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The Potential and Limitations of Augmented Reality and Virtual Reality in Enhancing Conceptual Understanding

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ABSTRACT

The rapid advancement of digital technology has encouraged the integration of *Augmented Reality* (AR) and *Virtual Reality* (VR) as innovative learning tools capable of providing interactive and immersive learning experiences. However, the effectiveness of these technologies in enhancing conceptual understanding remains inconsistent across educational contexts. This study aims to comprehensively analyze the potential and limitations of AR and VR in learning, particularly regarding students' conceptual understanding. A qualitative approach employing a *Systematic Literature Review* (SLR) method was adopted following the PRISMA 2020 guidelines. Data were collected from articles indexed in Scopus, Web of Science, ScienceDirect, SpringerLink, ERIC, and Google Scholar published between 2015 and 2025. Following the screening and selection process, 36 eligible articles were analyzed using thematic analysis. The findings reveal that AR and VR have significant potential to improve the visualization of abstract concepts, learning motivation, student engagement, and exploration-based learning experiences. Nevertheless, their impact on conceptual understanding is not always consistent and is strongly influenced by instructional design quality, pedagogical integration, learner characteristics, as well as infrastructure readiness and teacher competencies. Furthermore, challenges such as cognitive load, implementation costs, and digital access disparities remain significant barriers to the adoption of immersive technologies in education. This study highlights that the effectiveness of AR and VR depends not merely on technological sophistication but also on their integration with appropriate pedagogical strategies. Therefore, the development of more comprehensive AR- and VR-based learning models is necessary to support meaningful and sustainable conceptual understanding.

ABSTRAK

Perkembangan teknologi digital telah mendorong pemanfaatan *Augmented Reality* (AR) dan *Virtual Reality* (VR) sebagai inovasi pembelajaran yang mampu menghadirkan pengalaman belajar yang lebih interaktif dan imersif. Meskipun demikian, efektivitas kedua teknologi tersebut dalam meningkatkan pemahaman konsep masih menunjukkan hasil yang beragam. Penelitian ini bertujuan untuk menganalisis secara komprehensif potensi dan keterbatasan penggunaan AR dan VR dalam pembelajaran, khususnya terhadap pemahaman konsep peserta didik. Penelitian menggunakan pendekatan kualitatif dengan metode *Systematic Literature Review* (SLR) yang mengacu pada pedoman PRISMA 2020. Data diperoleh melalui penelusuran artikel pada basis data Scopus, Web of Science, ScienceDirect, SpringerLink, ERIC, dan Google Scholar dengan rentang publikasi tahun 2015–2025. Berdasarkan proses seleksi, sebanyak 36 artikel yang memenuhi kriteria inklusi dianalisis menggunakan teknik analisis tematik. Hasil kajian menunjukkan bahwa AR dan VR memiliki potensi yang signifikan dalam meningkatkan visualisasi konsep abstrak, motivasi belajar, keterlibatan peserta didik, dan pengalaman belajar berbasis eksplorasi. Namun, dampaknya terhadap pemahaman konsep tidak selalu konsisten dan dipengaruhi oleh kualitas desain instruksional, integrasi pedagogis, karakteristik peserta didik, serta kesiapan infrastruktur dan kompetensi pendidik. Selain itu, tantangan seperti beban kognitif, biaya implementasi, dan kesenjangan akses teknologi masih menjadi hambatan dalam penerapan teknologi imersif di lingkungan pendidikan. Penelitian ini menegaskan bahwa keberhasilan penggunaan AR dan VR tidak hanya ditentukan oleh kecanggihan teknologi, tetapi juga oleh kemampuan mengintegrasikan teknologi dengan strategi pembelajaran yang tepat. Oleh karena itu, diperlukan pengembangan model pembelajaran berbasis AR dan VR yang lebih terintegrasi untuk mendukung pemahaman konsep secara optimal dan berkelanjutan.

INTRODUCTION

The transformation of the digital era in education has encouraged significant changes in how students acquire, process, and construct knowledge. Advances in information and communication technology have given rise to various new learning models that emphasize meaningful, interactive, and contextual learning experiences. However, not all students have learning experiences that are interactive, contextual, and meaningful. In this context, Augmented Reality (AR) and Virtual Reality (VR) have emerged as technologies that offer innovative approaches to providing richer and more engaging learning experiences, while supporting the visualization of concepts that are difficult to understand directly (Fadlianti et al., 2020; Markasniak & Petersen, 2021; Hamilton et al., 2021).

AR combines real-world environments with virtual elements in real time, enabling users to interact with digital information that enhances physical reality (Azimi, 1997). Meanwhile, VR creates a fully digital environment that immerses users in an interactive virtual space, using devices such as head-mounted displays (Slater & Sanchez-Vives, 2016). Both technologies are increasingly being utilized in the education sector because they offer engaging and effective learning approaches, particularly in improving students' understanding of concepts and supporting learning visualization. Consequently, AR and VR have the potential to improve learning outcomes through meaningful experiences (UNESCO, 2023).

Theoretically, the use of AR and VR in learning is supported by constructivist learning theory, which emphasizes that knowledge is built through direct experiences within a learning environment (Piaget, 1972; Vygotsky, 1978). Learning environments based on AR and VR enable learners to actively interact, manipulate objects, simulate real-world situations, and observe abstract concepts that are difficult to embody in everyday conditions (Díaz & Delgado-Kloos, 2018). Through experiential learning, students can actively engage in the learning process and gain a deeper understanding of complex concepts.

Conceptual understanding is one of the main objectives of learning because it serves as the foundation for students to comprehend information effectively and apply it in everyday life. According to Bloom's revised taxonomy, conceptual understanding is not merely oriented toward knowledge mastery, but also toward the ability to understand relationships among concepts and apply them in various contexts. Therefore, various disciplines of science, including mathematics, science, and technology, highly depend on dimensions of conceptual understanding (Jensen & Konradsen, 2018). For this reason, the use of AR and VR technology is considered to have significant potential in helping students understand the presentation of objects and phenomena in more realistic and interactive visual forms.

Numerous studies have shown that AR and VR have a positive impact on various aspects of learning. Meta-analyses conducted by Garzón et al. (2019) indicate that AR generally has a significant effect on improving students' motivation, engagement, and learning outcomes. Research by Hamilton et al. (2021) found that AR-based learning helps learners better understand abstract concepts through more concrete and contextual visualizations. In the context of VR, Makransky et al. (2019) reported that immersive learning significantly enhances the sense of presence, emotional engagement, and learners' overall learning experiences. Similar findings were reported by Wu et al. (2023), who stated that immersive technology has considerable potential to improve the quality of learning experiences across various educational levels.

Nevertheless, the effectiveness of AR and VR in improving conceptual understanding remains a subject of debate in the literature. Several studies have reported significant improvements in conceptual learning outcomes following the use of AR and VR (Akçayır & Akçayır, 2017; Ibáñez & Delgado-Kloos, 2018), whereas other studies have found that conceptual understanding may not be substantially enhanced when learning activities focus more on visual and non-immersive media (Parong & Mayer, 2018; Makransky et al., 2019). In some cases, students who learn through VR report highly engaging learning experiences, yet these do not necessarily translate into significant gains in conceptual understanding. This condition suggests that the relationship between immersive technology and conceptual understanding is not linear and requires further in-depth investigation.

One factor frequently used to explain these inconsistent findings is cognitive load. According to Cognitive Load Theory, human working memory has a limited capacity to process information, and learning environments that are overly complex can hinder learning processes (Sweller et al., 2019). AR and VR environments rich in visual elements, audio, and high levels of interaction can potentially increase extraneous cognitive load if not designed appropriately (Mayer, 2021). Consequently, learners' attention may become diverted from the core learning content toward less relevant visual aspects. Therefore, the success of AR and VR implementation is highly dependent on the quality of instructional design employed.

In addition to cognitive factors, the effectiveness of AR and VR implementation is also influenced by various pedagogical and contextual factors. Research indicates that immersive technology integration with active learning approaches such as inquiry-based learning, problem-based learning, and project-based learning can produce more positive impacts than the passive use of technology (Bacca-Acosta et al., 2022; Wu et al., 2023). Thus, technology should not be regarded as a single factor determining learning success, but rather as part of a broader learning ecosystem that must be harmoniously integrated with appropriate pedagogical strategies.

On the other hand, the implementation of AR and VR in education also faces various challenges. Limitations in access, high technology costs, readiness of infrastructure, teacher competence, and disparities in technological access remain major obstacles, particularly in developing countries (UNESCO, 2023; OECD, 2023). In the Indonesian context, the use of AR and VR is still predominantly focused on local-scale studies and has not yet provided a comprehensive picture of the effectiveness of these technologies in enhancing conceptual understanding. In addition, most existing studies still focus on aspects of motivation and learner engagement, while studies specifically examining the relationship between immersive technologies and conceptual understanding remain relatively limited.

Based on the literature reviewed, there is a significant research gap that warrants further investigation. Although numerous studies have examined the use of AR and VR in education, there is still inconsistency in the findings regarding their impact on conceptual understanding. Furthermore, comprehensive studies that systematically synthesize various factors influencing the success or limitations of immersive technology implementation in learning are still lacking. Therefore, a systematic study is needed that not only identifies the potential of AR and VR but also critically evaluates the various limitations and challenges associated with their implementation.

This study aims to systematically analyze the potential and limitations of using Augmented Reality and Virtual Reality in learning, particularly in relation to conceptual understanding. The findings are expected to contribute theoretically to the development of the educational technology literature and serve as a reference for educators, technology developers, and policymakers in designing AR and VR implementations that are more effective, sustainable, and oriented toward improving the quality of learning.

METHOD

his study employed a qualitative approach using the Systematic Literature Review (SLR) method to comprehensively analyze the potential and limitations of the use of Augmented Reality (AR) and Virtual Reality (VR) in learning, particularly in enhancing students' conceptual understanding. The SLR method was selected because it enables researchers to systematically identify, evaluate, and synthesize findings from multiple studies, thereby providing a deeper understanding of a research phenomenon (Kitchenham & Charters, 2007; Xiao & Watson, 2019). The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines developed by Page et al. (2021) to ensure transparency, traceability, and credibility throughout the literature review process.

Data were collected through a systematic search of scientific articles indexed in several internationally recognized databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, ERIC, and Google Scholar. These databases were selected due to their extensive coverage of publications in the fields of educational technology and digital learning. The search process employed combinations of the keywords “Augmented Reality,” “Virtual Reality,” “Conceptual Understanding,” “Learning Outcomes,” “Immersive Learning,” and “Educational Technology,” combined using Boolean operators (AND and OR) to obtain more specific and relevant search results. To ensure the relevance and timeliness of the review, the search was limited to articles published between 2015 and 2025, considering the substantial growth and implementation of AR and VR technologies in education during the last decade (Radianti et al., 2020; Hamilton et al., 2021).

The article selection process was conducted systematically based on predefined inclusion and exclusion criteria established before the literature search. Eligible studies were peer-reviewed journal articles written in either English or Indonesian, focusing on the application of AR and/or VR in educational contexts and directly related to conceptual understanding, learning outcomes, or instructional processes. Conversely, studies that focused solely on technical aspects of software or hardware development, lacked full-text accessibility, or were published as conference proceedings, theses, dissertations, or books were excluded from the analysis. A summary of the inclusion and exclusion criteria is presented in Table 1.

Table 1. Inclusion and Exclusion Criteria for Literature Selection

Aspect	Inclusion Criteria	Exclusion Criteria
Publication Type	Peer-reviewed journal articles	Books, conference proceedings, undergraduate theses, master's theses, dissertations
Publication Year	2015–2025	Before 2015
Language	English and Indonesian	Languages other than English and Indonesian
Research Topic	AR and/or VR in education	Outside educational contexts
Research Focus	Conceptual understanding and learning	Technical device development
Availability	Full-text available	Full-text unavailable

The initial identification process yielded 436 articles across all selected databases. After duplicate screening, 82 articles were removed, leaving 354 articles for the screening stage. Subsequently, title and abstract screening resulted in 97 articles deemed relevant to the research focus. A full-text review was then conducted, leading to the exclusion of 61 articles that did not meet the established eligibility criteria. Consequently, 36 articles satisfied all inclusion requirements and were selected as the primary sources for data synthesis. The complete process of literature identification and selection is illustrated in Figure 1.

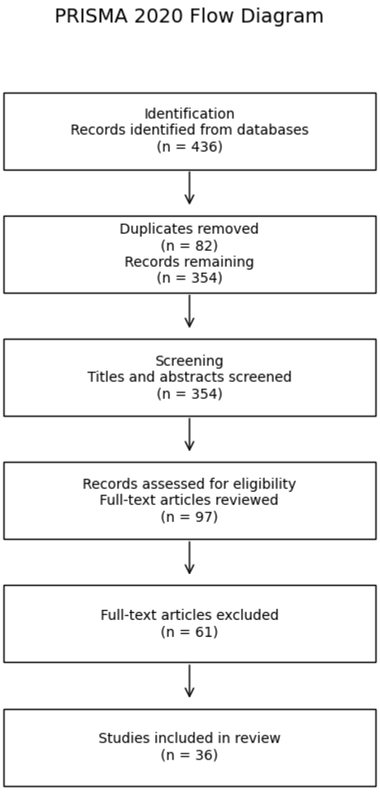

Figure 1. Literature Selection Flowchart Based on PRISMA 2020

To provide a more systematic overview of the literature selection process, a summary of the number of articles at each stage is presented in Table 2.

Table 2. Summary of the Literature Selection Process

Stage	**Number of Articles**
Articles identified	436
Duplicate articles	82
Articles after duplicate removal	354
Articles passing title and abstract screening	97
Articles excluded during the full-text review stage	61
Final articles included in the analysis	36

The articles that met the eligibility criteria were subsequently extracted and analyzed using thematic analysis, as proposed by Braun and Clarke (2022). The analysis involved a thorough examination of all selected articles, identification of emerging themes, categorization of findings based on shared characteristics, and the development of a descriptive-critical synthesis. The extracted information included study identification, country of origin, educational level, subject area, type of technology employed, research methodology, key findings, impact on conceptual understanding, as well as supporting and inhibiting factors related to the implementation of AR and VR in educational settings.

The analysis revealed four major themes that dominated the literature: (1) the contribution of AR and VR to enhancing the visualization of abstract concepts; (2) the influence of AR and VR on learning motivation and student engagement; (3) the impact of AR and VR on students' conceptual understanding; and (4) various implementation challenges associated with pedagogical, technological, and contextual factors. These findings were subsequently compared and critically interpreted to identify patterns, consistencies, and inconsistencies across the existing body of research.

To ensure the credibility of the review findings, this study employed source triangulation by comparing studies conducted across different countries, educational levels, and academic disciplines. Furthermore, the processes of literature searching, screening, data extraction, and analysis were carried out systematically in accordance with the PRISMA 2020 guidelines, thereby enhancing transparency and enabling future replication by other researchers. Through these procedures, the study aims to provide a more objective and comprehensive understanding of the effectiveness, potential, and limitations of AR and VR in improving conceptual understanding across diverse educational contexts.

RESULTS AND DISCUSSION

Results

Based on the literature selection process conducted in accordance with the PRISMA 2020 guidelines, a total of 36 articles met the inclusion criteria and were included in the analysis. These studies originated from various countries, educational levels, and academic disciplines, providing a comprehensive overview of the application of Augmented Reality (AR) and Virtual Reality (VR) in educational settings. The analysis revealed a significant increase in research on AR and VR over the past decade, particularly after 2020, when digital transformation in education accelerated worldwide.

Characteristics of the Analyzed Literature

Analysis of publication years indicates that most studies were published during the 2020–2025 period, reflecting growing academic interest in the use of immersive technologies for teaching and learning.

Table 3. Distribution of Articles by Publication Year

Year	Number of Articles
2015	1
2016	2
2017	3
2018	4
2019	5
2020	6
2021	5
2022	4
2023	3
2024	2
2025	1
Total	**36**

Based on educational level, the majority of studies were conducted in higher education and secondary education contexts. This trend suggests that AR and VR implementations have been more widely adopted among learners with relatively higher levels of digital literacy.

Table 4. Distribution of Articles by Educational Level

Educational Level	Number of Articles
Primary School	5
Secondary School	11
Higher Education	16
Professional Training	4
Total	**36**

In terms of academic disciplines, AR and VR applications were most frequently reported in science, technology, engineering, and health-related education.

Table 5. Distribution of Articles by Academic Discipline

Discipline	Number of Articles
Science	12
Technology and Engineering	8
Medicine and Health Sciences	7
Mathematics	4
General Education	5
Total	**36**

Furthermore, the analysis indicated that research on Virtual Reality (VR) was more prevalent than research on Augmented Reality (AR). Of the 36 studies analyzed, 20 articles focused on VR, 11 articles examined AR, and 5 articles investigated the combined use of AR and VR in educational contexts.

Potential of Augmented Reality and Virtual Reality in Education

The synthesis revealed that enhanced visualization was the most frequently reported benefit of immersive technologies. Most studies found that AR and VR facilitate students' understanding of abstract concepts through more concrete, interactive, and three-dimensional visual representations. In science and health-related disciplines, these technologies enable learners to observe objects and phenomena that are difficult or impossible to examine directly, such as molecular structures, human anatomy, the solar system, and complex physical processes.

Among the 36 articles analyzed, 30 studies reported improvements in conceptual visualization following the implementation of AR or VR. This finding suggests that immersive technologies possess considerable potential for supporting learners in constructing accurate mental representations of complex concepts.

In addition to improving conceptual visualization, most studies also reported increased learning motivation and engagement. Interactive and immersive learning environments encourage students to participate actively in instructional activities. A total of 28 articles indicated that AR and VR enhanced students' interest in learning, curiosity, and engagement throughout the learning process.

The synthesis further demonstrated that AR and VR support experiential learning. Rather than receiving information passively, students can interact directly with virtual objects, conduct simulations, and explore learning scenarios that would be difficult to recreate in real-world environments. This finding was reported in 24 studies included in the review.

Impact of AR and VR on Conceptual Understanding

Although most studies highlighted the positive contributions of AR and VR to learning processes, the findings regarding conceptual understanding exhibited more varied patterns.

A total of 18 studies reported that AR and VR significantly improved students' conceptual understanding. These improvements were particularly evident in learning materials characterized by high levels of abstraction, complexity, and spatial reasoning requirements.

In contrast, 12 studies reported moderate improvements or found no statistically significant differences when compared with conventional instructional approaches. Meanwhile, 6 studies found that AR and VR did not produce meaningful improvements in conceptual understanding, despite increases in student motivation and engagement.

Table 6. Impact of AR and VR on Conceptual Understanding

Finding Category	Number of Articles
Significant Impact	18
Moderate Impact	12
No Significant Impact	6
Total	**36**

These findings suggest that enhanced learning experiences provided by immersive technologies do not necessarily translate into equivalent improvements in conceptual learning outcomes.

Factors Supporting the Effectiveness of AR and VR

The literature identified several factors that contribute to the successful implementation of AR and VR in educational settings. The most frequently cited factor was the integration of immersive technologies with active learning strategies, such as inquiry-based learning, problem-based learning, and project-based learning.

A total of 22 studies reported that AR and VR yielded more effective outcomes when combined with instructional activities that encourage exploration, investigation, and problem-solving. In addition, clear instructional design, alignment between technology and learning content, and ease of technology use were consistently identified as important factors supporting instructional effectiveness.

Limitations and Implementation Challenges

Despite their considerable potential, the literature also identified several limitations associated with AR and VR implementation. The most commonly reported barriers were the high cost of equipment and the need for adequate technological infrastructure. A total of 25 studies identified economic constraints and device availability as major obstacles to the adoption of immersive technologies.

Another frequently reported challenge was the limited competence of teachers in integrating technology into instructional practices. Nineteen studies indicated that educator readiness plays a critical role in determining the successful implementation of AR and VR in classrooms.

Furthermore, several studies identified the issue of cognitive overload among learners when virtual environments were designed with excessive complexity. A total of 14 studies reported that an abundance of visual and interactive elements in AR and VR environments could distract students from the core learning content.

Table 7. Factors Limiting the Implementation of AR and VR

Limiting Factor	**Frequency**
Cost and Equipment	25
Technological Infrastructure	22
Teacher Competence	19
Cognitive Load	14
Access and Digital Divide	12
Software Technical Issues	10

Overall, the findings indicate that AR and VR possess substantial potential to support learning, particularly in enhancing conceptual visualization, learning motivation, and interactive learning experiences. However, their effectiveness in improving conceptual understanding remains variable and is influenced by a range of pedagogical, cognitive, and contextual factors. These findings provide a foundation for further discussion regarding the conditions that determine the success and limitations of AR and VR implementation in educational settings.

Discussion

The findings of this review indicate that the use of Augmented Reality (AR) and Virtual Reality (VR) has significant potential to support the learning process, particularly in enhancing conceptual visualization, learner engagement, and overall learning experiences. However, the findings also reveal that the impact of immersive technologies on conceptual understanding is not always consistent. While some studies reported substantial improvements in students' conceptual comprehension, others found only moderate effects or no significant differences compared to conventional instructional approaches. These variations suggest that the effectiveness of AR and VR cannot be explained solely by the sophistication of the technologies employed. Rather, their effectiveness should be understood as the result of a complex interaction among technological, pedagogical, learner-related, and contextual factors (Makransky & Petersen, 2021; Hamilton et al., 2021).

The finding that AR and VR enhance conceptual visualization supports the constructivist perspective, which posits that learning becomes more effective when learners are provided with opportunities to construct knowledge through meaningful and concrete experiences (Piaget, 1972; Vygotsky, 1978). In this context, AR and VR transform abstract concepts into visual representations that are easier to observe, manipulate, and understand. In science education, for example, molecular structures, human organ systems, and astronomical phenomena can be presented in three-dimensional formats, enabling learners to develop more accurate mental representations than those formed through text-based or two-dimensional instructional materials alone (Ibáñez & Delgado-Kloos, 2018; Wu et al., 2023). This finding reinforces the conclusions of Radianti et al. (2020), who identified the ability to present otherwise inaccessible objects and phenomena as one of the primary advantages of immersive technologies in educational environments.

Nevertheless, improved visualization does not automatically lead to equivalent gains in conceptual understanding. This issue emerged as one of the most important findings across the literature reviewed. Many learners reported more engaging and enjoyable learning experiences when using AR and VR, yet these positive experiences did not always translate into significantly improved conceptual learning outcomes. This phenomenon highlights a potential gap between the affective and cognitive dimensions of learning in immersive environments. In other words, while immersive technologies are highly effective in increasing motivation and engagement, they do not necessarily promote deeper information processing or meaningful conceptual learning (Parong & Mayer, 2018; Makransky et al., 2019).

This phenomenon can be explained through Cognitive Load Theory, developed by Sweller et al. (2019). According to this theory, human working memory has limited capacity for processing information. AR- and VR-based learning environments typically present multiple forms of information simultaneously, including visual elements, audio cues, animations, and interactive features. When these elements become excessively complex, learners may devote substantial cognitive resources to navigating the virtual environment itself rather than understanding the instructional content. As a result, extraneous cognitive load increases, potentially hindering the construction of new knowledge schemas. This finding is consistent with the work of Makransky and Petersen (2021), who demonstrated that higher levels of immersion do not necessarily correspond to improved learning outcomes.

From the perspective of multimedia learning theory, the effectiveness of AR and VR depends heavily on the quality of instructional design. Mayer (2021) argues that multimedia learning environments are most effective when they adhere to established principles such as the coherence principle, signaling principle, segmenting principle, and redundancy principle. When these principles are neglected, technologies intended to support learning may instead become sources of distraction. Consequently, the findings of this review suggest that the success of AR and VR implementation depends less on technological sophistication and more on the ability of instructional designers and educators to create learning experiences that align with learners' cognitive characteristics and instructional needs.

The review also demonstrates that the integration of immersive technologies with appropriate pedagogical approaches is a critical determinant of learning effectiveness. Studies that combined AR and VR with inquiry-based learning, problem-based learning, and project-based learning generally reported more positive effects on conceptual understanding than studies that used technology merely as a tool for presenting information (Bacca-Acosta et al., 2022; Wu et al., 2023). These findings support the view that technology should function as a means of facilitating higher-order thinking rather than serving solely as a visualization tool. In inquiry-based learning environments, for example, virtual simulations can be used for exploration, observation, experimentation, and hypothesis testing, allowing learners to actively construct knowledge through authentic learning experiences.

Furthermore, the findings indicate that the effectiveness of AR and VR is influenced by individual learner characteristics. Factors such as spatial ability, digital literacy, prior technological experience, and learning readiness play important roles in determining the success of immersive learning experiences (Jensen & Konradsen, 2018; Hamilton et al., 2021). Learners with strong spatial abilities tend to process and interpret three-dimensional information more effectively than those with lower spatial abilities. Consequently, the implementation of AR and VR should take into account learner diversity to ensure equitable learning opportunities and to minimize disparities in educational outcomes.

Beyond pedagogical and cognitive considerations, this review identified several structural and contextual challenges associated with the implementation of immersive technologies. High hardware costs, the need for adequate technological infrastructure, and limited internet accessibility remain major barriers to the widespread adoption of AR and VR, particularly in developing countries (UNESCO, 2023; OECD, 2023). In the Indonesian context, these challenges are further compounded by persistent disparities in technological access between urban and rural regions. As a result, the adoption of AR and VR may inadvertently create new forms of educational inequality if not accompanied by policies that promote equitable access to technology and digital resources.

Another important finding concerns the role of teacher competence in determining the success of immersive technology integration. Several studies emphasized that even the most advanced technologies are unlikely to produce optimal educational outcomes if teachers lack sufficient pedagogical expertise and digital literacy skills (Hamilton et al., 2021; UNESCO, 2023). Teachers play a central role in selecting appropriate learning content, designing instructional activities, facilitating learner interaction, and connecting virtual experiences with intended learning objectives. Therefore, investments in teacher professional development should be considered as important as investments in technological infrastructure and equipment.

Based on the synthesis of these findings, this study proposes a conceptual framework that views the effectiveness of AR and VR as the outcome of interactions among three key components: (1) cognitive theory-based instructional design, (2) pedagogical integration oriented toward active learning, and (3) implementation readiness, which includes technological infrastructure, teacher competence, and access to digital resources. These components interact dynamically and collectively determine whether immersive technologies contribute to meaningful improvements in conceptual understanding or create additional challenges within the learning process. This framework highlights that the success of AR and VR cannot be separated from the broader educational ecosystem in which these technologies are implemented.

Overall, the findings of this review affirm that AR and VR possess considerable potential to support 21st-century learning, particularly by enhancing conceptual visualization, learning experiences, and student engagement. However, their effectiveness in improving conceptual understanding is neither automatic nor guaranteed. Rather, it is strongly influenced by the quality of instructional design, the pedagogical strategies employed, learner characteristics, and the readiness of the learning environment. Therefore, future development and implementation of immersive technologies should adopt a pedagogy-driven technology integration approach, in which educational needs and learning objectives serve as the primary foundation for technology use, rather than allowing technological capabilities to dictate instructional practices.

CONCLUSION

Based on the findings of this Systematic Literature Review of studies published between 2015 and 2025, it can be concluded that Augmented Reality (AR) and Virtual Reality (VR) possess considerable potential to support educational processes, particularly in enhancing the visualization of abstract concepts, learning motivation, student engagement, and the creation of more interactive and immersive learning experiences. However, the effectiveness of these technologies in improving conceptual understanding is not automatic and varies across different learning contexts.

The review findings indicate that the successful implementation of AR and VR is strongly influenced by the quality of instructional design, their integration with active learning-oriented pedagogical approaches, learner characteristics, and the readiness of technological infrastructure and educator competencies. Furthermore, challenges such as the high cost of equipment, disparities in access to technology, and the potential for increased cognitive load must be carefully considered in the development and implementation of immersive technologies in educational settings.

Therefore, the adoption of AR and VR should not focus solely on technological innovation. Instead, it should emphasize the development of instructional models that effectively integrate technology, pedagogy, and contextual factors in a balanced manner. Such an approach is more likely to maximize the educational benefits of immersive technologies and contribute meaningfully to the improvement of conceptual understanding and the achievement of sustainable learning outcomes.

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