal of Geography*, *14*(3), 68–78. https://doi.org/10.48088/ejg.c.mar.14.3.068.078

Membrillo-Hernández, J., Cuervo-Bejarano, W. J., Mejía-Manzano, L. A., Caratozzolo, P., & Vázquez-Villegas, P. (2023). Global Shared Learning Classroom Model: A Pedagogical Strategy for Sustainable Competencies Development in Higher Education. *International Journal of Engineering Pedagogy*, *13*(1), 20–33. https://doi.org/10.3991/ijep.v13i1.36181

Mynaříková, L., & Novotnỳ, L. (2020). Knowledge society failure? Barriers in the

use of ICTs and further teacher education in the Czech Republic. *Sustainability (Switzerland)*, *12*(17). https://doi.org/10.3390/SU12176933

Nagovitsyn, R. S., Berezhnykh, E. A., Popovic, A. E., & Srebrodolsky, O. V. (2021). Formation of Legal Competence of Future Bachelors of Psychological and Pedagogical Education. *International Journal of Emerging Technologies in Learning*, *16*(1), 188–204. https://doi.org/10.3991/IJET.V16I01.17591

Nevrelova, N., Korenova, L., Lavicza, Z., Bruzkova, N., & Schmid, A. (2024). Enhancing digital literacy in primary education through augmented reality. *Frontiers in Education*, *9*. https://doi.org/10.3389/feduc.2024.1390491

Nilsson, P., & Lund, J. (2023). Design for learning – involving teachers in digital didactic design (D3). *Interactive Technology and Smart Education*, *20*(1), 142–159. https://doi.org/10.1108/ITSE-08-2021-0143

Nothacker, J., & Lavicza, Z. (2020). Digital Didactic Objectives of Primary, Secondary, and Higher Education Curricula in the 21st Century Executable with a Single-board Computer. *Open Education Studies*, *2*(1), 344–359. https://doi.org/10.1515/edu-2020-0135

Nurmeidina, R., Zaqiyah, N. N., Nugroho, A. G., Andini, A., Faiziyah, N., Adnan, M. B., & Syar'i, A. (2025). Analysis of students' problem-solving abilities in solving contextual problems of Linear Equations with Three Variables in terms of Habits of Mind. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, *7*(1), 117–135. https://doi.org/10.23917/ijolae.v7i1.23550

Opesemowo, O. A. G., & Adekomaya, V. (2024). Harnessing Artificial Intelligence for Advancing Sustainable Development Goals in South Africa's Higher Education System: A Qualitative Study. *International Journal of Learning, Teaching and Educational Research*, *23*(3), 67–86. https://doi.org/10.26803/ijlter.23.3.4

Pinto-Santos, A. R., Villanueva-Valadez, C., & Cortés-Peña, O. (2024). Transcultural Analysis of The Digital Environment For Managing Learning in University Students. *Revista de Gestao Social e Ambiental*, *18*(2). https://doi.org/10.24857/rgsa.v18n2-177

Prasetyo, W. H., Sunardjoko, B., Muhibbin, A., Mahadir Naidu, N. B., & Muthali'in, A. (2023). Promoting Digital Citizenship among Student-Teachers: The Role of Project-Based Learning in Improving Appropriate Online Behaviors. *Participatory Educational Research*, *10*(1), 389–407. https://doi.org/10.17275/per.23.21.10.1

Prayitno, H. J., Markhamah, Nasucha, Y., Huda, M., Ratih, K., Ubaidullah, Rohmadi, M., Boeriswati, E., & Thambu, N. (2022). Prophetic educational values in the Indonesian language textbook: pillars of positive politeness and character education. *Heliyon*, *8*(8), e10016. https://doi.org/10.1016/j.heliyon.2022.e10016

Ravn, S. (2023). Integrating qualitative research methodologies and phenomenology—using dancers' and athletes' experiences for phenomenological analysis. *Phenomenology and the Cognitive Sciences*, *22*(1), 107–127. https://doi.org/10.1007/s11097-021-09735-0

Ripsam, M., & Nerdel, C. (2023). Teachers' attitudes and self-efficacy toward augmented reality in chemistry education. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1293571

Romero-Tena, R., León-Garrido, A., & Gutiérrez-Castillo, J. J. (2025). The influence of the moment of training of future early childhood education teachers on their digital teaching competencies. *Journal of Technology and Science Education*, *15*(1), 91. https://doi.org/10.3926/jotse.3149

Salim, A., Narongraksakhet, I., Hayani, A., Putri, M. A., Hassama, A., & Abdullah, A. A. (2026). Outcome-Based Education, E-Learning, and Student Satisfaction: Evidence from Indonesia and Thailand. *Jurnal Ilmiah Peuradeun*, *14*(1), 531–550. https://doi.org/10.26811/peuradeun.v14i1.1285

Schmid, U. K., Kümpel, A. S., & Rieger, D. (2024). How social media users perceive different forms of online hate speech: A qualitative multi-method study. *New Media and Society*, *26*(5), 2614–2632. https://doi.org/10.1177/14614448221091185

Soboleva, E. V, & Karavaev, N. L. (2020). Preparing engineers of the future: The development of environmental thinking as a universal competency in teaching robotics. *European Journal of Contemporary Education*, *9*(1), 160–176. https://doi.org/10.13187/ejced.2020.1.160

Soboleva, E. V, Zhumakulov, K. K., Umurkulov, K. P., Ibragimov, G. I., Kochneva, L. V, & Timofeeva, M. O. (2022). Developing a Personalised Learning Model Based on Interactive Novels to Improve the Quality of Mathematics Education. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(2). https://doi.org/10.29333/EJMSTE/11590

Sosnovskaya, I. V, Nikonova, N. I., Zalutskaya, S. Y., Terentyeva, N. P., & Galitskyh, E. O. (2021). Visualization Practices in Training Pedagogy Students. *Webology*, *18*(Special Issue), 1144–1159. https://doi.org/10.14704/WEB/V18SI04/WEB18188

Suprapto, N., Prahani, B. K., & Deta, U. A. (2021). Top 100 Cited Publications in Physics Education in The Last Thirty Years: A Bibliometric Analysis. *Library Philosophy and Practice*, *2021*, 1–13.

Trabelsi, O., Bouchiba, M., Souissi, M. A., Gharbi, A., Mezghanni, N., Kammoun, M. M., Masmoudi, L., & Mrayeh, M. (2022). Technology-mediated Physical Education teaching practices in Tunisian public schools: a national teacher survey. *Sport, Education and Society*, *27*(7), 878–892. https://doi.org/10.1080/13573322.2021.1926962

Vaterlaus, J. M., Shaffer, T., & Pulsipher, L. (2025). College student interpersonal and institutional relationships during the COVID-19 pandemic: A qualitative exploratory study. *Social Science Journal*, *62*(2), 271–284. https://doi.org/10.1080/03623319.2021.1949553

Vázquez-Cano, E., Marín-Díaz, V., Oyarvide, W. R. V, & López-Meneses, E. (2020). Use of augmented reality to improve specific and transversal competencies in students. *International Journal of Learning, Teaching and Educational Research*, *19*(8), 393–408. https://doi.org/10.26803/ijlter.19.8.21

Villalustre-Martínez, L. (2024). Gamification narratives and competency assessment in initial teacher training. *OCNOS*, *23*(2). https://doi.org/10.18239/ocnos_2024.23.2.431

Wijaya, F. A., & Nizam, A. K. (2026). Training Preachers in a Changing Society: A Socio-Educational Evaluation of Muhammadiyah Universities. *Islamic Pedagogy Evaluation Journal*, *1*(1 SE-Articles), 61–74.

Younas, A., Fàbregues, S., Durante, A., Escalante, E. L., Inayat, S., & Ali, P. (2023). Proposing the "Miracle" Narrative Framework for Providing Thick Description in Qualitative Research. *International Journal of Qualitative Methods*, *22*. https://doi.org/10.1177/16094069221147162

Zambrana-Tévar, M. C., Martin-Valmayor, M. A., Gil-Alana, L. A., & Martínez González, J. M. (2025). Evaluation of environmental website preferences using fuzzy AHP. *Technology, Pedagogy and Education*. https://doi.org/10.1080/1475939X.2025.2476462

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Manuscript submitted: ***September 15, 2025***
Manuscript revised: ***April 6, 2026***
Accepted for publication: ***April 18, 2026***