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Integrating augmented reality, virtual reality, and artificial intelligence into game-based learning: A systematic review

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Abstract
The integration of game-based learning with emerging technologies such as Augmented Reality, Virtual Reality, and Artificial Intelligence has gained considerable attention in educational research due to its potential to create engaging, interactive, and personalized learning environments. This study aimed to systematically review recent research on the integration of Augmented Reality, Virtual Reality, and Artificial Intelligence technologies into game-based learning contexts. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, a systematic search was conducted in the Web of Science database. After applying predefined inclusion and exclusion criteria, 39 peer-reviewed studies published between 2021 and 2025 were selected for analysis. The collected data were examined using thematic analysis. The findings revealed a substantial increase in studies investigating Augmented Reality-, Virtual Reality-, and AI-supported game-based learning, particularly after 2022. The majority of studies were conducted in Taiwan, China, and the United States and mainly focused on undergraduate and secondary school students. The results demonstrated that integrating Augmented Reality, Virtual Reality, and Artificial Intelligence technologies into game-based learning environments positively influenced cognitive, behavioral, and affective learning outcomes. Specifically, these technologies enhanced student motivation, engagement, metacognitive awareness, self-efficacy, academic achievement, and problem-solving skills while providing immersive and personalized learning experiences. The review also identified various educational games, digital content development tools, and implementation strategies that contribute to effective learning processes. The findings suggest that Augmented Reality, Virtual Reality, and Artificial Intelligence technologies can significantly enrich game-based learning environments by supporting active participation, individualized learning, and meaningful knowledge construction. The study provides implications for educators, instructional designers, and policymakers seeking to integrate emerging technologies into educational practice and offers recommendations for future research on technology-enhanced game-based learning.

Keywords: Artificial intelligence; Augmented reality; Game-based learning; Virtual reality

1. Introduction

Education is a foundational element in the advancement of societies, and the integration of technology has significantly enhanced the efficiency, accessibility, and quality of educational processes (Ottenbreit-Leftwich et al., 2018; Xie et al., 2023). In recent years, technological advancements have transformed traditional teaching models into more interactive and student-centered approaches (McKnight et al., 2016; Wijnen et al., 2023). Loveless (2011) emphasized that digital transformation in education has gone beyond conventional methods by offering learners more personalized and participatory experiences.

The incorporation of emerging technologies into educational contexts has triggered substantial changes in instructional strategies and learning environments (Aygün & Çelik, 2024; Edwards, 2016; Tinkler et al., 2023). One of the most notable shifts in 21st-century education is the increased reliance on digital tools to support and enhance learning. In this regard, technologies such as augmented reality [AR], virtual reality [VR], and artificial intelligence [AI] have emerged as innovative solutions that foster student engagement, deepen conceptual understanding, and improve learning efficiency (Ko & Shin, 2023; Maas & Hughes, 2020). According to Herro et al. (2021), these tools can help students visualize abstract ideas, design dynamic learning scenarios, and make learning more immersive.

AR enhances learning by blending physical environments with digital information, thus enabling learners to experience content through enriched visual and auditory stimuli (Abdusselam & Karal, 2020; Huang & Musah, 2024; Rizki et al., 2024; Yusuf, 2025). This fusion facilitates deeper understanding of abstract concepts (Sökmen et al., 2024). VR, on the other hand, allows learners to actively explore and interact within simulated environments, personalizing the experience and making it more engaging (Maher & Buchanan, 2021; Wu et al., 2023). Meanwhile, AI systems support individualized instruction by analyzing learner data and providing adaptive content suited to students' learning styles and pace (Veletsianos et al., 2024; Walter, 2024). As noted by Işık and Köse (2024), these technologies redefine conventional educational boundaries and promote more interactive and meaningful learning experiences.

Game-based learning is another instructional approach that effectively integrates engagement and enjoyment into the educational process. By fostering motivation and active participation, educational games provide a dynamic and interactive learning experience (Chen & Lin, 2016; Holbrey, 2020). Through mechanisms such as rewards and challenges, students remain cognitively engaged while reinforcing knowledge acquisition (Emihovich, 2024; Fiş-Erümit & Karakuş-Yılmaz, 2022). According to Liu et al. (2020), this approach also cultivates essential skills such as problem-solving, teamwork, and critical thinking. In addition to academic success, game-based learning promotes creativity, imagination, and collaborative skills (Kangas, 2010).

Digital games are increasingly being used in educational contexts as tools to enhance learning outcomes and student engagement (Hayak & Avidov-Ungar, 2023). These games offer students opportunities to apply their knowledge in practical contexts, making learning more meaningful and connected to real life (Anastasiadis et al., 2018; Yang & Chen, 2024). Mayer (2019) emphasizes that the combination of game-based methods with digital technologies results in more effective and efficient learning environments. When supported by immersive technologies like AR, VR, and AI, these environments provide rich, multi-dimensional experiences that help students visualize abstract ideas and gain new perspectives (Dyulicheva & Glazieva, 2022). Wagan et al. (2023) also highlight the role of such technologies in boosting student motivation and engagement.

Recent literature increasingly focuses on the integration of game-based learning with AR, VR, and AI technologies in education (Şen & Şahin, 2024). Each of these technologies contributes uniquely to pedagogical practices and has the potential to transform educational processes into more interactive and effective experiences. For instance, AR-based games have been applied in various disciplines—including language learning, science, mathematics, and visual arts—to enhance student engagement, motivation, and retention (Cai et al., 2019; Huang et al., 2021; Hwang et al., 2016; Khalid & Pozi, 2019; Lee, 2022; Pellas et al., 2019; Remolar et al., 2021; Wang, 2020; Wedyan et al., 2022; Yu, Denham et al., 2022). Similarly, VR applications provide immersive experiences that help concretize abstract concepts and offer hands-on learning opportunities (Hasenbein et al., 2022; Huang et al., 2019; Liu et al., 2022; McGovern et al., 2020; Shi et al., 2022; Yıldırım et al., 2020). AI-based educational systems have also demonstrated promise in tracking student progress and providing personalized learning pathways to improve educational effectiveness (Alam et al., 2022; Byun & Kim, 2022; Devi et al., 2022; Fahimirad & Kotamjani, 2018; Hu et al., 2022; Kavitha & Joshith, 2024; Opesemowo & Ndlovu, 2024; Popenici & Kerr, 2017; Yang et al., 2023).

From a theoretical perspective, the integration of augmented reality, virtual reality, artificial intelligence, and game-based learning can be understood through Constructivist Learning Theory and Experiential Learning Theory. Constructivism suggests that learners actively construct knowledge through interaction with their environment rather than passively receiving information (Piaget, 1972; Vygotsky, 1978). Likewise, Experiential Learning Theory emphasizes that meaningful learning occurs through active experience, reflection, and engagement (Kolb, 1984). AR and VR technologies provide immersive and interactive environments that enable learners to explore concepts in authentic contexts, while AI technologies facilitate personalized learning through adaptive feedback and individualized instructional support. When combined with game-based learning principles, these technologies create learner-centered environments that promote active participation, exploration, problem-solving, and knowledge construction.

Although previous systematic reviews have separately examined AR (Laine, 2018; Lampropoulos et al., 2022; Pellas et al., 2019), VR (Lampropoulos & Kinshuk, 2024; Oyelere et al., 2020), AI (Rizvi et al., 2023; Zhan et al., 2024), and game-based learning in educational settings, limited attention has been paid to the combined integration of these technologies within game-based learning environments. Existing reviews generally focus on a single technology, a particular educational level, or specific learning outcomes. Consequently, there remains a lack of comprehensive evidence regarding how AR, VR, and AI collectively contribute to game-based learning processes, educational outcomes, and learner experiences. Furthermore, recent developments in generative AI, immersive virtual environments, and adaptive learning systems have considerably expanded the educational applications of these technologies, highlighting the need for an updated and comprehensive synthesis of the current literature.

Given these gaps and the rapidly evolving nature of emerging educational technologies, a comprehensive synthesis of recent evidence is needed. Accordingly, this study aims to provide a systematic review of research investigating the integration of AR, VR, and AI technologies into game-based learning environments. By examining research characteristics, educational games, digital content development tools, learning contents, learning outcomes, educational benefits, and future research recommendations, this review seeks to provide a holistic understanding of how emerging technologies are transforming game-based learning and supporting educational innovation. Specifically, the review focused on the following dimensions:

- Research Characteristics of AR-, VR-, and AI-Supported Game-Based Learning Studies
- Educational Games and Digital Content Development Tools Used in AR-, VR-, and AI-Supported Game-Based Learning
- Learning Contents and Learning Outcomes in AR-, VR-, and AI-Supported Game-Based Learning
- Educational Benefits of Integrating AR, VR, and AI into Game-Based Learning Environments
- Recommendations for Future Research

2. Method

2.1. Research Design

This study employed a systematic review design to synthesize and evaluate current research on the integration of augmented reality, virtual reality, and artificial intelligence technologies into game-based learning environments. The review process was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses [PRISMA] guidelines (Page et al., 2021), which provide a rigorous and transparent framework for identifying, screening, selecting, and synthesizing relevant studies. Through a systematic review approach, the study aimed to provide a comprehensive understanding of recent trends, educational applications, learning outcomes, and research directions concerning AR-, VR-, and AI-supported game-based learning.

2.2. Eligibility Criteria

To ensure the quality, relevance, and consistency of the reviewed studies, predefined inclusion and exclusion criteria were established before the literature search process. Studies were included if they focused on the educational outcomes of AR, VR, or AI-supported game-based learning environments. Additional inclusion criteria required studies to be written in English, provide full-text access, be published as journal articles, be indexed in SSCI or SCI-Expanded, belong to the Education Educational Research category, and be published between 2021 and 2025.

Studies that did not satisfy these criteria were excluded from the review. This included systematic reviews and studies unrelated to the application of AR, VR, or AI technologies in game-based learning environments. The detailed inclusion and exclusion criteria are presented in Table 1.

Table 1
Inclusion and exclusion criteria

Inclusion Criteria [IC]	*Exclusion Criteria* [EC]
IC1: Studies focusing on the educational outcomes of AR, VR, or AI technologies in game-based learning environments **IC2:** Studies published in English **IC3**: Full-text access available **IC4:** Journal articles only **IC5:** Articles indexed in SSCI or SCI-Expanded **IC6:** Studies classified under the Education and Educational Research category **IC7:** Studies published between 2021 and 2025	**EC1:** Studies not published in English **EC2:** Studies without full-text access **EC3:** Systematic review studies **EC4:** Studies not focusing on the educational outcomes of AR, VR, or AI technologies in game-based learning environments

As presented in Table 1, a set of predefined inclusion and exclusion criteria was established to ensure the quality, relevance, and methodological consistency of the reviewed studies. These criteria enabled the selection of studies that specifically focused on the educational outcomes of AR-, VR-, and AI-supported game-based learning environments while excluding studies that did not meet the scope or quality requirements of the review. The application of these criteria contributed to the rigor and reliability of the study selection process.

2.3. Information Sources and Search Strategy

The literature search was conducted in the Web of Science [WoS] database on February 5, 2025. Web of Science was selected because it is one of the most comprehensive and widely recognized databases for high-quality peer-reviewed educational research. The search strategy was designed to identify studies examining the integration of AR, VR, and AI technologies into game-based learning contexts.

The following search string was employed:

> ("game" OR "gami") AND ("augmented reality" OR "virtual reality" OR "artificial intelligence" OR "AR" OR "VR" OR "AI" OR "ChatGPT" OR "chatbot") AND (student*) NOT ("systematic review")

The search terms were developed based on the main concepts of the study and adapted to the indexing structure of the Web of Science database. The initial search yielded 2,308 records. To improve the relevance of the search results, the keyword "student*" was searched within the topic field, whereas the remaining keywords were restricted to article titles.

2.4. Study Selection

The study selection process followed the PRISMA framework and consisted of identification, screening, eligibility assessment, and inclusion stages. After applying publication year, language, document type, indexing, and research category filters, 48 studies remained for full-text examination. Subsequently, all studies were independently reviewed by the researchers according to the predefined eligibility criteria. Studies that did not directly investigate the integration of AR, VR, or AI technologies within game-based learning environments were excluded from further analysis. As a result of the screening process, 39 studies met all inclusion criteria and were included in the final review. The complete study selection process is illustrated in Figure 1.

Figure 1 presents the PRISMA flow diagram illustrating the identification, screening, eligibility assessment, and inclusion stages of the study selection process. Following the application of the predefined inclusion and exclusion criteria and full-text screening procedures, 39 studies met all eligibility requirements and were included in the final review.

Figure1
PRISMA diagram

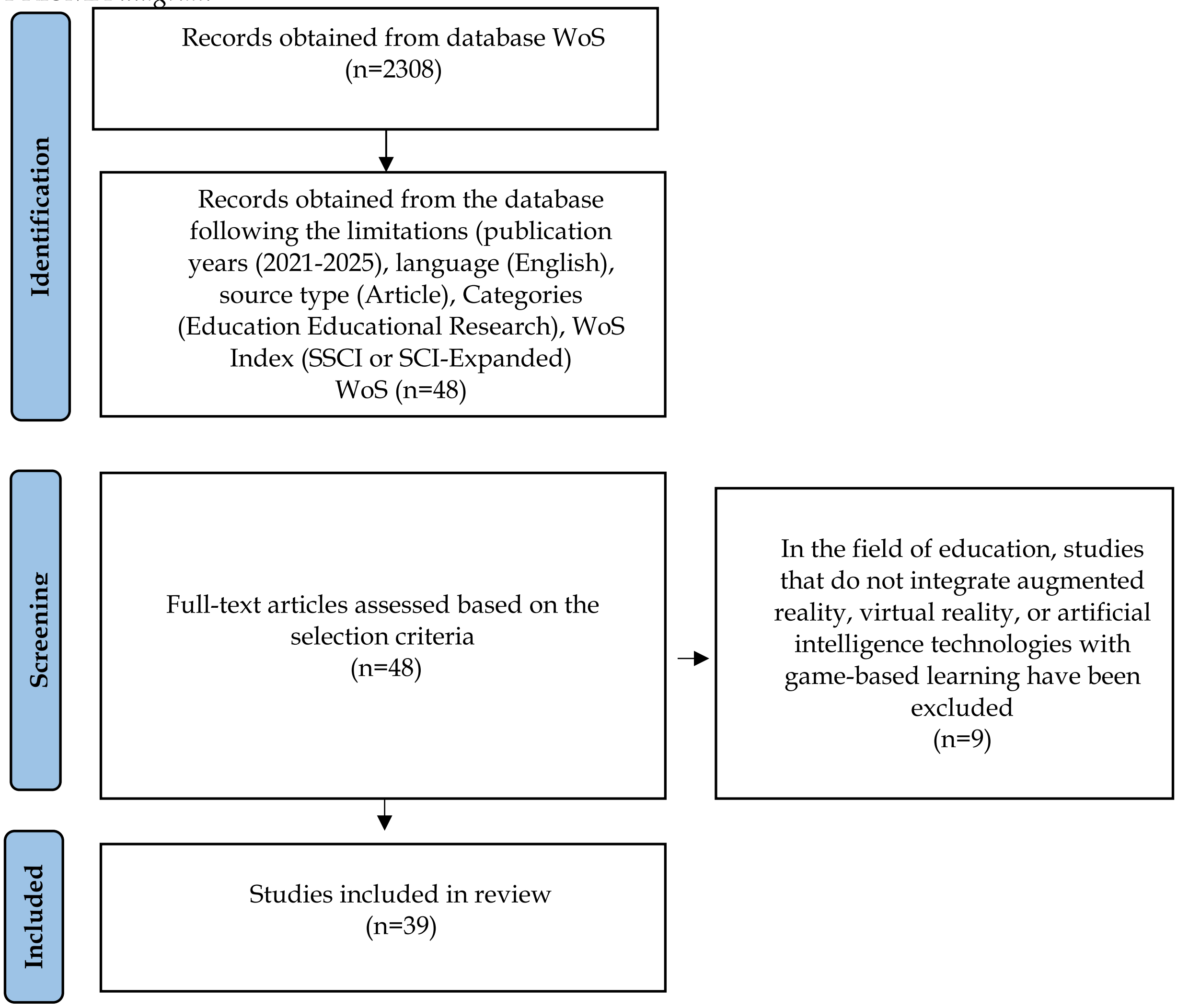


Table 2 presents the studies included in the systematic review and provides an overview of the literature analyzed within the scope of this study.

Table 2
Articles included in the systematic review

No	*Article Title*	*Author(s)*
1	Artificial intelligence in sport management education: Playing the AI game with ChatGPT	Keiper et al. (2023)
2	Effect of an AI-based chatbot on students' learning performance in alternate reality game-based museum learning	Liang et al. (2024)
3	Undergraduates' process safety knowledge development with virtual reality game	Sofri et al. (2024)
4	The effect of augmented reality-based serious game on traditional pattern learning	Ye et al. (2024)
5	Designing an alternate reality board game with augmented reality and multi-dimensional scaffolding for promoting spatial and logical ability	Hou et al. (2023)
6	Timing matters: Effects of augmented reality game on students' learning achievement, satisfaction and acceptance	Zhang et al. (2024)
7	Virtual reality games for 3D multimodal designing and knowledge across the curriculum	Mills et al. (2024)
8	Effects of the augmented reality game Pokemon GO on fitness and fatness in secondary school students	Martínez López et al. (2022)

Table 2 continued

No	*Article Title*	*Author(s)*
9	Combining Inquiry, Universal Design for Learning, Alternate Reality Games and Augmented Reality Technologies in Science Education: The IB-ARGI Approach and the Case of Magnetman	Sofianidis et al. (2024)
10	Augmented reality games in linguistic education: model of cultural concepts in the linguistic worldview of philology students	Khamitova et al. (2023)
11	A Commercial off-the-Shelf Immersive virtual reality game: its Effect on Engineering Students	Ramadhana and Chen (2023)
12	Exploring the feasibility of augmented reality game-supported flipped classrooms in reading comprehension of English for Medical Purposes	Khazaie and Ebadi (2025)
13	Augmented-reality-enhanced game-based learning in flipped English classrooms: Effects on students' creative thinking and vocabulary acquisition	Hung and Yeh (2023)
14	A multi-dimensional scaffolding-based virtual reality educational board game design framework for service skills training	Lin et al. (2024)
15	Can an augmented reality-integrated gamification approach enhance vocational high school students' learning outcomes and motivation in an electronics course?	Weng et al. (2024)
16	In-game performance: The role of students' socio-economic status, self-efficacy and situational interest in an augmented reality game	Arztmann et al. (2024)
17	Effects of a self-regulated-based gamified virtual reality system on students' English learning performance and affection	Zhao et al. (2024)
18	Using a mobile Virtual Reality and computer game to improve visuospatial self-efficacy in middle school students	Kuznetcova et al. (2023)
19	Children's drawings as an interpretive response to a gamified narrative with augmented reality: the case of Towards the South Pole	Neira-Piñeiro et al. (2024)
20	Exploring the viability of augmented reality game-enhanced education in WhatsApp flipped and blended classes versus the face-to-face classes	Khodabandeh (2023)
21	Integrating immersive virtual reality technology in scaffolded game-based learning to enhance low motivation students' multimodal science learning	Ding et al. (2024)
22	Investigating the effect of imikode virtual reality game in enhancing object oriented programming concepts among university students in Nigeria	Sunday et al. (2022)
23	The value of athletics class with the use of virtual reality games for better communication and socialization of students	Niu et al. (2025)
24	Enhancing primary school students' performance, flow state, and cognitive load in visual arts education through the integration of augmented reality technology in a card game	Chen et al. (2024)
25	Applying educational design research to develop a low-cost, mobile immersive virtual reality serious game teaching safety in secondary vocational education	Boel et al. (2024)
26	Developing a gamified artificial intelligence educational robot to promote learning effectiveness and behavior in laboratory safety courses for undergraduate students	Yang et al. (2023)
27	Exploring the motivational factors and learning outcomes of Virtual Reality educational games for middle school students: a unity 3D case study	Liu et al. (2025)
28	Fostering students' AI literacy development through educational games: AI knowledge, affective and cognitive engagement	Ng et al. (2024)
29	Using an Augmented-Reality Game-Based Application to Enhance Language Learning and Motivation of Elementary School EFL Students: A Comparative Study in Rural and Urban Areas	Liao et al. (2024)
30	The influences of virtual-reality- and animation-supported gamified learning processes on students' learning achievement and behavioral intention in retailing management courses	Lin and Wang (2024)
31	Effects of a place-based digital gameful learning experience on middle school students' watershed literacy and attitudes about desktop virtual reality gameplay	Araujo-Junior and Bodzin (2024)
32	The evaluation of a scaffolding-based augmented reality educational board game with competition-oriented and collaboration-oriented mechanisms: differences analysis of learning effectiveness, motivation, flow, and anxiety	Lin and Hou (2024)

Table 2 continued

No	*Article Title*	*Author(s)*
33	Effects of integrating a role-playing game into a virtual reality-based learning approach on students' perceptions of immersion, self-efficacy, learning motivation and achievements	Chen and Syu (2024)
34	A Mobile Contextualized Educational Game Framework With ChatGPT Interactive Scaffolding for Employee Ethics Training	Chen and Hou (2024)
35	Learning by playing with generative AI: design and evaluation of a role-playing educational game with generative AI as scaffolding for instant feedback interaction	Chien et al. (2024)
36	A comparative study on the effects of a VR and PC visual novel game on vocabulary learning	Lai and Chen (2023)
37	Effectiveness of AI-assisted game-based learning on science learning outcomes, intrinsic motivation, cognitive load, and learning behavior	Chen and Chang (2024)
38	Impact of AI gamification on EFL learning outcomes and nonlinear dynamic motivation: Comparing adaptive learning paths, conversational agents, and storytelling	Liu (2024)
39	To move or not to move? The effect of active versus passive pre-training on cognitive load and in-game performance in an AR game	Arztmann et al. (2024)

As shown in Table 2, the reviewed studies were identified within the 2021–2025 review period. No eligible studies meeting the inclusion criteria were identified for 2021. The studies examined diverse educational applications of AR, VR, and AI technologies in game-based learning environments and represented a variety of educational levels, disciplines, and technological implementations. Collectively, they provide a broad perspective on current developments in technology-enhanced game-based learning.

2.5. Data Extraction

A structured data extraction form was developed to systematically collect information from each included study. The extracted data included publication year, country, sample characteristics, research design, educational level, technological tools used (AR, VR, or AI), game type, learning content, learning outcomes, educational benefits, and recommendations for future research. The extracted information provided the foundation for the subsequent thematic analysis and synthesis of findings.

2.6. Data Analysis

The extracted data were analyzed using thematic analysis to systematically examine how AR, VR, and AI technologies have been integrated into game-based learning environments. Following the data extraction process, each study was reviewed in detail to identify the role and contribution of AR, VR, and AI technologies within game-based learning environments and was subsequently coded in line with the objectives of the review. Conceptually related findings were grouped into broader thematic categories, enabling the identification of common patterns and trends across the studies.

A coding framework was developed based on the research objectives and was organized around five major themes: research characteristics, learning content and development tools, learning outcomes, educational benefits, and recommendations for future research. The coding framework developed for the thematic analysis is presented in Table 3.

The coding process was conducted independently by three researchers to enhance the reliability and credibility of the findings. Any discrepancies identified during coding were discussed until consensus was reached. Inter-coder reliability was assessed using Cohen’s (1968) kappa coefficient, indicating a high level of agreement among the coders. This rigorous analytical procedure strengthened the trustworthiness of the review and facilitated a comprehensive synthesis of the selected studies.

Table 3
Coding Scheme

Themes	*Descriptions*	*Subcategories*
Research Features	Methodological characteristics of the reviewed studies such as year, country, research design, sample levels and sample size are discussed.	Year, country, research design, sample levels and sample size
Learning Content and Development Tools	This theme focuses on AR-, VR-, and AI-supported game-based learning environments, including the educational games, technologies, and digital content development tools used in the reviewed studies.	AR, VR or AI game-based educational games and genres, Digital content development tools
Learning Outcomes	The learning outcomes examined within the scope of the topics addressed in this study are discussed.	Cognitive, behavioral and affective learning outcomes
Educational Benefits	In the study, the educational contributions of AR, VR or AI technologies to students in learning-teaching processes and their advantages in the learning process were explained.	Academic achievement, cognitive load, motivation, etc.
Research Recommendations	Various suggestions were presented to practitioners and researchers for future studies.	Recommendations

As shown in Table 3, the coding framework enabled a systematic examination of the reviewed studies from methodological, pedagogical, and technological perspectives. The identified themes and subcategories guided the thematic analysis and facilitated the synthesis of findings across diverse educational contexts and technology-supported game-based learning environments.

3. Results

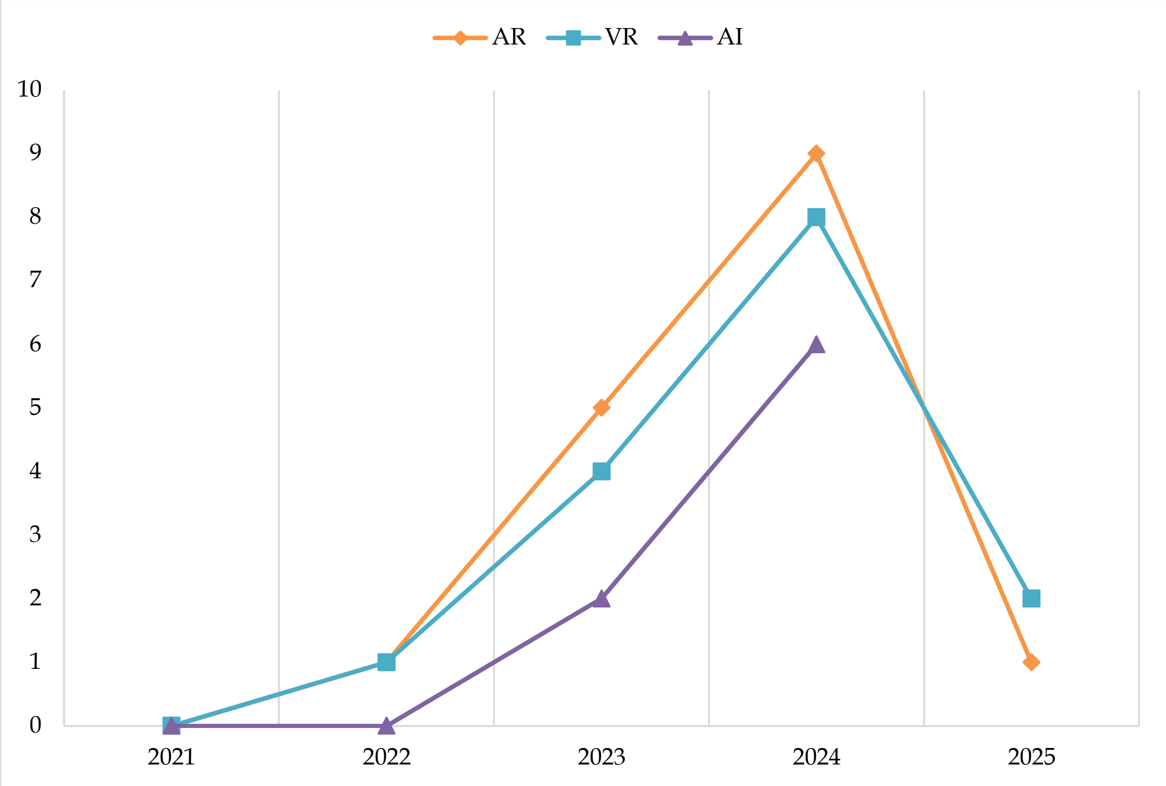
3.1. Research Characteristics of AR-, VR-, and AI-Supported Game-Based Learning Studies

In this study, research articles published over the past five years were analyzed to identify emerging trends in the integration of game-based learning with AR, VR, and AI technologies. As illustrated in Figure 2, no studies meeting the defined inclusion and exclusion criteria were found for the year 2021. However, starting from 2022, there has been a notable increase in the number of studies addressing this topic. This trend is consistent with findings in the broader literature, which highlight the growing interest in leveraging immersive and intelligent technologies to enhance educational experiences.

Specifically, recent research indicates that the application of AR (Aslam et al., 2024; Gill et al., 2024), VR (Ding et al., 2024; Song et al., 2024), and AI (Fitri et al., 2024; Zhan et al., 2024) in game-based learning environments is on the rise. These technologies have demonstrated positive effects on various learning outcomes, including increased student motivation, improved academic performance, and enhanced engagement. Figure 2 presents the distribution of studies on AR-, VR-, and AI-supported game-based learning according to publication year.

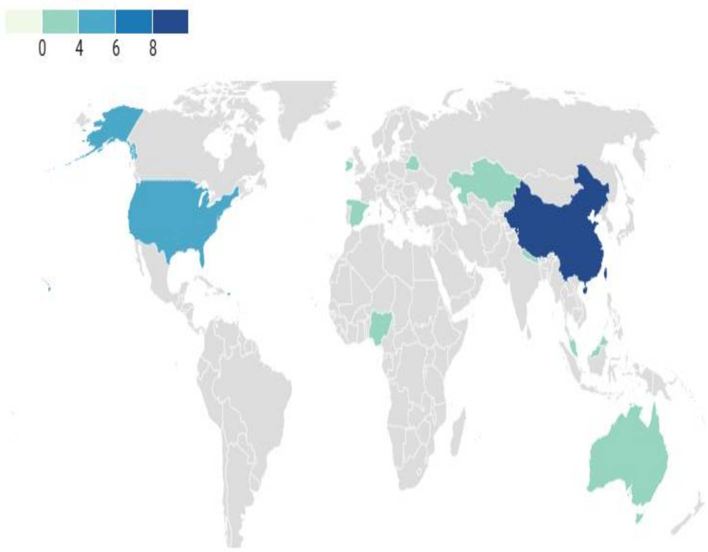
As shown in Figure 2, research on AR-, VR-, and AI-supported game-based learning has increased considerably in recent years. The findings indicate a growing scholarly interest in integrating emerging technologies into educational game-based learning environments, particularly after 2022.

Figure 2
Distribution of research on AR, VR or AI-supported game-based learning by years



To better understand the geographical distribution of the reviewed studies, the countries in which the studies were conducted were analyzed. Figure 3 presents the distribution of studies by country.

Figure 3
Distribution of studies per country

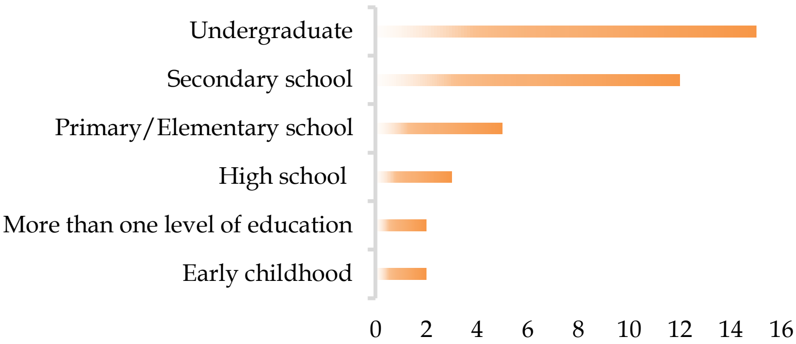


Country	*Number of studies*
Taiwan	13
China	8
USA	4
Iran	2
Netherlands	2
Spain	2
Brunei	1
Hong Kong	1
Malaysia	1
Belgium	1
Kazakhstan	1
Macedonia	1
Australia	1
Nigeria	1

According to the findings (Figure 3), the majority of the related studies were conducted in countries such as Taiwan (f=13), China (f=8) and the USA (f=4). In addition, various studies have been conducted in different countries such as Iran (f=2), Netherlands (f=2), Spain (f=2), Brunei (f=1), Hong Kong (f=1), Malaysia (f=1), Belgium (f=1), Kazakhstan (f=1), Macedonia (f=1), Australia (f=1) and Nigeria (f=1).

The reviewed studies were also analyzed according to educational level and sample size. Figure 4 presents the distribution of articles according to these characteristics.

Figure 4
Distribution of articles according to educational levels and sample size



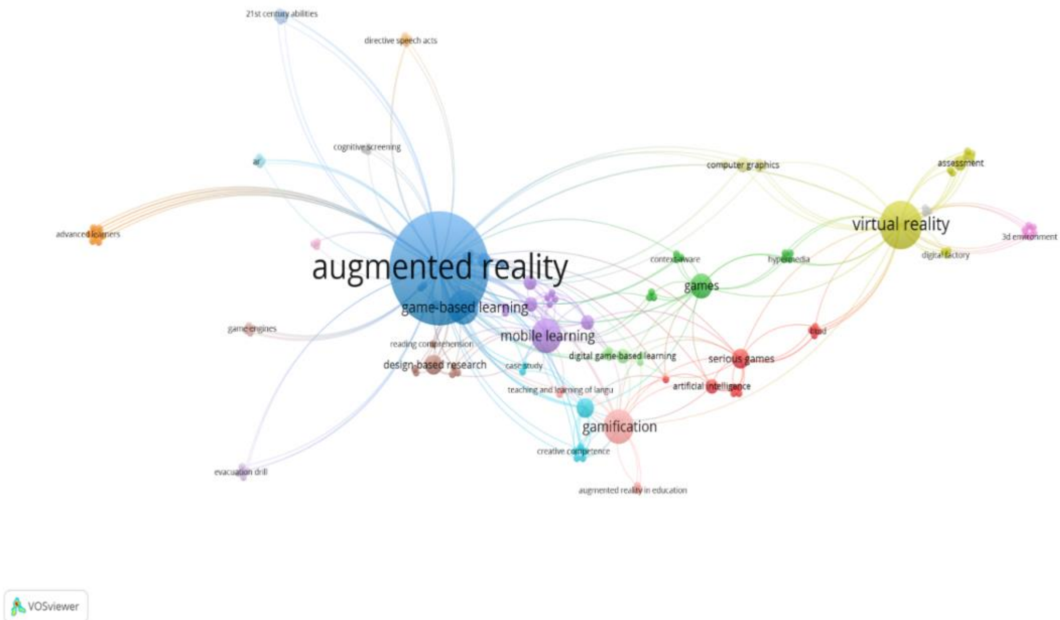
Sample size	n
0-50	7
51-100	15
101-150	6
151-200	3
201-250	2
251-300	2
300-	3
Unspecified	1

According to Figure 4, it was determined that most of the studies were conducted at the undergraduate level (f=15) and secondary school (f=12). On the other hand, it is seen that the number of studies conducted at primary school level (f=5) is less. Regarding sample size, studies involving between 51 and 100 participants were the most common. These findings indicate that research on AR-, VR-, and AI-supported game-based learning has primarily concentrated on secondary and higher education settings.

The reviewed studies employed a variety of research designs. Quantitative approaches, particularly experimental and quasi-experimental designs, were the most frequently used methodologies. Mixed-method studies also represented a substantial proportion of the reviewed literature, whereas qualitative studies were comparatively limited. These findings indicate a strong emphasis on evaluating the effectiveness of AR-, VR-, and AI-supported game-based learning interventions through empirical research designs.

To better understand the focus of the studies included in the systematic review, a bibliometric keyword analysis was conducted. Figure 5 presents the keyword network generated from the analyzed studies.

Figure 5
Analysis on keywords



As shown in Figure 5, the most frequently used keywords include "augmented reality," "virtual reality," "gamification," "mobile learning," and "game-based learning." These findings indicate that immersive technologies constitute the primary focus of current research on technology-enhanced game-based learning.

3.2. Educational Games and Digital Content Development Tools Used in AR-, VR-, and AI-Supported Game-Based Learning

This study examines the integration of AR, VR, and AI technologies into game-based learning processes from multiple perspectives. As shown in Table 4, a variety of tools are employed to enable direct user interaction and immersive experiences. These include Oculus Quest headsets, 4D+ cards, and both image-based and marker-based AR cards (Keiper et al., 2023; Lai & Chen, 2023; Liang et al., 2024; Neira-Piñeiro et al., 2024; Niu et al., 2025; Sofianidis et al., 2024; Weng et al., 2024). In addition to hardware, software platforms such as Unity 3D, Vuforia, Maya 2020, Adobe Photoshop, Illustrator, and AI-based tools are widely used to create and enhance educational content (Hung & Yeh, 2023; Lin et al., 2024; Mills et al., 2024; Neira-Piñeiro et al., 2024; Ye et al., 2024).

For example, VR systems like Oculus Quest 1 and 2 and HTC Vive track users' movements and present virtual environments through head-mounted displays, offering highly immersive game-based experiences (Pereira et al., 2023). In one study, Niu et al. (2025) utilized VR glasses in virtual games designed to improve running techniques and obstacle avoidance. Results showed improved movement efficiency, highlighting the physical benefits of VR-based learning environments.

Similarly, Neira-Piñeiro et al. (2024) investigated a gamified digital story titled *Journey to the South Pole*, which included AR tools such as Google 3D Animals, Metaverse, and Animal 4D+. The story followed a child helping a lost penguin return to the South Pole, incorporating educational activities to support mathematical thinking, hand-eye coordination, language development, and emotional awareness. The results showed that students aged 5–6 displayed strong emotional engagement and immersion through augmented reality features. These findings are supported by earlier work by Aliagas and Margallo (2017), who argued that digital storytelling redefines how literature is experienced, promoting deeper emotional and cognitive engagement.

Such AR and VR technologies offer multisensory learning environments that combine visual, auditory, and tactile stimuli, making learning more effective and immersive (Al-Ansi et al., 2023; AlGerafi et al., 2023; Papanastasiou et al., 2019).

AI-based tools and adaptive learning platforms have also emerged as powerful instruments in game-based education. These tools personalize the learning experience by adjusting content and pace to individual learners' needs (Aggarwal, 2023; Gligorea et al., 2023). For instance, Liang et al. (2024) designed an AI-powered chatbot to support students in an Alternate Reality Game within a museum setting. The chatbot provided adaptive feedback based on learners' prior knowledge and metacognitive skills. Results indicated significant improvements in students' metacognitive awareness, emotional engagement, and behavioral involvement.

In a similar vein, Chen and Chang (2024) examined the effects of AI-supported game-based learning on scientific outcomes, motivation, cognitive load, and learning behavior. Their findings showed that students using ChatGPT-integrated games outperformed those using standard game-based approaches. Students reported that AI-assisted learning helped them focus on key concepts and refine their gaming strategies. One student reflected:

"Using ChatGPT in the game helps deepen my understanding of the relationship between speed, distance, and time. It also helps in solving problems and reinforces my comprehension of these concepts."

An example visual from the game *Summon of Magicrystal* used in the study is shown in Figure 6.

Figure 6
ChatGPT integrated with examples in the game Summon of Magicrystal (Chen & Chang, 2024)

As shown in Figure 6, ChatGPT functions as an intelligent learning assistant by providing adaptive feedback and guidance throughout the game-based learning process.

Educational games enhance the learning environment by immersing individuals in simulated worlds through technologies such as AR and VR. Meanwhile, AI tools offer personalized feedback by adapting content to individual learning styles, resulting in a more effective and engaging educational experience (Rapaka et al., 2025). Some of the educational games analyzed in this study include *Lulu's Birthday Party* (Liang et al., 2024), *PokemonGo* (Martínez López et al., 2022), *Magnetman* (Sofianidis et al., 2024), *Treasure Island* (Ng et al., 2024), and *Angels and Demigods* (Lai & Chen, 2023).

Within the reviewed literature, these games fall into various categories such as Alternate Reality Games, serious games, role-playing games, serious role-playing games, AR board games, AR-based card games, and immersive VR games. Each category contributes uniquely to enriching the learning experience.

In recent years, serious games incorporating AR have gained increasing attention from researchers. Moreover, VR-enhanced features provide expanded opportunities for teaching and learning, and are widely applied in fields such as medicine, psychology, and education (Ye et al., 2024). For example, Sofianidis et al. (2024) employed a virtual reality game to improve chemical engineering students' understanding of process safety. The serious role-playing game format enabled students to practice and enhance safety skills through realistic scenarios, integrating role-play elements that foster experiential learning.

Board games, traditionally played on tables with physical components (Carter et al., 2014), have also been adapted with AR technology to increase engagement and learning outcomes. Hung and Yeh (2023) investigated the effects of an AR-supported board game on EFL learners' vocabulary acquisition and creative thinking. The study demonstrated that the AR-enriched board game actively involved students in classroom activities and yielded better learning results compared to traditional game-based methods.

Overall, these studies highlight the effectiveness of game-based learning approaches, demonstrating how they engage students in active, enjoyable, and interactive learning processes.

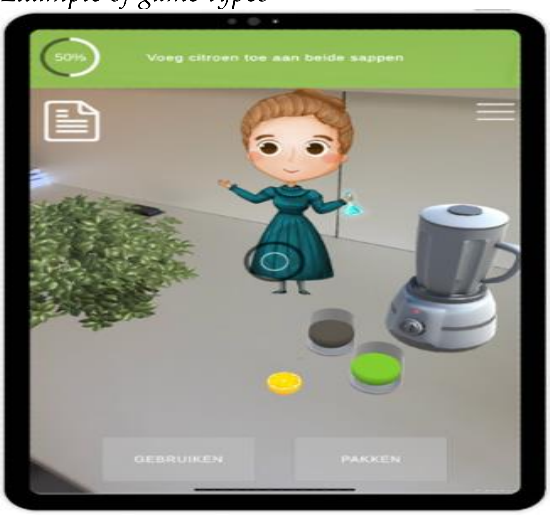
To provide a clearer overview of the technologies, educational games, and game types identified in the reviewed studies, these elements are summarized in Table 4. As shown in Table 4, a wide variety of AR-, VR-, and AI-supported tools were employed in game-based learning environments. These technologies were integrated into diverse educational games and game formats, including alternate reality games, serious games, role-playing games, AR-enhanced board games, and immersive VR games. The findings demonstrate the versatility of emerging technologies in supporting interactive and engaging learning experiences.

Table 4
Types of games and digital content development tools used in AR, VR or AI

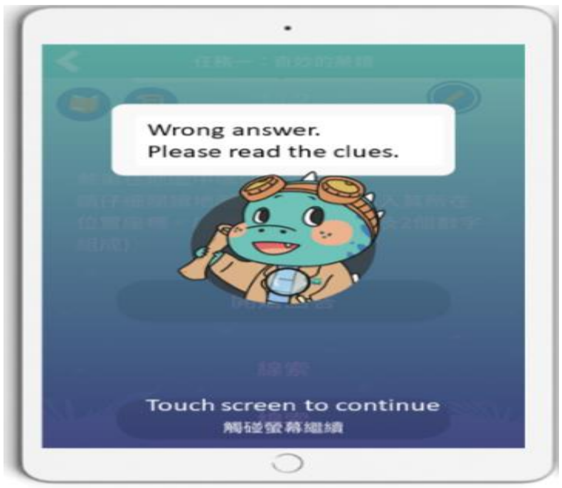
	Description	*Samples*	*Sample Studies*
Digital content development tools used in AR, VR and AI	Digital content development tools for AR, VR, and AI technologies are software applications and platforms used to create interactive and immersive learning experiences.	ChatGPT, Chatbot, Oculus Quest Headset, 3D models, immersive VR, 4D+ cards, image-based AR cards, marker-based AR, Unity 3D, Vuforia, Maya 2020, Adobe Photoshop and Adobe Illustrator, and the modeling software Cinema 4D, Artefact, Google 3D, Metaverse app, QR	Chen and Chang (2024); Hung and Yeh (2023); Keiper et al. (2023); Lai and Chen (2023); Liang et al. (2024); Lin et al. (2024); Neira-Piñeiro et al. (2024); Mills et al. (2024); Niu et al. (2025); Sofianidis et al. (2024); Weng et al. (2024); Ye et al. (2024)
Educational games	Games that enable learning while playing.	Lulu's Birthday Party, Marie's ChemLab, PokemonGo, Magnetman; Treasure Island; The Unfinished Cave Mission, Angels and Demigods	Arztmann et al. (2024); Chen and Chang (2024) Chien et al. (2024); Lai and Chen (2023); Liang et al. (2024); Martínez López et al. (2022); Ng et al. (2024); Sofianidis et al. (2024)
Types of educational games	They are various types of games used to achieve different learning objectives.	alternate reality games, serious game, role-playing game (RPG), serious role play game, AR board game, AR-based card game, immersive VR game	Chen et al. (2024); Hou et al. (2023); Hung and Yeh (2023); Ramadhana and Chen (2023); Sofri et al. (2024); Ye et al. (2024)

Examples of the educational game types identified in the reviewed studies are presented in Figure 7. As shown in Figure 7, the reviewed studies incorporated diverse game formats, including simulation games, alternate reality games, role-playing games, and AR-enhanced board games. These examples illustrate how AR-, VR-, and AI technologies can be integrated into different game structures to support a variety of educational objectives and learning experiences.

Figure 7
Example of game types



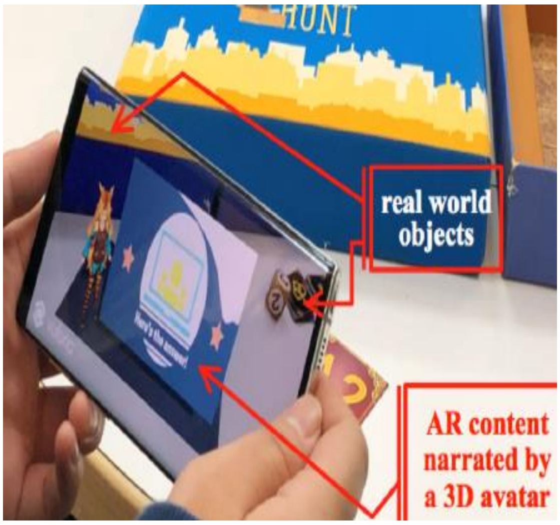
Source. Marie's ChemLab.- Simulation game (Arztmann et al., 2024)



Source. Lulu's Birthday Party- alternate reality game (Liang et al., 2024)

Figure 7 continued

Source. Role playing game (Chen & Syu, 2024)



Source. AR-enhanced board game (Hung & Yeh, 2023)

3.3. Learning Contents and Learning Outcomes in AR-, VR-, and AI-Supported Game-Based Learning

This section examines the learning contents addressed in AR-, VR-, and AI-supported game-based learning environments. To provide a systematic overview of these contents, the categories adapted from Ng et al. (2024) and revised for the purposes of the present study are presented in Table 5.

Table 5
Learning contents covered in the studies

Learning contents samples	*Definition*	*Sample studies*
Experiencing AI, AR, VR	Using AI, AR, and VR applications, as well as the benefits and limitations of these technologies (Ng et al., 2024; Verhulst et al., 2021)	Liang et al. (2024); Sofri et al. (2024)
Simple AI, AR, VR concepts	History, introduction, and recent developments in AI, AR, and VR, including their subfields, differences between humans and machines, and natural language processing (Ng et al., 2024; Oberdörfer et al., 2021)	Niu et al. (2025)
Societal impacts and AI, AR, VR ethics	AI ethics, societal impacts of AI, AR, and VR, machine reasoning, and problem-solving (Ng et al., 2024; Wassom, 2014)	Lin & Hou (2024)
Complex AI, AR, VR topics	Wearable devices, natural language processing, near-eye displays, cognition, biomedical informatics, robotics, information networks, human–robot interactions, and computational sustainability (Al-Ansi et al., 2023; Ng et al., 2024)	Niu et al. (2025)
Technical components (for AI, AR, VR education)	Fisher's exact test, inductive reasoning, nearest neighbor algorithms, correlation, graph search algorithms, computational game theory, optimization, agent-based modeling, and probabilistic reasoning (Ng et al., 2024)	Chen & Syu (2024)
Learning components	Design-based research and connected social learning (Aguayo et al., 2017)	Chen et al. (2024)

As shown in Table 5, the reviewed studies addressed a broad range of learning contents, including introductory concepts, technical components, ethical considerations, and practical applications of AR, VR, and AI technologies. These findings indicate that game-based learning environments support both foundational and advanced technology-related learning objectives.

3.4. Artificial Intelligence in Education and Its Impact on Learning

Artificial intelligence, developed by scientists and engineers over the past 65 years, aims to create human-like intelligence. Today, AI plays significant roles across various sectors, including healthcare, transportation, education, and industry, by enhancing diagnostic processes, improving safety through autonomous vehicles, and delivering personalized educational experiences (Jiang et al., 2022).

Education is one of the key fields influenced by AI. Ng et al. (2024) emphasize that designing appropriate learning content for middle and high school students is crucial for developing their problem-solving competencies. For middle school students, experiencing AI helps build foundational algorithmic thinking skills. Meanwhile, high school seniors, by engaging with more complex AI concepts and technical components, acquire in-depth knowledge essential for their future academic and professional endeavors. As a result, students at both levels reported gaining the necessary competencies to navigate challenges in the increasingly digital and technological world.

Within the reviewed studies, Sofianidis et al. (2024) highlight that virtual reality gaming enhances students' problem-solving and decision-making skills while motivating active participation in process safety examinations. They also note that an ideal virtual reality game should be online and web-based, incorporating serious role-playing elements integrated with real-life simulations. Similarly, Chen and Syu (2024) contribute to advancing VR technology by demonstrating that digital role-playing games can strengthen the immersive features of VR-based learning environments, thereby improving students' task engagement and concentration.

To better understand the educational impact of AR-, VR-, and AI-supported game-based learning environments, the learning outcomes reported in the reviewed studies were categorized into cognitive, behavioral, and affective domains. The identified outcomes are presented in Table 6.

Table 6
Learning outcomes covered in the studies

Learning outcome	*Learning outcome subcategories*	*Sample studies*
Cognitive	memorization, cognitive load, learning achievements, flow, spatial skill, reading performance, vocabulary acquisition, creative thinking, learning effectiveness, meta-cognition tendency, literary skills, computational thinking, problem-solving, language performance, watershed literacy, language skills	Chen and Mokmin (2024)
Behavioral	intrinsic goal orientation, extrinsic goal orientation, task value, self-efficacy, self-regulation, cognitive ability, technology acceptance, course interaction on satisfaction, course interaction on confidence, visual appeal on satisfaction, visual appeal on confidence, confidence on behavioral intention, learning behaviors,	Yang et al. (2023)
Affective	motivation, perception, satisfaction, parents' perception, acceptance, positive and negative emotions, interest, control beliefs about learning, learning motivation, learning attitudes, hazard perception, enjoyment, perceived usefulness, learning anxiety,gaming anxiety	Chen and Syu (2024); Ding et al. (2024); Lin and Hou (2024); Weng et al. (2024)

Note. Cognitive learning outcomes refer to mental processing and metacognition; behavioral learning outcomes refer to gestures, concrete actions, and movement; and affective learning outcomes refer to emotional processing and regulation (Domagk et al., 2010).

As shown in Table 6, the identified learning outcomes span cognitive, behavioral, and affective dimensions. The reviewed studies reported positive effects on learning achievement, motivation, engagement, metacognitive awareness, self-regulation, and problem-solving skills. For instance, Liang et al. (2024) demonstrated that an artificial intelligence-based chatbot incorporated into middle school students' alternate reality game-based museum learning significantly enhanced their metacognitive awareness. In contrast, traditional teaching tools were less effective in improving behavioral, social, cognitive, and emotional interactions as well as learning outcomes compared to mobile learning technologies and social media tools. Future research may benefit from focusing on the development of serious games aimed at improving student interaction and learning outcomes (Yu, Xu, et al., 2022).

Similarly, Weng et al. (2024), in their study on a gamified learning approach integrated with augmented reality, found that the experimental group exhibited higher motivation levels than the control group. The motivational aspect of games remains one of the most frequently highlighted features in the literature (Plass et al., 2015).

Game-based learning [GBL] is an educational approach designed to enhance student engagement and make learning processes more effective by integrating game elements and design techniques into education. This approach not only increases students' motivation but also positively influences learning outcomes. Research on GBL has shown that it plays a vital role in fostering critical thinking (Chang & Yeh, 2021), problem-solving skills, and learning motivation (Yang, 2012). Student motivation is widely recognized as a core component of game-based learning. Moreover, digital game-based learning has been identified as an effective method for improving student achievement (Partovi & Razavi, 2019).

A meta-analysis conducted by Karakoç et al. (2022) further supports these findings, indicating that game-based learning has a substantial overall effect size on student achievement. Beyond academic achievement, GBL also enriches the learning experience by making it more meaningful (Aydın & Ata, 2024). Psychologists have long acknowledged the critical role of play in cognitive development and learning processes (Plass et al., 2015). For example, Hainey et al. (2016), in their systematic review, found that GBL has been effectively utilized to teach a range of subjects to children and adolescents, with physical education, mathematics, science, language, and social studies being among the most common.

In conclusion, game-based learning stands out as a significant educational method that enhances student engagement, strengthens motivation, and improves learning effectiveness. This approach not only helps students develop essential critical thinking and problem-solving skills but also creates a fun and interactive learning environment. Systematic reviews of game-based learning effects contribute to a deeper understanding of the method's role and importance in modern education.

3.5. Educational Benefits of Integrating AR, VR, and AI into Game-Based Learning Environments

This section examines the educational benefits associated with the integration of AR, VR, and AI technologies into game-based learning environments. To synthesize the advantages reported across the reviewed studies, a thematic analysis was conducted, and the identified benefits are summarized in Table 7. Overall, the findings indicate that the integration of these technologies has a predominantly positive impact on educational processes. The reviewed studies consistently reported improvements in student motivation, engagement, metacognitive awareness, academic achievement, and learning effectiveness. Furthermore, AR-, VR-, and AI-supported game-based learning environments were found to promote more interactive, personalized, and immersive learning experiences. These findings suggest that emerging technologies can play a significant role in enhancing teaching and learning across different educational contexts and levels.

As shown in Table 7, the most frequently reported benefits include increased motivation, enhanced engagement, improved metacognitive awareness, stronger academic performance, and more positive learning experiences. These findings suggest that the integration of AR, VR, and AI technologies contributes substantially to the effectiveness of game-based learning environments.

Table 7
Educational benefit of gamified or game-based AR, AI, VR applications and experiences

Educational benefits	*Reference(s)*
Improve metacognition awareness	Hou et al. (2023); Liang et al. (2024); Zhao et al. (2024)
Improve engagement	Chen and Hou (2024); Liang et al. (2024); Neira-Piñeiro et al. (2024)
Cognitive load	Chen and Chang (2024); Ye et al. (2024)
Increase learning outcomes and academic performance	Chen and Hou (2024); Liao et al. (2024); Zhang et al. (2024)
Linguistic and cognitive skills.	Lai and Chen (2023); Khamitova et al. (2023)
Offer enjoyable and fun learning experiences	Lai and Chen (2023); Ramadhana and Chen (2023)
Creative thinking	Hung and Yeh (2023)
Positive perceptions	Hung and Yeh (2023)
Positive and negative emotions	Lin et al. (2024)
Intrinsic goal orientation	Weng et al. (2024)
Self-regulation	Zhao et al. (2024)
Learning motivation	Chen and Chang (2024); Chen and Hou (2024); Chen and Syu (2024); Liao et al. (2024); Lin and Hou (2024); Liu (2024); Zhao et al. (2024)
Learning attitudes	Zhao et al. (2024)
Self-efficacy	Chen and Syu (2024); Kuznetcova et al. (2023)
Ease of use	Lin & Hou (2024); Sunday et al. (2022)
Satisfaction	Lin and Wang (2024); Sunday et al. (2022)
Provide interesting and enthusiastic learning experiences	Araujo-Junior and Bodzin (2024)
Low anxiety	Chien et al. (2024)

3.6. Recommendations for Future Research

The findings of the reviewed studies indicate that AR-, VR-, and AI-supported game-based learning environments offer substantial educational benefits, including enhanced motivation, engagement, learning effectiveness, and higher-order thinking skills. Building on these findings, researchers have proposed a range of recommendations to guide future research and practice. These recommendations primarily focus on expanding sample diversity, conducting long-term interventions, improving curriculum integration, strengthening personalized learning support, and exploring the application of emerging technologies across different educational contexts. The recommendations identified in the reviewed studies are summarized in Table 8.

As shown in Table 8, future research should focus on larger and more diverse participant groups, longitudinal study designs, curriculum integration, and the development of more personalized and adaptive AR-, VR-, and AI-supported game-based learning environments.

4. Discussion

This systematic review examined the integration of augmented reality, virtual reality, and artificial intelligence technologies into game-based learning environments by synthesizing findings from 39 studies published during the 2021–2025 review period. The findings revealed a substantial increase in research interest after 2022, suggesting that emerging technologies are becoming increasingly important components of technology-enhanced learning environments. This trend may be associated with recent advances in immersive technologies, the widespread availability of mobile and wearable devices, and the growing interest in personalized and interactive learning experiences. Similar trends have been reported in recent reviews highlighting the rapid expansion of AR, VR, and AI applications in education (Lampropoulos et al., 2022; Lampropoulos & Kinshuk, 2024; Rizvi et al., 2023).

Table 8
Authors, aim, conclusion and suggestions of the studies analyzed

Author(s)	*Suggestions*
Keiper et al. (2023)	Future studies should examine the outcomes carefully before ChatGPT can be used as an effective tool in education.
Liang et al. (2024)	Future studies should investigate the potential of AI-based chatbots to support students' self-regulated learning in game-based learning environments.
Sofri et al. (2024)	Future studies should examine how virtual reality-based games can be used in process safety education to enable students to gain industry experience.
Ye et al. (2024)	Future studies should investigate how incorporating AR-based serious games into art education curricula can improve students' learning processes.
Hou et al. (2023)	Future studies should investigate the integration of multidimensional scaffolding into games so that augmented reality-based games can be used more effectively in education.
Zhang et al. (2024)	Future studies should investigate ways to optimize the timing of delivery of AR games based on student goals.
Mills et al. (2024)	Future studies should investigate how the integration of VR technology into the curriculum can more effectively deliver virtual and tangible learning experiences to students.
Martínez López et al. (2022)	Future studies should investigate how Pokémon GO can be used to increase adolescents' physical activity levels in school and family contexts.
Sofianidis et al. (2024)	Future studies should investigate applying the IB-ARGI approach at different educational levels and evaluating its effects in long-term studies.
Khamitova et al. (2023)	Future studies should examine how the integration of augmented reality and cultural disciplines can benefit the language learning process.
Ramadhana & Chen (2023)	Future studies should examine whether longer-term interventions and studies with different game designs may yield more significant results.
Khazaie & Ebadi (2023)	Future studies should examine the potential of AR games in education with larger groups and different learning styles to identify effective learning strategies.
Hung & Yeh (2023)	Future studies should investigate the effectiveness of the ARGBL approach in improving language skills in flipped classrooms.
Lin et al. (2024)	Future studies should investigate in-depth exploration of collaboration mechanisms using more realistic VR scenarios and online interactive games.
Weng et al. (2024)	Future studies should overcome the study's limitations by conducting studies that include more participants from different levels.
Arztmann et al. (2024)	Future studies should examine the impact of socioeconomic status differences in studies with different gaming technologies.
Zhao et al. (2024)	Future studies should investigate gamified virtual reality (VR) systems that allow students to monitor their learning progress.
Kuznetcova et al. (2023)	Future studies should contribute to a better understanding of this relationship by examining factors affecting VSSE, VS skills, and STEM performance.
Neira-Piñeiro et al. (2024)	Future studies should further analyze children's response to AR-gamified stories and conduct similar interventions in different age groups.
Khodabandeh (2023)	Future studies should examine the effects of ARG on language skills and how students' personal characteristics affect their performance in these applications.
Ding et al. (2024)	Future studies should investigate whether game-based learning methods are effective for students with low motivation.

Table 8 continued

Author(s)	*Suggestions*
Sunday et al. (2022)	Future studies should investigate how virtual reality technology for teaching OOP can be used as a complementary tool to classroom teaching.
Niu et al. (2025)	Future studies should investigate strengthening students' communication skills and social relationships through the integration of VR technology into sports education.
Chen et al. (2024)	Future studies should conduct in-depth research with larger samples on the integration of AR technology into teaching processes.
Boel et al. (2023)	Future studies should examine the long-term effects of iVR-based games in education and their applications in different areas of professional education.
Yang et al. (2023)	Future studies should more thoroughly validate the current findings with larger sample groups and by testing the GAFCC model with different classes of robots.
Liu et al. (2025)	Future studies should investigate the development of comprehensive strategies for aligning VR educational games with curriculum.
Ng et al. (2024)	Future studies should investigate how pedagogical elements such as flipped classrooms and project-based learning can be used effectively to develop students' higher-level cognitive skills.
Liao et al. (2024)	Future studies should further examine the effects of ARGBL on specific language skills and the role of technology on student engagement.
Lin & Wang (2024)	Future studies should examine the long-term effects of VR and animation-assisted learning technologies.
Araujo-Junior & Bodzin (2024)	Future studies should examine the impact of more deeply personalizing game content to improve students' systems thinking skills.
Lin & Hou (2024)	Future studies should investigate further examination of the integration of competitive and collaborative mechanisms in the design of AR-based educational games.
Chen & Syu (2024)	Future studies should examine instructional support and strategy development in VR-based learning environments.
Chen & Hou (2024)	Future studies should examine the impact of this technology by extending the use of ChatGPT-based NPCs as scaffolds to different educational contexts.
Chien et al. (2024)	Future studies should investigate how generative AI-based interactive scaffolds can be used more effectively in learning environments.
Lai & Chen (2023)	Future studies should examine the long-term effects of VR-based educational games on language learning and how students adapt to more interactive learning environments.
Chen & Chang (2024)	Future studies should examine the effectiveness of AI-supported game-based learning across different age groups and subject areas.
Liu (2024)	Future studies should examine the relationship of adaptive learning pathways to cognitive load and the long-term effects of AI-assisted teaching strategies.
Arztmann et al. (2024)	Future studies should provide more effective support to students with low visuospatial working memory capacity and examine the long-term effects of pretraining strategies.

One notable finding is that the majority of studies were conducted in Taiwan, China, and the United States. This concentration may reflect the strong investments made by these countries in educational technology infrastructure, digital transformation initiatives, and artificial intelligence research. Previous studies have similarly reported that East Asian countries have become leading contributors to technology-supported learning research due to their emphasis on innovation-driven educational policies and technology integration initiatives (Lampropoulos et al., 2022; Rizvi et al., 2023). However, the limited representation of developing countries suggests that the global evidence base remains geographically uneven. Consequently, future studies should examine the implementation of AR-, VR-, and AI-supported game-based learning in diverse cultural and socioeconomic contexts.

Another important finding of this review is that most studies were conducted with undergraduate and secondary school students, whereas relatively few studies focused on primary school learners. This imbalance may be explained by the technical complexity of AR-, VR-, and AI-supported learning environments, which often require advanced digital literacy skills, access to technological infrastructure, and the ability to engage with complex learning tasks. Researchers may therefore prefer older learners who can more easily interact with immersive and intelligent technologies. However, this finding also reveals an important research gap. Considering that early educational experiences play a critical role in cognitive and motivational development, future studies should investigate how AR-, VR-, and AI-supported game-based learning can be adapted for younger learners in primary education. Expanding research at this level may provide valuable insights into the long-term educational impact of emerging technologies (Ahdhianto et al., 2025; Kaşkaya & Ateş, 2025; Kavitha & Joshith, 2024; Xie et al., 2025).

The findings further indicate that augmented reality technologies were more frequently represented in the reviewed studies than virtual reality and artificial intelligence applications. One possible explanation is that AR technologies are generally more accessible, cost-effective, and easier to implement in educational settings than fully immersive VR systems. In many cases, AR applications can be delivered through smartphones and tablets that are already available in schools, whereas VR environments often require specialized equipment and technical support. Similarly, although AI technologies have recently gained substantial attention, their integration into educational games remains an emerging area of research. This finding is consistent with recent AR-focused studies suggesting that augmented reality has become an increasingly practical and engaging technology in educational settings. Its growing use may be related to its capacity to support interactive visualization, flexible and experiential learning, learner motivation, and perceived ease of use, rather than to implementation cost alone (Ahdhianto et al., 2025; Du & DeWitt, 2024; Koumpouros, 2024; Lampropoulos et al., 2022; Pellas et al., 2019; Rizki et al., 2024).

A central finding of this review is that AR-, VR-, and AI-supported game-based learning environments generally enhanced student motivation, engagement, learning achievement, and metacognitive awareness. These outcomes can be interpreted through the lens of Constructivist Learning Theory and Experiential Learning Theory, as such environments position learners as active participants who explore, interact with, reflect on, and construct knowledge through authentic and meaningful learning experiences. AR and VR technologies can make abstract or otherwise inaccessible content more concrete through immersive visualization and interaction, while AI-supported systems can provide personalized support, feedback, and adaptive learning pathways. Consequently, the observed gains should not be attributed to technological novelty alone, but to learner-centered designs that combine immersion, feedback, exploration, and active participation. This interpretation is consistent with recent studies reporting positive outcomes of AR-based game or project learning for motivation, creativity, critical thinking, and active exploration; VR applications for learning outcomes and learning experiences; and AI-supported learning for engagement, problem-solving, performance, and personalized learning (Kavitha & Joshith, 2024; Lampropoulos & Kinshuk, 2024; Lampropoulos et al., 2022; Maanu et al., 2026; Rizki et al., 2024; Rizvi et al., 2023; Yusuf, 2025).

Despite the predominantly positive findings, several implementation challenges were identified across the reviewed studies. The effectiveness of AR-, VR-, and AI-supported game-based learning environments appears to depend not only on the quality of the technological tools but also on the availability of digital infrastructure, students' access to appropriate devices, teachers' technological and pedagogical competencies, and institutional support. High development or access costs, technical difficulties, digital divides, and limited teacher preparedness may restrict the large-scale implementation of these technologies, particularly in resource-constrained educational settings. In addition, learners' acceptance of immersive technologies may be influenced by perceived usefulness, ease of use, course design, technological competence, and the cognitive load created by adapting to both the learning content and the digital environment. These findings suggest that technological innovation alone is insufficient; successful implementation requires careful pedagogical planning, teacher training, equitable access, and sustainable institutional support (Du & DeWitt, 2024; Ling et al., 2025; Mnguni, 2023; Pasipamire et al., 2025; Pratiwi et al., 2025).

Although the overall results were positive, the findings should be interpreted with caution. The reviewed studies differed considerably in terms of educational level, subject area, intervention duration, technological tools, and outcome measures. Such variations may partially explain inconsistencies in reported effect sizes and educational outcomes. While most studies reported positive outcomes, a limited number of studies identified challenges related to cognitive load, usability, and technology adaptation. While many studies reported significant improvements in learning achievement and motivation, the magnitude of these effects varied across contexts. This observation suggests that the effectiveness of AR-, VR-, and AI-supported game-based learning may be influenced by contextual factors such as instructional design quality, learner characteristics, and technology integration strategies. Future research should therefore move beyond examining whether these technologies are effective and focus more closely on identifying the conditions under which they produce the greatest educational benefits.

The findings demonstrate that AR-, VR-, and AI-supported game-based learning environments have considerable potential to transform educational practices by promoting active participation, personalized learning, and meaningful engagement. At the same time, the findings emphasize the importance of addressing pedagogical, technological, and contextual factors to maximize the effectiveness and sustainability of these emerging technologies in educational settings.

5. Limitations

This study has several limitations that should be considered when interpreting the findings. First, the review was limited to studies indexed in the Web of Science database and classified within the Education and Educational Research category. Although this approach ensured the inclusion of high-quality studies, relevant research indexed in other databases such as Scopus, ERIC, or Google Scholar may have been excluded. Second, only English-language journal articles published between 2021 and 2025 were included in the review. Consequently, valuable studies published in other languages or outside the selected time frame may not have been captured. Third, the reviewed studies varied considerably in terms of educational level, subject area, technological tools, intervention duration, and research design. This diversity limited direct comparisons across studies and may have influenced the interpretation of findings. Finally, because the review relied on information reported in published studies, some implementation details regarding the design and use of AR-, VR-, and AI-supported game-based learning environments may not have been fully documented. Future systematic reviews may benefit from including multiple databases, broader publication criteria, and additional sources of evidence to provide a more comprehensive understanding of this rapidly evolving field.

6. Implications

The findings of this review suggest that AR-, VR-, and AI-supported game-based learning environments can enhance student motivation, engagement, learning achievement, and higher-order thinking skills. Therefore, educators may consider integrating these technologies into teaching practices to create more interactive, immersive, and learner-centered learning experiences. However, effective integration requires that technological innovations be aligned with clear pedagogical objectives to maximize learning outcomes.

The findings also offer important implications for educational technology developers, practitioners, and institutions. AR-, VR-, and AI-supported educational games should be designed as accessible, user-friendly, and pedagogically meaningful learning environments. Their successful implementation requires not only adequate technological infrastructure but also teacher training, technical support, and institutional commitment. Accordingly, educational institutions should invest in both technological resources and professional development opportunities to facilitate effective integration.

In addition, this review identifies several directions for future research. More studies are needed at the primary education level, where research remains relatively limited. Future studies should also examine the long-term effects of AR-, VR-, and AI-supported game-based learning interventions through longitudinal research designs. Moreover, further research is needed to explore how contextual factors such as culture, socioeconomic conditions, teacher competencies, and instructional design influence learning outcomes. Finally, future studies should investigate how emerging technologies can be integrated to create adaptive, personalized, and inclusive learning environments for diverse learner populations.

7. Conclusion

This systematic review synthesized findings from 39 studies investigating the integration of augmented reality, virtual reality, and artificial intelligence technologies into game-based learning environments. The findings indicate a growing research interest in these technologies, particularly after 2022, and demonstrate their considerable potential to enhance student motivation, engagement, academic achievement, metacognitive awareness, and problem-solving skills. The review further revealed that AR-, VR-, and AI-supported game-based learning environments provide immersive, interactive, and personalized learning experiences that can positively influence educational outcomes across different contexts.

Despite these benefits, the successful implementation of emerging technologies in education depends on several pedagogical, technological, and contextual factors. Issues related to infrastructure, teacher preparedness, accessibility, and sustainability should be carefully considered when integrating these technologies into educational practice. The findings suggest that AR, VR, and AI have the potential to play a transformative role in future learning environments. As technological developments continue to accelerate, further research and practical applications will be essential for maximizing the educational value of these innovative technologies and ensuring their effective and equitable use in education.

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