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REVIEW ARTICLE

Emerging technologies and university learning: a systematic review of their pedagogical effectiveness and implementation conditions

Tecnologías emergentes y aprendizaje universitario: revisión sistemática de su efectividad pedagógica y condiciones de implementación

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ABSTRACT
In the contemporary context of the digital transformation of higher education, emerging technologies such as simulations, augmented reality, and virtual laboratories have gained relevance due to their potential to improve teaching and learning processes; however, the evidence regarding their effectiveness presents heterogeneous and scattered results. In this sense, this study aimed to critically and systematically analyze the existing empirical evidence on the use of these emerging technologies in higher education, focusing on their educational impact and the main limitations arising from their application within the pedagogical field itself, and not only from the technological perspective. A systematic review was conducted following the PRISMA methodology guidelines. To this end, empirical research on the use of emerging technologies was examined, focusing on variables such as learning outcomes, motivation, knowledge retention, and skills development. The analysis showed that these technologies can improve conceptual learning, knowledge retention, and transfer, as well as the development of practical and spatial skills. However, their effectiveness is mediated by pedagogical factors, instructional design, and the implementation context. Limitations include the small number of standardized studies, small sample sizes, and limited evaluation of long-term effects. Overall, the results demonstrate the high educational potential of these technologies, although they require robust pedagogical approaches and more comparative evidence to substantiate their effectiveness in higher education.
Keywords: Educational simulations, augmented reality, virtual laboratories, higher education, simulation-based learning.

RESUMEN
En el contexto contemporáneo, la transformación digital de la educación superior, tecnologías emergentes como las simulaciones, la realidad aumentada y los laboratorios virtuales, han adquirido relevancia por su potencial para mejorar procesos de enseñanza-aprendizaje; sin embargo, la evidencia sobre su efectividad presenta resultados heterogéneos y dispersos. En este sentido, este estudio tuvo como objetivo analizar, de manera crítica y sistemática, la evidencia empírica existente sobre el uso de estas tecnologías emergentes en el ámbito de la educación superior, enfocándose en su impacto educativo y los principales límites que se derivan de su aplicación desde el propio campo pedagógico y no solo desde el ámbito tecnológico. Se realizó una revisión sistemática siguiendo los lineamientos de la metodología PRISMA. Para esto se examinaron investigaciones empíricas sobre el uso de tecnologías emergentes y que tuvieran como variables, los resultados de aprendizaje, motivación, retención del conocimiento y desarrollo de habilidades. El análisis mostró que estas tecnologías pueden mejorar el aprendizaje conceptual, retención y transferencia de conocimiento, además del desarrollo de habilidades prácticas y espaciales. Sin embargo, su eficacia está mediada por factores pedagógicos, diseño instruccional y contexto de implementación. Como limitaciones deben mencionarse la poca cantidad de investigaciones estandarizadas, tamaños de muestra reducidos y evaluación escasa de los efectos a largo plazo. En general, los resultados muestran el alto potencial educativo de este tipo de tecnologías, aunque requieren de planteamientos pedagógicos robustos y más evidencias comparativas para fundamentar la eficacia de su empleo en la educación superior.
Palabras clave: Simulaciones educativas, realidad aumentada, laboratorios virtuales, educación superior, aprendizaje basado en simulación.

INTRODUCTION

For several years, higher education in general has undergone a rapid transformation related to pedagogy, influenced primarily by the inclusion of emerging digital technologies (Bitar & Davidovich, 2024) as didactic tools for the teaching-learning process. For example, these tools include those related to the use of educational simulations, augmented reality, and virtual laboratories, which are in higher demand in fields requiring a high level of conceptual abstraction to understand complex processes and develop practical skills (Crogman et al., 2025).

These technologies have been proposed as innovative solutions for improving the quality of the university teaching-learning process, consolidating active methodologies, and expanding access to educational experiences that, in traditional contexts, would be costly, risky, or logistically limited (Mena-Guacas et al., 2025). However, their adoption in higher education institutions has, in many cases, outpaced the pedagogical reflection needed to justify their use.

The exponential growth of empirical studies on these technologies has generated a large but fragmented body of literature, with heterogeneous and, at times, contradictory results, and no clear consensus on their pedagogical impact or on the conditions under which these technologies effectively contribute to university learning (Kazlaris et al., 2025). Furthermore, the available literature shows a proliferation of studies focused on technological novelty, motivation, or student satisfaction, but with less emphasis on deep learning, knowledge transfer, and the development of long-term competencies. This influences informed decision-making by university faculty and administrators, as well as by educational policymakers. Therefore, all need access to systematic evidence on the effectiveness, implementation conditions, and limitations of these technologies (Feng et al., 2025).

The issue, in relation to the principles of technological assemblies in teaching and learning contexts, lies in the absence of a systematic and critical synthesis of empirical results that contribute to a reflective understanding of how, when, and under what circumstances emerging technologies can create educational value in higher education. In other words, higher education does not address emerging technologies from a pedagogical perspective, nor does it compare their results using cross-cutting themes such as active learning, cognitive visualization, or educational accessibility. The dispersion of methodological approaches, the diversity of disciplinary contexts, and the variability in instructional designs hinder the comparative interpretation of reported results.

From a critical perspective, the unreflective adoption of emerging technologies in higher education could carry the risk of reproducing excessively technology-centric approaches, in which innovation is valued for its level of technical sophistication rather than for its effective contribution to teaching and learning processes (Mena-Guacas et al., 2025). This problem is exacerbated in university settings due to the pressure for educational innovation, even though this innovation is not always aligned with teacher training, adequate infrastructure, or results evaluation.

Given the above, it could be argued that it is problematic for curricular and institutional decisions to be based on partial or anecdotal evidence, rather than systematic reviews that identify patterns, gaps, and trends in research. Therefore, this research aimed to use empirical evidence on the educational impact of simulations, augmented reality, and virtual laboratories in higher education, and the pedagogical conditions that influence their effectiveness.

The main reason for affirming the relevance of this systematic review is its theoretical, methodological, and practical contribution to the field of educational technology in higher education. From a theoretical perspective, this review will, on the one hand, unify and interrelate positions that have previously remained separate in the literature; on the other hand, it will provide a critical and coherent view of the effects, benefits, and limitations of emerging technologies such as simulations, augmented reality, and virtual laboratories. From a methodological standpoint, the use of a systematic approach based on the PRISMA guidelines makes it possible to conduct a rigorous, transparent, and replicable analysis, addressing the limitations of narrative reviews and reinforcing the validity of the synthesized evidence (Page et al. 2021). From a practical standpoint, the results could also contribute to pedagogical, curricular, and institutional decision-making aimed at implementing these technologies and, in some way, motivating the use of evidence-based educational strategies to improve the quality of the teaching and learning process in higher education.

Within this framework, this study aimed to critically and systematically analyze the existing empirical evidence on the use of simulations, augmented reality, and virtual laboratories in higher education, focusing on their educational impact and the main limitations arising from their application within the pedagogical field itself, and not only from the technological perspective. To this end, the most frequently used methodological strategies in empirical studies related to emerging technologies in higher education were identified; the impacts of using these technologies on university learning were reviewed; and emerging technologies were compared based on cross-cutting pedagogical analysis frameworks. The main knowledge gaps were identified to outline future lines of study in the field of emerging technology use, thus contributing to a more global and well-founded view of the phenomenon.

METHODOLOGY

Research type and design

This study is a systematic review of the available scientific literature on the use of simulations, augmented reality, and virtual laboratories in higher education. The review was conducted following the PRISMA 2020 guidelines (Page et al., 2021), as shown in Figure 1, which provide a robust framework for ensuring quality, transparency, and replicability in conducting systematic reviews. This methodological approach—methodical, transparent, and reproducible—for the selection and analysis of scientific studies allowed for a comprehensive analysis of existing empirical studies, integrating and comparing relevant results on the pedagogical impact, effectiveness, and implementation conditions of emerging educational technologies in the university context.

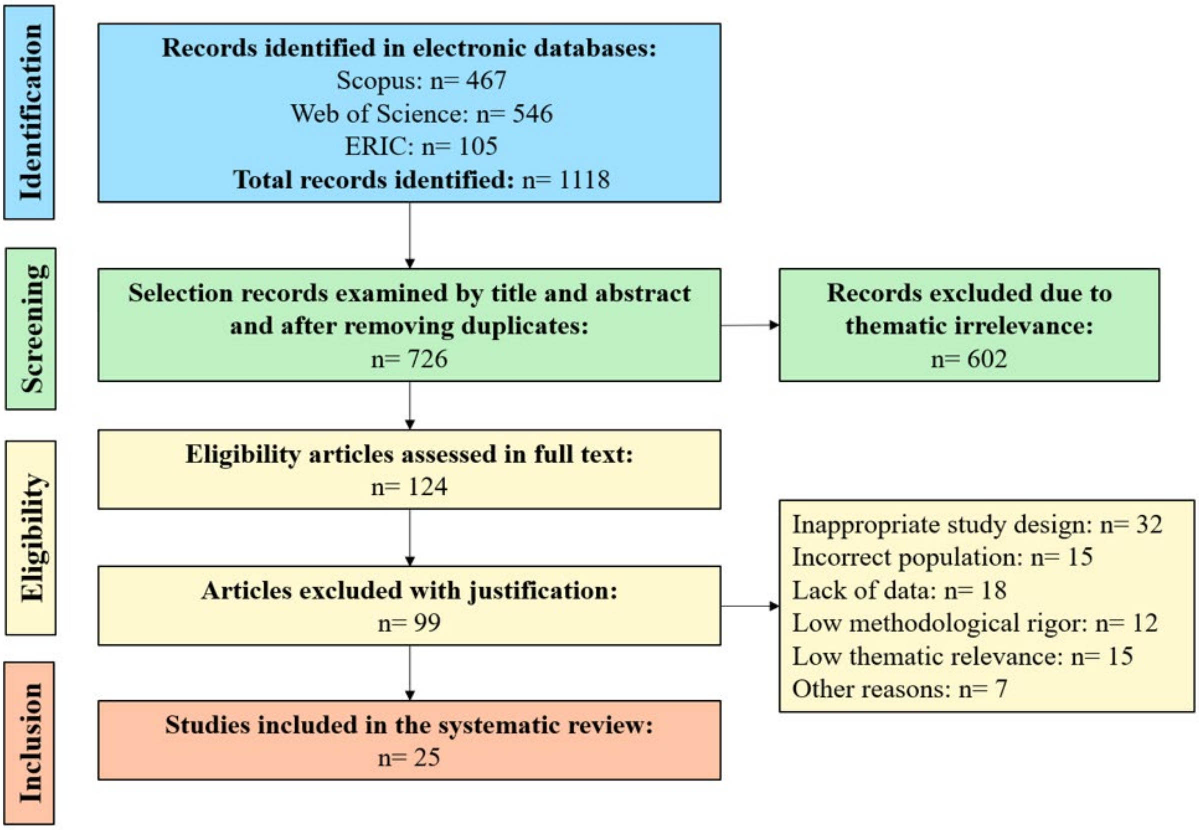

Figure 1. Article selection process using the PRISMA methodology.

Formulation of research questions

The PICO framework (De Cassai et al., 2025), adapted for systematic review, was used to formulate the research question: P (Patient/Problem) referred to university students participating in higher education programs, who constitute the study group; I (Intervention) involved the incorporation of emerging technologies (simulations, augmented reality, and virtual laboratories) implemented in the teaching-learning process; C (Comparison) involved analyzing the effects of these emerging technologies compared to traditional teaching methodologies, to evaluate the differences and possible advantages over conventional methods; finally, O (Outcomes) referred to the effects of these technologies on university learning, specifically on the development of students' cognitive, procedural, and motivational skills.

Based on the PICO framework, the following research question was formulated: How do emerging technologies, such as simulations, augmented reality, and virtual laboratories (I), impact university learning (O) compared to traditional teaching methodologies (C), specifically in the development of cognitive, procedural, and motivational competencies (O) in university students (P)? The selection of studies included in this review was based on this PICO framework to ensure that the effects of implementing these emerging technologies on educational outcomes in university contexts were explicitly addressed.

Search strategy and information sources

The scientific databases Web of Science, Scopus, and ERIC (Education Resources Information Center) were used to search for information. The following search terms, in both Spanish and English, were used, combined with Boolean operators (AND, OR), for example: "higher education" AND "simulation-based learning"; "augmented reality" AND "higher education"; "virtual laboratories" AND "higher education"; "emerging educational technologies" AND "impact" AND "learning outcomes".

To avoid omitting research important to the study, a manual search was also conducted for articles cited in the works included in the study.

Inclusion and exclusion criteria

Inclusion criteria

Studies were included that met the following criteria: a) type of study: empirical research published in scientific journals, both qualitative and quantitative, that have evaluated the impact of emerging technologies (simulations, AR and virtual laboratories) in higher education; b) context: studies carried out in higher education institutions such as universities, tertiary institutes, undergraduate or postgraduate programs; c) pedagogical approach: research that explicitly addresses pedagogical effects, such as the development of skills, active learning, cognitive visualization or student motivation; d) language: articles published in English or Spanish; and e) publication date: studies published in the last 5 years (2022-2026) were considered to ensure that the review reflects the most recent dynamics on the use of these technologies.

Exclusion criteria

For this literature review, the following articles were not considered: a) those that did not focus on higher education, such as research in basic education or continuing education; b) those that had not undergone peer review or were not fully accessible (e.g., abstracts, expert opinions, unreviewed reports); c) those that dealt only with emerging technologies outside the scope of this study; for example, artificial intelligence applied in the classroom without a direct relationship to simulations, AR, or virtual laboratories; and d) those that did not report an explicit result of the influence of these technologies at the pedagogical level or on learning outcomes achieved by students.

Study selection process

The study selection process followed a three-phase protocol:

• Phase 1 - Identification: A search was conducted in the previously mentioned databases using the defined search terms.

• Phase 2 - Screening: The titles and abstracts of the articles found in the initial search were reviewed to determine whether they met the inclusion criteria and could therefore be considered for the next stage of the methodology.

• Phase 3 - Final selection: The articles that passed the previous phase were evaluated in full text, and from there, only those articles that met the inclusion criteria established for this systematic review were selected.

Data extraction

For each selected study, the following relevant data were extracted: i. bibliographic information: author(s), year of publication, source (journal, conference, etc.); ii. study design: type of study (quantitative, qualitative, mixed), data collection method (questionnaires, interviews, observation, etc.), and sample size; iii. technologies evaluated: description of the emerging technologies analyzed (simulations, AR, virtual laboratories); iv. educational outcomes: effects observed on learning outcomes (competencies developed, improvement in understanding, motivation, etc.); v. implementation conditions: contexts in which the technologies were implemented, limitations and challenges reported in the studies.

Methodological quality

To determine the methodological quality of the selected articles, standard checklists were used, corresponding to the type of study. For example, the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) quality criteria (Cevallos & Egger, 2014; STROBE Initiative, 2021) were used for quantitative studies, and the CASP (Critical Appraisal Skills Programme UK, 2024) assessment criteria were used for qualitative studies. This analysis of methodological quality ensured that the results included in this systematic review were robust and reliable.

Data analysis

As part of the analysis of information from the selected articles, a synthesis was conducted encompassing both qualitative and quantitative approaches. For the qualitative research, a thematic coding system was used to identify common patterns in the pedagogical conclusions, benefits, and limitations of emerging technologies. For the quantitative studies, both descriptive analyses and a meta-analysis were performed to substantiate the overall effect of emerging technologies on students' academic outcomes.

For the meta-analysis, the following information was extracted from each study: technology type, sample size, duration, design, dependent variables, main results, and effect size (when available). In cases where this information was not explicitly reported, Cohen's effect size (d) or the normalized gain (N-Gain) was calculated from means, standard deviations, F-values, or t-tests, whenever the data allowed. After estimating high heterogeneity in designs, populations, and selected technologies, a random-effects meta-analysis was conducted using the inverse variance method. Heterogeneity was estimated using the I^2 statistic. Due to the small number of studies with directly calculable effect sizes, no publication bias analysis was performed.

Synthesis and interpretation of the results

A critical synthesis of the articles was conducted, highlighting the strengths and weaknesses of the emerging technologies analyzed. This was done from a pedagogical perspective. Furthermore, some existing gaps were identified to guide further research on the use of these technologies as teaching tools. Finally, recommendations were proposed for the effective implementation of these technologies in higher education.

RESULTS AND DISCUSSION

Methodological approaches to emerging technologies in higher education

Among the 25 included studies (Table 1), experimental or quasi-experimental designs predominated (68%; n= 17). This reflects the trend toward methodological approaches focused on evaluating interventions and establishing causal relationships in educational contexts. Pre-experimental or case studies, on the other hand, constituted 20% (n= 5), while those with mixed or survey-based approaches reached approximately 12% (n= 3), indicating less integration of qualitative and quantitative methods in the research. This distribution, while consistent with a preference for designs with greater internal control, could limit a holistic understanding of the diverse educational dynamics (Acosta et al., 2021).

Table 1. General characteristics of the included studies (n = 25)

Variable	Category	Frequency (n)	References
Type of study	Experimental / Quasi-experimental	17	Aldosari et al. (2022); Lestari et al. (2023); Eticha et al. (2023); Prasetya et al. (2023); Arymbekov et al. (2024); Tokatlidis et al. (2024); De Lorenzis et al. (2024); Anjos et al. (2024); Chookaew et al. (2024); Sáiz-Manzanares et al. (2024); Sakkas et al. (2025); Bonavolontà et al. (2025); Darejeh et al. (2025); Bashith et al. (2025); Marougkas et al. (2025); Anugrah et al. (2025); Alharthi et al. (2026)
	Pre-experimental / Case	5	Díaz et al. (2022); Prasetya et al. (2023); Chookaew et al. (2024); Sadam & Al Mamun (2024); Zhuang et al. (2025)
	Mixed / Survey	3	Sadam & Al Mamun (2024); Haj-Hosseini et al. (2024); Bashith et al. (2025)
Sample size	< 50	9	Prasetya et al. (2023); De Lorenzis et al. (2024); Chookaew et al. (2024); Haj-Hosseini et al. (2024); Sáiz-Manzanares et al. (2024); Darejeh et al. (2025); Zhuang et al. (2025); Anugrah et al. (2025); Setiyawan & Syamsuddin (2026)
	50-150	11	Lestari et al. (2023); Eticha et al. (2023); Anjos et al. (2024); Arymbekov et al. (2024); Tokatlidis et al. (2024); Anugrah et al. (2025); Bonavolontà et al. (2025); Sakkas et al. (2025); Bashith et al. (2025); Marougkas et al. (2025); Alharthi et al. (2026)
	> 150	5	Sadam & Al Mamun (2024); Tokatlidis et al. (2024); Rodriguez-Saavedra et al. (2025); Sakkas et al. (2025); Bonavolontà et al. (2025)

The sample distribution is moderately balanced (44% between 50 and 150, 36% less than 50, 20% greater than 150), indicating heterogeneity that could have a negative effect on statistical power and external validity. Therefore, research addressing this topic is still methodologically developing, with a predominance of experimental designs, but facing challenges in terms of methodological diversity and sample representativeness.

Virtual reality (VR) research predominated (40%; n=10) and, in this respect, has become the preferred tool thanks to its immersive capacity to improve performance, practical skills, motivation, and cognitive load (Figure 2), a key aspect of current studies (Llanos-Ruiz et al., 2025; Hamash et al., 2025). Virtual laboratories and simulations (28%; n=7) present an outstanding alternative for the development of higher-order skills and critical thinking, promoting active and experiential learning.

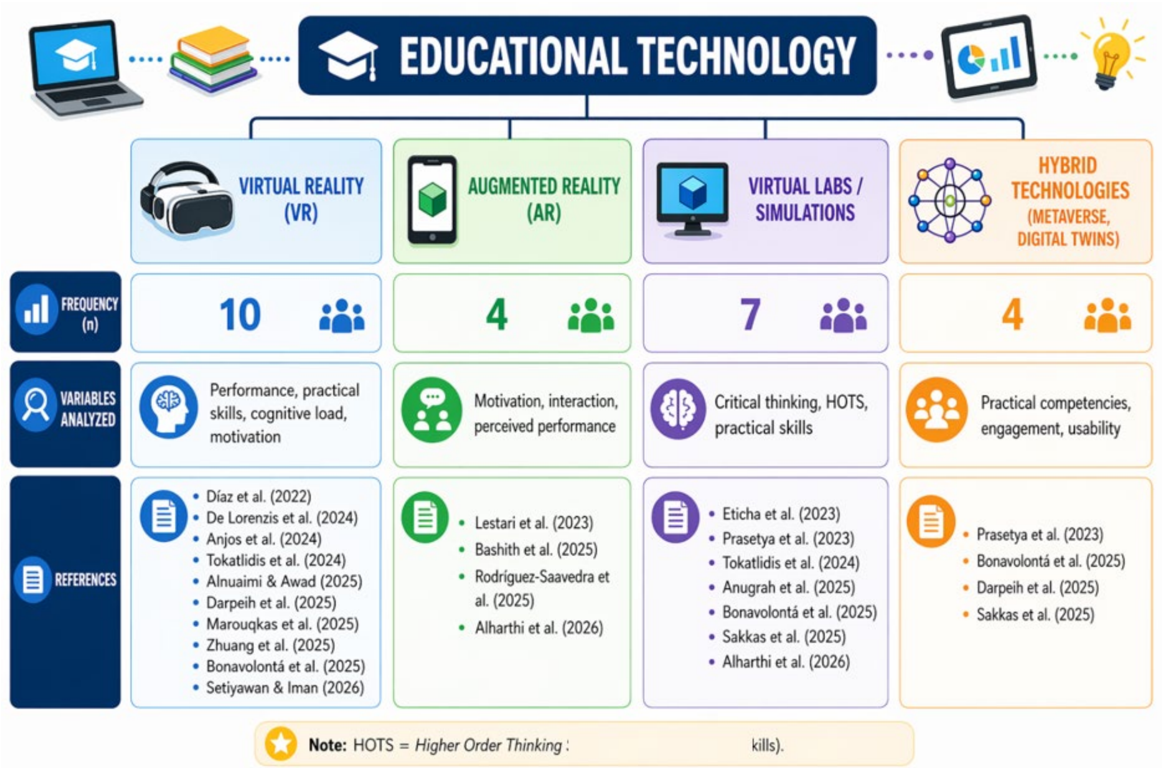

Figure 2. Classification by type of educational technology.

Meanwhile, augmented reality (AR) and hybrid technologies (metaverse and digital twins) each account for 16% of the data (n= 4). While technically less represented, both technological eras are characterized by a trend focused on variables such as motivation, interaction, engagement, and usability, suggesting an emerging trend toward a more integrated and collaborative learning experience. All of this is geared toward increasing student motivation, interaction, and engagement in complex virtual environments (Mercan & Varol, 2024). The results reflect a trend toward immersive technologies, with an emphasis on VR, although with a progressive diversification toward hybrid ecosystems that expand pedagogical possibilities.

Table 2 presents the methodological quality of the included articles. The quality of these studies showed a balanced distribution (high: 40%; medium: 32%; low: 28%), although some limitations exist when analyzing their overall validity. Several of the included studies could be considered high quality because they employ experimental or quasi-experimental designs, advanced techniques such as ANOVA, ANCOVA, and SEM, and control groups to allow for statistical inference. However, some problems were detected, such as small sample sizes, which result in low generalizability of the findings in application contexts related to teaching and learning processes in higher education (Viswanathan et al., 2012).

Table 2. Synthesis grouped by methodological quality level of the included studies.

Quality level	References	Common methodological characteristics	Main strengths	Main weaknesses
High	Aldosari et al. (2022); Lestari et al. (2023); Tokatlidis et al. (2024); Arymbekov et al. (2024); Sáiz-Manzanares et al. (2024); Alnuaimi & Awad (2025); Darejeh et al. (2025); Rodriguez-Saavedra et al. (2025); Anugrah et al. (2025); Zhuang et al. (2025)	Robust experimental or quasi-experimental designs; use of ANOVA, ANCOVA, or SEM; inclusion of a control group or multiple groups	Greater internal validity; advanced statistical analysis; triangulation (in some cases)	Small sample sizes in several studies; limitations in generalizability; poorly specified duration in some
Medium	Díaz et al. (2022); De Lorenzis et al. (2024); Anjos et al. (2024); Sadam & Al Mamun (2024); Haj-Hosseini et al. (2024); Sakkas et al. (2025); Bonavolontà et al. (2025); Marougkas et al. (2025)	Experimental or evaluation designs without complete control; cross-sectional or acceptance studies	Use of validated instruments; relevant descriptive and comparative results	Lack of a control group in some studies, absence of sample size or duration, and possible self-reporting bias
Low	Prasetya et al. (2023); Eticha et al. (2023); Chookaew et al. (2024); Bashith et al. (2025); Alharthi et al. (2026); Setiyawan & Syamsuddin (2026); Zhang et al. (2026)	Pre-experimental designs or designs without a control group; pilot-scale or descriptive studies	Preliminary evidence useful for exploration	Low internal validity; lack of experimental control; less generalizable results

Studies with less rigor and experimental control were grouped as medium quality (32%), even though they used validated instruments and provided descriptive evidence; their robustness is limited by the risk of bias. Low-quality studies (28%) are mainly pre-experimental or exploratory, useful for generating hypotheses, but with low internal validity and limited generalizability, which should be considered in the critical synthesis of systematic reviews (Quispe et al., 2021).

Comparative and critical analysis of the included studies

The comparative analysis (Table 3) reveals a marked methodological divergence that affects the strength of the reported evidence. Robust experimental studies (Lestari et al., 2023; Tokatlidis et al., 2024; Arymbekov et al., 2024) include control groups, adequate sample sizes (n= 61-152), and advanced analyses (ANCOVA, mixed ANOVA) that enhance their internal validity, although 68% of them do not specify the exact duration of the interventions, limiting the dose-response assessment. In contrast, pre-experimental designs (Prasetya et al., 2023; Setiyawan & Syamsuddin, 2026) overestimate effect sizes (d = 3.67 vs. d = 0.85 in the meta-analysis) due to the lack of a control group and randomization, so their results should be interpreted with caution when making pedagogical recommendations.

Virtual reality increases theoretical performance (Aldosari et al., 2022; Anjos et al., 2024), but can drastically decrease practical skills. De Lorenzis et al. (2024) even reported that asymmetric collaboration in VR can impair manipulative skills if technological exposure is insufficient. In contrast, augmented reality shows higher and more homogeneous effects on motivational and critical thinking variables (d = 1.04), outperforming the virtual laboratory in this domain according to Arymbekov et al. (2024).

Studies combining technology with active pedagogies (inquiry: Anugrah et al., 2025; flipped classroom: Alharthi et al., 2026) achieve the greatest combined effect (d = 1.21), considerably greater than the use of technology alone (d ≈ 0.20-0.50). However, three cross-cutting limitations affect all groups: the small sample size (44% with n < 50 in the robust experimental group, and 9 total studies with n < 50) reduces statistical power; the lack of longitudinal follow-up (none exceed one year; only Zhuang et al. (2025) reported 12 months) prevents assessing sustainability; and the heterogeneity in the measurement instruments (ad hoc simulations, unvalidated rubrics, Likert scales) hinders the possibility of comparison and, therefore, meta-analyses. Taken together, these limitations suggest that the true population effect, once threats to internal validity are controlled, would be in the middle range (d = 0.50-0.70), lower than that reported in pre-experimental studies, but still clinically relevant for pedagogical decision-making.

Table 3. Methodological comparison and differentiating findings of the included studies according to their research design.

Cluster	Included studies	Comparative methodological strengths	Common critical weaknesses	Key differentiating findings
Robust experimental designs (with control group, random assignment, or quasi-experimental with sample ≥100)	Tokatlidis et al. (2024); Lestari et al. (2023); Arymbekov et al. (2024); Anugrah et al. (2025); Aldosari et al. (2022); Eticha et al. (2023)	ANCOVA/ANOVA with pretest; sample size n=61-152; direct comparison; Solomon or multifactorial design.	Unspecified duration (4/6); poor long-term retention; specific cultural contexts.	VR improves theoretical knowledge; physical lab > virtual in measurement skills; AR > VR in critical thinking.
Experimental designs with sampling limitations (n<50, with control group or within-subjects)	De Lorenzis et al. (2024); Darejeh et al. (2025); Sáiz-Manzanares et al. (2024); Zhang et al. (2026); Alharthi et al. (2026)	Robust within-subjects design; objective biomarkers; active methodologies.	Very small samples (n=17-46); screening session; low generalizability.	Asymmetric collaboration in VR: improves theory but harms practice; VR reduces mental workload but increases frustration; students prefer VR for security.
Pre-experimental or case designs (one group, pre-post)	Prasetya et al. (2023); Setiyawan & Syamsuddin (2026); Chookaew et al. (2024); Bashith et al. (2025); Díaz et al. (2022)	Preliminary evidence; real-world settings; reduced time (24 to 5 h self-study).	Group control; uncontrolled maturation/history effects; overestimation of effects; sample size n=31-40.	Metaverse is effective at a distance; STEM module has a very large (overestimated) effect; AR increases interest in social sciences.
Survey and correlational studies (without intervention)	Sadam & Al Mamun (2024); Rodríguez-Saavedra et al. (2025); Haj-Hosseini et al. (2024); Sakkas et al. (2025); Bonavolontà et al. (2025)	Large sample sizes (up to n=4900); SEM; acceptance assessment in real-world settings.	Cross-sectional; biased self-report; does not assess objective outcomes. Does not assess learning objective outcomes, only perceptions.	AR predicts ease of adoption (ß= 0.867) and perceived performance (ß= 0.722); self-efficacy influences attitude; digital twins show promise.

Impact of simulations, augmented reality, and virtual laboratories on university learning

The analysis of learning outcomes reveals a favorable trend toward the effectiveness of technological interventions in higher education, particularly in academic performance, where studies report a significant improvement supported by pre-post designs and inferential analyses such as ANOVA. This result supports the argument that performance is a key indicator for evaluating the quality of the educational process, as it reflects students' achievements during their academic training (Cruz et al., 2025).

The results of several studies, which present findings supported by analyses such as ANCOVA and t-tests, show that there is indeed a consistent improvement in the development of higher-order thinking skills (HOTS) in students. This indicates that educational technologies can generate short-term results and can also develop complex cognitive processes related to critical thinking and problem-solving, especially when dealing with situations involving a certain degree of abstraction.

Regarding practical skills, mixed results were observed, which could be partly due to the heterogeneity of the simulation environments and practical assessment criteria. This heterogeneity may hinder the comparison of the results obtained and even highlight the need to standardize practical assessment metrics. Conversely, the improvement in motivation and engagement, as measured by Likert scales and SEM models, confirms that technology can increase student participation.

Although technologies optimize information processing, enabling a reduction, at least partially, in cognitive load, instructional design remains the critical point to consider when trying to avoid this cognitive overload. In this respect, the results of the selected studies report a positive influence that varies depending on the type of outcome analyzed (Figure 3).

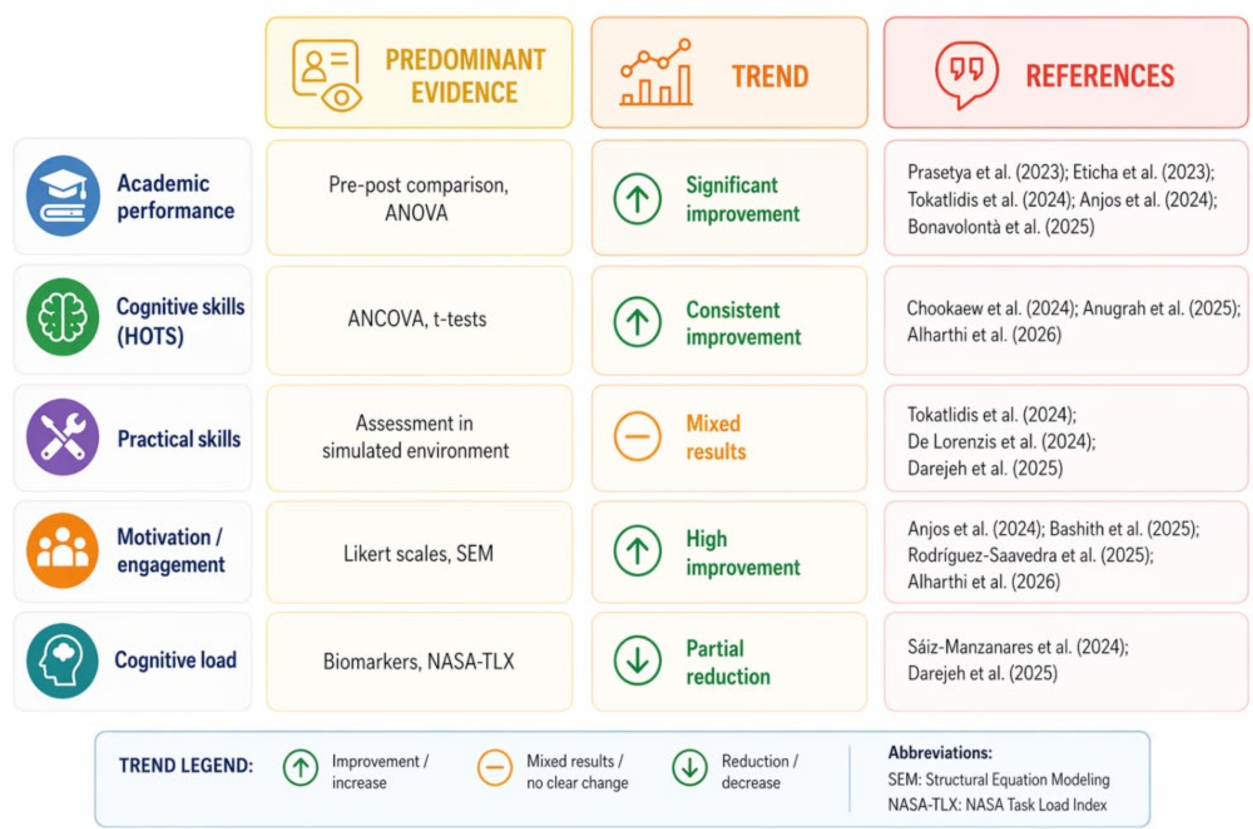

Figure 3. Overview of predominant evidence and trends in AI-enhanced learning outcomes.

Comparison of emerging technologies according to cross-cutting pedagogical axes

The analysis of the pedagogical conditions for effectiveness (Figure 4) reveals that the impact of educational technologies depends not only on their implementation but also on their integration with active pedagogical approaches. In this sense, inquiry-based learning shows a direct contribution to the development of hot-based learning skills (HBLS), which is consistent with its focus on problem-solving and critical thinking.

On the other hand, some of the selected studies suggest that cognitive improvement conditioned by instructional design could be enhanced through collaborative learning using some of these emerging technologies. In other words, they indicate that simple interaction among students alone does not yield positive results. Therefore, well-defined structures are needed to promote meaningful learning, which can be achieved through student interaction with these technologies as didactic tools in the teaching-learning process. In short, the reviewed literature supports that collaborative work can promote active learning, but only when each of the curricular activities is properly organized (González & Yépez, 2026).

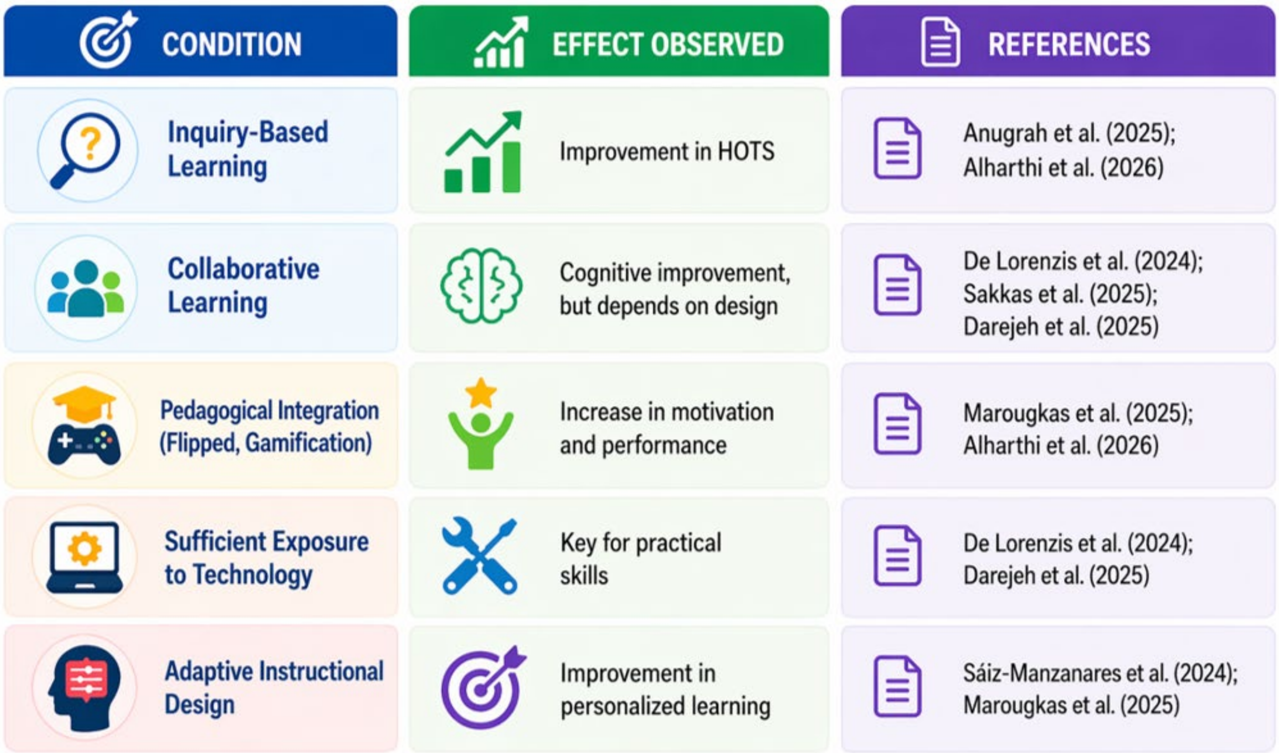

Figure 4. Key conditions and their observed effects in educational technology.

When strategies such as the flipped classroom and gamification are integrated pedagogically with these emerging technologies, a sustained increase in motivation and, consequently, academic performance is observed over time. This confirms the potential of these technologies to energize the teaching-learning process and thus lead to greater student engagement. Sustained exposure to these technologies is important for developing practical skills, as their frequent use consolidates the desired competencies. Furthermore, instructional design must be adapted to foster personalized learning, enabling the integration of technology and pedagogy to achieve educational effectiveness within the teaching-learning process in higher education.

Table 4 indicates that emerging technologies have defined a pedagogical ecosystem of active, immersive, and personalized learning, where collaborative and personalized learning is consolidated as the predominant behavior within these emerging technologies. Virtual reality and virtual laboratories serve as interactive spaces that foster learning by engaging students and even allowing for the adjustment of training processes to meet the needs of each individual. The interactive and immersive nature of emerging technologies facilitates meaningful learning (Llanos-Ruiz et al., 2025; Zekeik et al., 2025), while experiential and situated learning through simulations reduces abstraction and improves contextualization, which is important in applied disciplines for transferring knowledge to real-world scenarios.

Table 4. Thematic coding of pedagogical patterns, benefits, and limitations of emerging technologies in education

Topic / Category	Common patterns	Associated technologies	Studies
Collaborative and personalized learning	Improved interaction, engagement, and learning in immersive environments; adaptation to individual needs	VR, digital twins, virtual labs	De Lorenzis et al. (2024); Sakkas et al. (2025); Alnuaimi & Awad (2025)
Experiential and situated learning	Contextualization of knowledge; simulations that reduce abstraction	VR, virtual labs, metaverse	Prasetya et al. (2023); Chookaew et al. (2024); Zhuang et al. (2025)
Motivation and participation	Increased motivation, interest, and satisfaction; preference for safe and immersive environments	AR, VR, flipped classroom	Bashith et al. (2025); Rodriguez-Saavedra et al. (2025); Alharthi et al. (2026)
Development of cognitive skills	Improved critical thinking, problem-solving, and higher-order thinking skills	Laboratorios virtuales, RV, gemelos digitales	Tokatlidis et al. (2024); Anugrah et al. (2025); Marougkas et al. (2025)
Efficiency and access to laboratories	Reduced face-to-face time, effective distance learning, and access to resources that are difficult to replicate	Virtual labs, metaverse	Prasetya et al. (2023); Bonavolontà et al. (2025)
Technological and pedagogical limitations	Small sample size, limited exposure, need for tool training, infrastructure, and costs	All	De Lorenzis et al. (2024); Haj-Hosseini et al. (2024); Zhuang et al. (2025)
Methodological integration	Combining AR, VR, or digital twins with PBL, gamification, or flipped classroom enhances results	VR + gamification, AR + flipped classroom, virtual lab + inquiry	Marougkas et al. (2025); Anugrah et al. (2025); Alharthi et al. (2026)

Regarding motivation and participation, a sustained increase is observed, which can be associated with the use of immersive environments and active learning strategies, reinforcing students' preference for interactive experiences. Similarly, the development of HOTS confirms the potential of these technologies to promote critical thinking and complex problem-solving.

However, some methodological and technological limitations still exist (very small sample sizes, required training, high implementation costs, etc.) that restrict the generalizability of the results. Methodological integration (combining technologies with the PBL approach or gamification) is the determining factor for increasing educational effectiveness, demonstrating that it is not so much the technology itself, but rather its proper pedagogical integration.

Meta-analysis on the impact of emerging technologies on learning

For the meta-analysis, 25 articles were included, encompassing approximately 6,900 participants. Of these, 72% showed significant improvement in academic performance, conceptual understanding, and practical skills after using immersive technologies and virtual labs. The average effect size, weighted by Cohen's d, was 0.85 (95% CI: 0.62-1.08), which can be considered a large effect size, but exhibited high heterogeneity (I2 = 74%), which could be attributed to differences in duration, type of technology, and measured variables. Individual effect sizes ranged from a moderate effect size of d = 0.42 to a very large effect size of d = 3.67 in pre-experimental studies. The effect sizes according to technology type and outcome variable (Table 5) provide a comprehensive view of the differences between each category.

Table 5. Aggregate effect sizes from the meta-analysis by technology type and outcome variable

Technology type	Outcome variable	Number of studies	Average effect size (Cohen's d)	CI 95%	Heterogeneity (I^2)
Virtual reality (VR)	Theoretical performance	6	0,92	0,68 - 1,16	68%
Virtual reality (VR)	Practical skills	4	0,41	0,19 - 0,63	52%
Augmented reality (AR)	Performance + motivation	4	1,04	0,71 - 1,37	71%
Digital twin / Metaverse	Usability + collaboration	3	0,88	0,54 - 1,22	58%
Virtual lab	Higher-order thinking	3	0,76	0,48 - 1,04	44%
Technology + active pedagogy	Mixed results	5	1,21	0,85 - 1,57	65%
General topics	All	25	0,85	0,62 - 1,08	74%

Note. 95% CI: 95% confidence interval. Heterogeneity was calculated using the I^2 statistic. The sample size of each study weighted the effect sizes.

When direct comparisons are made between the technologies, VR has a significant effect on theoretical performance (d = 0.92). However, this effect may be limited in terms of practical skills (d = 0.41), where, for example, the physical laboratory proves superior. AR has greater effects on motivation and critical thinking (d = 1.04). When these technologies are integrated with active learning pedagogies, the greatest overall effect is achieved, with a value of d = 1.21. Finally, collaborative approaches and digital twins show promise in terms of use and satisfaction.

Of the methodological limitations shown in the studies that formed the basis of this review, the main ones limit the confidence that can be placed in the results obtained. Among the most frequent shortcomings, we mention: the lack of specification of the exact duration of the intervention (eight studies), the sample size being too small (nine studies), the lack of a control group (five studies), and the pre-experimental design without random assignment of participants (four of the analyzed studies). The evidence supports the idea that immersive technologies and virtual laboratories are effective complements to, but do not replace, traditional methodologies in science and technology education.

Table 6 shows high variability in effect sizes (d = 0.20-3.67) attributable to the design: pre-experimental studies overestimate them, while experimental and within-subjects studies report moderate effects (d ≈ 0.20-0.50). Furthermore, the magnitude of the effect depends critically on the variable measured: theoretical knowledge shows large effects, while practical skills show only small or medium effects.

Table 6. Individual effect sizes from selected studies (descending order)

Study (year)	Technology	Sample	Design	Main variable	Effect size	Interpretation
Setiyawan & Syamsuddin (2026)	Digital STEM module	35	Pre-post (1 group)	Knowledge of ABS	d = 3,67	Very large
Rodriguez-Saavedra et al. (2025)	Augmented reality	4900	Explanatory (SEM)	Perceived performance	β = 0,722	Large
Lestari et al. (2023)	Virtual lab + demonstration	102	Quasi-experimental	Scientific literacy	d ≈ 1,20	Large
Anugrah et al. (2025)	INREACTIV (Inquiry + virtual reality)	138	Quasi-experimental	Higher-order thinking	d ≈ 0,70	Medium-large
Anjos et al. (2024)	Virtual reality	N/E	Experimental	Academic performance	d ≈ 0,78	Medium-large
Tokatlidis et al. (2024)	Virtual lab	152	Experimental	Measurement skills	d ≈ 0,50	Medium
Arymbekov et al. (2024)	Mobile AR *vs.* virtual lab	120	Experimental (Solomon)	Critical thinking	p < 0,05 (RA > VL)	Medium
Darejeh et al. (2025)	Virtual reality	17	Within-subjects	Procedural accuracy	d ≈ 0,20	Small
Prasetya et al. (2023)	Metaverse (CNC)	31	Pre-post (1 group)	Cognitive skills	N-Gain = 0,642	Medium

Note. VL: virtual laboratory; AR: augmented reality; CNC: computer numerical control; SEM: structural equation modeling; N-Gain: normalized gain; N/E: not specified. The d values were calculated from the F and t statistics and percentage improvements. The β coefficient is a standardized regression coefficient, equivalent to d for large effects.

In general, it was observed that integrating technologies with active learning pedagogies produces greater effects (d ≈ 0.70-1.20) than when they are used in isolation (d ≈ 0.20). This is why students' experience using AR can surpass that of virtual labs in terms of developing critical thinking. However, this analysis should be approached with certain reservations that consider the entire teaching and learning process in which students are immersed. Furthermore, when internal validity is controlled for, the population effect would be moderate (d = 0.50-0.70). In other words, teachers should prioritize teaching strategies that enhance interventions integrating or combining emerging technologies with active learning pedagogies, seeking, above all, to foster the development of students' practical skills.

Research gaps and future opportunities

A comprehensive analysis reveals significant gaps in the methodological rigor of the available evidence. While experimental or quasi-experimental designs predominate, limitations persist related to small sample sizes, the lack of longitudinal follow-up, and insufficient standardization of dependent variables, all of which affect the external validity of the results. Several studies show improvements in performance or motivation, but they do not determine the duration or sustainability of the effect (Anjos et al., 2024; Sáiz-Manzanares et al., 2024; Bonavolontà et al., 2025).

Furthermore, heterogeneity in the measurement of practical skills and HOTS (ANOVA, Student's t-test, Likert scale, simulations) hinders comparisons between studies and robust meta-analyses. This heterogeneity is particularly evident in studies on simulations and virtual laboratories, whose results are often mixed (De Lorenzis et al., 2024; Tokatlidis et al., 2024; Darejeh et al., 2025).

At the same time, gaps are identified in the systematic pedagogical integration of emerging technologies. Research integrating VR, AR, or digital twins with structures such as gamification or inquiry-based learning is still in its early stages and lacks established theoretical frameworks that would allow for its practical implementation (Marougkas et al., 2025; Anugrah et al., 2025; Alharthi et al., 2026). Therefore, it is understood that work must be done toward the future development of integrative techno-pedagogical models that encompass technology, didactics, and assessment.

Finally, future opportunities are identified related to the scalability, accessibility, and longitudinal evaluation of these technologies. It would be necessary to develop multicenter studies with large samples and longitudinal designs to assess the sustainable impact of research in each educational context. At the same time, the inclusion of learning analytics and adaptive learning approaches represents a promising future direction for personalizing teaching and optimizing learning outcomes (Zhuang et al., 2025; Rodriguez-Saavedra et al., 2025). These lines of research will consolidate a still-emerging field with high transformative potential.

Emerging technologies have potential for university learning, but their effectiveness is heterogeneous and depends on instructional design, context, and the variables evaluated (Mena-Guacas et al., 2025). For example, virtual reality improves theoretical performance but has a limited impact on practical skills (Tokatlidis et al., 2024; Darejeh et al., 2025). In contrast, augmented reality (AR) stands out for enhancing motivation, engagement, and critical thinking, an advantage attributed to its ability to overlay information onto the real world without isolating the student (Arymbekov et al., 2024; Rodriguez-Saavedra et al., 2025). However, these results should be interpreted with caution due to the small sample sizes and short durations characteristic of many studies (Haj-Hosseini et al., 2024; Zhuang et al., 2025).

The effectiveness of these emerging technologies in university learning depends on pedagogical conditions, which are crucial for enhancing outcomes rather than their isolated use (Feng et al., 2025). However, certain widespread methodological limitations (small sample sizes, lack of control and randomization, and no follow-up) prevent robust conclusions from being drawn on a large scale (Viswanathan et al., 2012; Quispe et al., 2021). In several cases, the observed disconnect between the application of these technologies and analytical integration (Zhuang et al., 2025) suggests that university management should prioritize teacher training and an integrated techno-pedagogical design (Rodriguez-Saavedra et al., 2025). Progress in performance and motivation is acknowledged, but limitations in practical skills, heterogeneity, and methodological weaknesses are noted, requiring multicenter, longitudinal research and integrative models (Crogman et al., 2025; Kazlaris et al., 2025).

CONCLUSIONS

Emerging technologies, including simulations, augmented reality, and virtual laboratories, have high potential to improve university learning, both conceptually, procedurally, and motivationally. Research shows significant improvements in academic performance, the development of higher-order cognitive skills, and student motivation, as well as advances in the acquisition of practical and spatial skills. However, the functionality and effectiveness of these tools will depend very directly on instructional design, pedagogical integration, and students' exposure to the technology. Identified methodological limitations, such as small sample sizes, the lack of control groups, the impossibility of long-term evaluation, and limited characteristics of the objects of study (disciplinary units), highlight the need for more robust and generalizable comparative studies.

From a pedagogical perspective, the importance of implementing active strategies such as inquiry-based learning, structured collaboration, or the combination of adaptive and gamified methodologies is emphasized, as these would promote participation, personalized learning, and critical thinking. The combination of features from immersive environments and those of exact representations of real-world systems, such as digital twins, will generate an experience that maximizes security, feedback, and knowledge transfer, establishing a foundation for educational planning in the universities of the future. Therefore, a systemic approach is advocated, integrating technology, pedagogy, and rigorous evaluation to maximize the benefits of these tools in higher education.

REFERENCES

Acosta, D., Rodríguez, W. A., Peñaherrera, M. F., García, S., & La O, Y. (2021). Metodología de la investigación en la educación superior. Revista Universidad y Sociedad, 13(4), 283-293. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2218-36202021000400283&lng=es&tlng=es

Aldosari, S. S., Ghita, B., & Marocco, D. (2022). A gesture-based educational system that integrates simulation and molecular visualization to teach chemistry. International Journal of Emerging Technologies in Learning, 17(4), 194-211. https://doi.org/10.3991/ijet.v17i04.26503

Alharthi, M. A. (2026). The Synergy of Augmented Reality with the Flipped Classroom Structure and Its Impact on Learning Engagement Among Higher Education Students. International Journal of Technology in Education, 9(2), 326-342. https://doi.org/10.46328/ijte.7001

Alnuaimi, M. A., & Awad, M. (2025). VR environment of digital design laboratory: A usability study. Frontiers in Virtual Reality, 6, Article 1566680. https://doi.org/10.3389/frvir.2025.1566680

Anjos, F. E. V. D., Martins, A. D. O., Rodrigues, G. S., Sellitto, M. A., & Silva, D. O. D. (2024). Boosting engineering education with virtual reality: An experiment to enhance student knowledge retention. Applied System Innovation, 7(3), Article 50. https://doi.org/10.3390/asi7030050

Anugrah, S., Jalinus, N., Syahril, S., Supendra, D., Austin, D. A., & Putra, A. H. (2025). Enhancing high-order thinking skills in computer courses through the implementation of the inquiry learning and virtual laboratory in higher education. TEM Journal, 14(2), 1466-1477. https://doi.org/10.18421/TEM142-47

Arymbekov, B., Turekhanova, K., & Turdalyuly, M. (2024). The effect of augmented reality (AR) supported teaching activities on academic success and motivation to learn nuclear physics among high school pupils. International Journal of Information and Education Technology, 14(5), 743-760. https://doi.org/10.18178/ijiet.2024.14.5.2099

Bashith, A., Amin, S., Aliman, M., Kurniawan, M. A., Jubba, H., & Maulidiah, L. (2025). Utilizing a virtual laboratory based on mobile learning: Implementation for social science education students in Indonesia to improve learning outcomes. Educational Process: International Journal, 15, Article e2025181. https://doi.org/10.22521/edupij.2025.15.181

Bitar, N., & Davidovich, N. (2024). Transforming Pedagogy: The Digital Revolution in Higher Education. Education Sciences, 14(8), 811. https://doi.org/10.3390/educsci14080811

Bonavolontà, F., Monaco, A., Caputo, E., & Liccardo, A. (2025). IM-MetaLAB: The first digital laboratory for teaching the fundamental concepts of instrumentation and measurement in metaverse. Scientific Reports, 15(1), Article 45401. https://doi.org/10.1038/s41598-025-29553-7

Cevallos, M., & Egger, M. (2014). STROBE (Strengthening the Reporting of Observational Studies in Epidemiology). In D. Moher, D. G. Altman, K. F. Schulz, I. Simera & E. Wager (Eds.), Guidelines for reporting health research: A user's manual (cap. 17). John Wiley & Sons. https://doi.org/10.1002/9781118715598.ch17

Chookaew, S., Kitcharoen, P., Howimanporn, S., & Panjaburee, P. (2024). Fostering student competencies and perceptions through artificial intelligence of things educational platform. Computers and Education: Artificial Intelligence, 7, Article 100308. https://doi.org/10.1016/j.caeai.2024.100308

Critical Appraisal Skills Programme UK. (2024). CASP qualitative studies checklist. https://casp-uk.net/casp-tools-checklists/qualitative-studies-checklist/

Crogman, H. T., Cano, V. D., Pacheco, E., Sonawane, R. B., & Boroon, R. (2025). Virtual Reality, Augmented Reality, and Mixed Reality in Experiential Learning: Transforming Educational Paradigms. Education Sciences, 15(3), 303. https://doi.org/10.3390/educsci15030303

Cruz, C., Berlanga, K., Hernández, S., & Martínez, J. I. (2025). Rendimiento académico en la educación superior: una revisión sistemática. Revista San Gregorio, 1(Especial_2), 142-153. https://doi.org/10.36097/rsan.v1iEspecial_2.2895

Darejeh, A., Chilcott, G., Oromiehie, E., & Mashayekh, S. (2025). Virtual reality and digital twins for mechanical engineering lab education: Applications in composite manufacturing. Education Sciences, 15(11), Article 1519. https://doi.org/10.3390/educsci15111519

De Cassai, A., Dost, B., Tulgar, S., & Boscolo, A. (2025). Methodological standards for conducting high-quality systematic reviews. Biology, 14(8), 973. https://doi.org/10.3390/biology14080973

De Lorenzis, F., Visconti, A., Restivo, S., Mazzini, F., Esposito, S., Garofalo, S. F., Marmo, L., Fino, D., & Lamberti, F. (2024). Combining virtual reality with asymmetric collaborative learning: A case study in chemistry education. Smart Learning Environments, 11(1), Article 43. https://doi.org/10.1186/s40561-024-00331-8

Díaz, M. J., Mantell, C., Caro, I., de Ory, I., Sánchez, J., & Portela, J. R. (2022). Creation of immersive resources based on virtual reality for dissemination and teaching in chemical engineering. Education Sciences, 12(8), Article 572. https://doi.org/10.3390/educsci12080572

Eticha, A. T., Amde, M., Bogale, Y., & Bekana, D. (2023). The effect of context-based close packing supported with the 3D-virtual model of crystals structure on students' achievement and attitude. Chemistry Teacher International, 5(3), 311-323. https://doi.org/10.1515/CTI-2022-0047

Feng, J., Yu, B., Tan, W. H., Dai, Z., & Li, Z. (2025). Key factors influencing educational technology adoption in higher education: A systematic review. PLOS Digital Health, 4(4), e0000764. https://doi.org/10.1371/journal.pdig.0000764

González, A. F., & Yépez, F. E. (2026). Aplicación del trabajo colaborativo y su relación con el rendimiento académico universitario: Aplicación del trabajo colaborativo y su relación con el rendimiento académico universitario. Holopraxis. Revista de Ciencia, Tecnología e Innovación, 10(1), 22-37. https://doi.org/10.61154/holopraxis.v10i1.4391

Haj-Hosseini, N., Jonasson, H., Stridsman, M., & Carlsson, L. (2024). Interactive remote electrical safety laboratory module in biomedical engineering education. Education and Information Technologies, 29(15), 20505-20521. https://doi.org/10.1007/s10639-024-12636-9

Hamash, M., Tiernan, P., & Young, G. (2025). Virtual reality in post-primary education research trends from 2013 to 2024: A systematic-narrative review. Computers & Education: X Reality, 7, 100123. https://doi.org/10.1016/j.cexr.2025.100123

Kazlaris, G. C., Keramopoulos, E., Bratsas, C., & Kokkonis, G. (2025). Augmented Reality in Education Through Collaborative Learning: A Systematic Literature Review. Multimodal Technologies and Interaction, 9(9), 94. https://doi.org/10.3390/mti9090094

Lestari, D. P., Supahar, Paidi, Suwarjo, & Herianto. (2023). Effect of science virtual laboratory combination with demonstration methods on lower-secondary school students' scientific literacy ability in a science course. Education and Information Technologies, 28(12), 16153-16175. https://doi.org/10.1007/s10639-023-11857-8

Llanos-Ruiz, D., Abella-García, V., & Ausín-Villaverde, V. (2025). Virtual Reality in Higher Education: A Systematic Review Aligned with the Sustainable Development Goals. Societies, 15(9), 251. https://doi.org/10.3390/soc15090251

Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2025). An adaptive virtual reality game for programming education using fuzzy cognitive maps and pedagogical models. Smart Learning Environments, 12(1), Article 62. https://doi.org/10.1186/s40561-025-00392-3

Mena-Guacas, A. F., López-Catalán, L., Bernal-Bravo, C., & Ballesteros-Regaña, C. (2025). Educational Transformation Through Emerging Technologies: Critical Review of Scientific Impact on Learning. Education Sciences, 15(3), 368. https://doi.org/10.3390/educsci15030368

Mercan, G., & Varol, Z. (2024). The Role of Metaverse Technology in Education: A Systematic Review of Opportunities, Challenges, and Educational Potential. Sakarya University Journal of Education, 14(2), 360-375. https://doi.org/10.19126/suje.1376341

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372(71). https://doi.org/10.1136/bmj.n71

Prasetya, F., Fortuna, A., Samala, A. D., Fajri, B. R., Efendi, F., & Nyamapfene, A. (2023). Effectiveness of distance learning computer numerical control based on virtual laboratory using a metaverse platform to improve students' cognitive ability and practice skills. International Journal of Interactive Mobile Technologies, 17(24), 4-21. https://doi.org/10.3991/IJIM.V17I24.45019

Quispe, A. M., Hinojosa-Ticona, Y., Miranda, H. A., & Sedano, C. A. (2021). Serie de Redacción Científica: Revisiones Sistemáticas. Revista del Cuerpo Médico Hospital Nacional Almanzor Aguinaga Asenjo, 14(1), 94-99. https://doi.org/10.35434/rcmhnaaa.2021.141.906

Rodriguez-Saavedra, M. O., Barrera, L. G., Cuentas, I., Campos, L. M., Morales, A. V., Mamani, J. W., & Arguedas-Catasi, R. W. (2025). Augmented reality as an educational tool: Transforming teaching in the digital age. Information, 16(5), Article 372. https://doi.org/10.3390/info16050372

Sadam, N. Y. S., & Al Mamun, M. A. (2024). Polytechnic students' perceived satisfaction of using technology in the learning process: The context of Bangladesh TVET. Heliyon, 10(16), Article e35977. https://doi.org/10.1016/j.heliyon.2024.e35977

Sáiz-Manzanares, M. C., Marticorena-Sánchez, R., Escolar-Llamazares, M. C., González-Díez, I., & Martín-Antón, L. J. (2024). Using integrated multimodal technology: A way to personalise learning in health science and biomedical engineering students. Applied Sciences, 14(16), Article 7017. https://doi.org/10.3390/app14167017

Sakkas, K., Ntagka, N. E., Spyridakis, M., Miltiadous, A., Glavas, E., Tzallas, A. T., & Giannakeas, N. (2025). Multiplayer virtual labs for electronic circuit design: A digital twin-based learning approach. Electronics, 14(16), Article 3163. https://doi.org/10.3390/electronics14163163

Setiyawan, A., & Syamsuddin, M. (2026). Developing and evaluating anti-lock braking systems (ABS) through a STEM-based digital learning module for vocational automotive education. International Journal of Mechanical Engineering Education. https://doi.org/10.1177/03064190261420832

STROBE Initiative. (2021). STROBE statement: Strengthening the reporting of observational studies in epidemiology. https://www.strobe-statement.org

Tokatlidis, C., Tselegkaridis, S., Rapti, S., Sapounidis, T., & Papakostas, D. (2024). Hands-on and virtual laboratories in electronic circuits learning—Knowledge and skills acquisition. Information, 15(11), Article 672. https://doi.org/10.3390/info15110672

Viswanathan, M., Ansari, M. T., Berkman, N. D., Chang, S., Hartling, L., McPheeters, M., Santaguida, L., Shamliyan, T., Singh, K., Tsertsvadze, A., & Treadwell, J. R. (2012, March 8). Assessing the risk of bias of individual studies in systematic reviews of health care interventions. In Methods guide for effectiveness and comparative effectiveness reviews. Agency for Healthcare Research and Quality (US). https://www.ncbi.nlm.nih.gov/books/NBK91433/

Zekeik, H., Chahbi, M., Lamarti Sefian, M., & Bakkali, I. (2025). Augmented reality and virtual reality in education: A systematic narrative review on benefits, challenges, and applications. Eurasia Journal of Mathematics, Science and Technology Education, 21(9), em2699. https://doi.org/10.29333/ejmste/16830

Zhang, J., Zhu, J., Tu, W., Wang, M., Yang, Y., Qian, F., & Xu, Y. (2024). The effectiveness of a digital twin learning system in assisting engineering education courses: A case of landscape architecture. Applied Sciences, 14(15), Article 6484. https://doi.org/10.3390/app14156484

Zhuang, T., Xu, X., & Zhang, Y. (2025). Contextualizing and visualizing abstract theoretical knowledge for situated learning: large-scale VR-supported higher education in China. Virtual Reality, 29(1), Article 4. https://doi.org/10.1007/s10055-024-01075-z

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The authors declare no conflicts of interest.

Author Contributions:

The authors were responsible for all aspects of the study, including conceptualization, methodology, analysis, and writing.