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Evaluating the Role of Augmented Reality in Enhancing Engagement and Learning in TVET Education: A Scoping Review

Chua Yee Peng, Fathiyah Mohd Kamaruzaman*, & Marlissa Omar

Center of STEM Enculturation, Faculty of Education, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Abstract

Augmented Reality (AR) has emerged as an innovative tool in Technical and Vocational Education and Training (TVET), offering immersive learning environments that enhance practical skills, engagement, and conceptual understanding. Despite its promise, AR adoption in TVET is still limited, often hindered by high costs, lack of infrastructure, and insufficient training for instructors. This scoping review explores how AR is being used in TVET settings, based on 17 peer-reviewed articles published between 2020 and 2024 in Scopus and Web of Science databases. Following Arksey and O'Malley's framework and PRISMA guidelines, the review identified three main themes: the benefits of AR in simulation-based learning and student engagement; key barriers including cost and technical challenges; and the importance of digital literacy and institutional support in successful implementation. The findings show that AR has significant potential to bridge the gap between theory and hands-on practice, enabling students to interact with realistic simulations while developing higher levels of motivation, collaboration, and problem-solving skills. However, the persistence of infrastructural, pedagogical, and attitudinal barriers means that successful adoption requires strong policy support, professional development for instructors, and long-term investment. By synthesizing current evidence, this study not only highlights emerging trends but also offers practical insights for educators, researchers, and policymakers. It stresses the need for context sensitive strategies to ensure AR's sustainable integration in preparing students for Industry 4.0 and the demands of modern smart manufacturing.

Keywords: Augmented Reality; educational technology; learning effectiveness; student engagement; TVET.

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1. Introduction

Technical and Vocational Education and Training (TVET) is critical in preparing skilled workers to meet the demands of rapidly evolving industries. Recognizing the importance of educational transformation, particularly in TVET, becomes essential to address global challenges (Ab Hamid et al., 2024) effectively. As digital transformation accelerates across sectors, there is growing pressure for TVET institutions to modernize their teaching and learning approaches. One of the emerging technologies with the potential to enhance vocational training is Augmented Reality (AR). By overlaying digital content onto real-world environments, AR offers immersive and hands-on learning experiences that can significantly improve technical understanding and learner engagement (Poonja et al., 2023).

Although AR has been successfully adopted in engineering, medicine, and industrial education, its integration within TVET systems remains limited. Most institutions continue to rely on traditional methods such as live demonstrations and printed materials, which may not fully support complex skill development (Muskhir et al., 2024). Major barriers include high implementation costs, insufficient infrastructure, and limited instructor readiness (Nusroh et al., 2022). Additionally, student acceptance of AR technology is inconsistent due to disparities in digital literacy, access to technological devices, and resistance to changes in pedagogical delivery (Villegas-Ch et al., 2024).

This review responds to these gaps by examining the use of AR in TVET from two main perspectives: the application and educational benefits of AR based training, and the challenges and mediating factors influencing its adoption among students and educators (Mahendru et al., 2024). While previous research supports AR's positive impact on

* Corresponding author.
E-mail address: fathiyah@ukm.my

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engagement and motivation, comprehensive insight is still lacking on how these outcomes vary across educational contexts.

This study is significant in several respects. For policymakers, the findings can inform strategic planning to align digital innovation with skills development agendas (Soltis et al., 2020) For educators, it offers guidance on how AR can be effectively integrated into teaching practices. From an industry perspective, it supports the creation of a workforce better prepared for technology-intensive work environments and ultimately helps reduce the skills gap between industry and educational institutions (Kamaruzaman et al., 2017).

1.1. Augmented Reality and Education

AR has shown great promise in transforming the landscape of skills-based education by enabling realistic simulations that do not rely on physical presence in an industrial setting. Studies have demonstrated that AR enhances students' understanding of complex technical systems, facilitates the application of theory to practice, and boosts learning motivation (Mondro et al., 2024). For instance, AR-based simulations have been used in mechanical and automotive training to visualize complex components and procedures (Smith et al., 2021), while other fields like science and biology have leveraged AR for immersive and exploratory learning (Geng, 2024).

However, the high cost of hardware (e.g., AR headsets), the need for stable digital infrastructure, and the lack of trained instructors continue to hinder implementation (Shwedeh et al., 2024). Moreover, the variability in student acceptance is often influenced by digital competence, prior exposure, and learning preferences complicates deployment (Waskito et al., 2024; Zahra et al., 2025).

Given these constraints, the successful integration of AR in TVET requires strategic planning that encompasses infrastructure investment, teacher professional development, and learner-centered design. This study offers a systematic review of how AR is currently applied in TVET, the key challenges faced, and the implications for future practice.

2. Research Methods

This study employed a scoping review approach to comprehensively map the existing literature on the use of AR in enhancing student understanding and engagement in TVET. Scoping reviews are particularly suitable for evaluating the breadth of evidence in emerging fields, as they accommodate diverse study designs and data sources. This allows for a broader and more systematic analysis of key issues under investigation (Arksey & O'Malley, 2005). Unlike systematic reviews, which emphasize evaluating the effectiveness of interventions, scoping reviews are commonly used in education and technology research to explore research trends and identify knowledge gaps (Pham et al., 2021; Peterson et al., 2016).

This methodology offers several advantages that make it ideal for the current study. One of its main strengths lies in its capacity to provide a holistic overview of the existing literature on AR in education. By examining patterns and trends in prior research, this review helps uncover underexplored areas and sets a foundation for future investigation (Anderson et al., 2021). Moreover, this approach enables the evaluation of contextual factors that shape the use of AR across different learning environments (Little et al., 2024).

The study is significant in that it systematically maps the effectiveness of AR in improving students' conceptual understanding and knowledge retention. In addition, it identifies key factors contributing to the successful use of AR in educational settings. The findings aim to inform educators and policymakers in formulating more effective AR integration strategies within the education system (Yahaya et al., 2022). Therefore, this scoping review not only contributes to the research base but also offers practical guidance for enhancing teaching and learning with AR.

This research adopts the six-step methodology proposed by (Arksey & O'Malley, 2005), as outlined below and illustrated in Figure 1.

Step 1: Identifying the Research Questions. The central focus of this review is to examine the role of AR based training in the TVET context. Three research questions guided the study: What are the benefits of AR based training in enhancing skills among TVET students? What is the relationship between the use of AR and student engagement in TVET institutions? How effective is AR integration, and what challenges do TVET students face in aligning with industry requirements?

Step 2: Identifying Relevant Studies. To ensure a comprehensive literature review, keyword-based searches were conducted in two major academic databases: Web of Science (WoS) and Scopus. These databases were chosen for their wide coverage of high-quality publications in relevant fields such as Computer Science, Social Sciences, Engineering, Science and Technology, and Education. Thematic searches were conducted using established keywords related to AR, TVET, student engagement, and manufacturing skills (see Figure 2).

Step 3: Study Selection. Articles were screened using clear inclusion and exclusion criteria. The included studies had to meet the following conditions: published in English between 2020 and 2024, focused on AR in educational contexts, particularly within the disciplines mentioned above, and published as peer-reviewed research articles. Excluded materials included conference proceedings, book chapters, review articles, and publications unrelated to the field of education.

Step 4: Charting the Data. To facilitate thematic and comparative analysis, the selected articles were organized in Microsoft Excel. The extracted data included author names, publication year, research focus, key findings, studied variables, and thematic classifications. A comprehensive table was created to synthesize this information and address the research questions (see Table 1).

Step 5: Collating, Summarizing, and Reporting Results. The findings were organized according to overarching themes and sub-themes that emerged through comparative analysis. Each selected article was classified and discussed based on its relevance to the study objectives. The characteristics of the reviewed studies are visualized in Figures 3, 4, and 5, which display patterns in research topics, geographic distribution, and publication trends.

Step 6: Interpreting and Discussing the Results. The results were analyzed with the research questions and study objectives. Given the novelty of AR applications in TVET, this section also discusses study limitations and proposes directions for future research. The conclusions provide a holistic understanding of how AR can enhance student engagement and conceptual learning in vocational education settings.

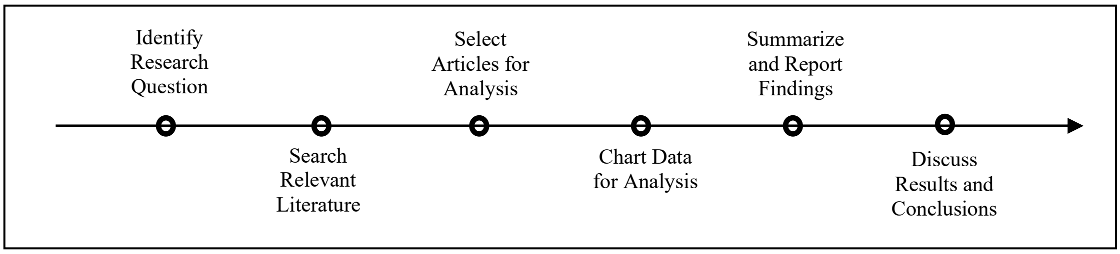

Fig. 1. Research Process - Six-step Methodology developed by Arksey & O'Malley (2005)

3. Results and Discussion

Based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, as shown in Othman et al. (2024) a total of 392 records were initially identified through comprehensive searches in the Web of Science (WoS) and Scopus databases. The search strategy employed key terms such as "Augmented Reality", combined with related keywords including "TVET", "manufacturing skills", "student engagement", and "industry requirements". These terms were selected to capture a wide range of studies investigating the role of AR in enhancing learning experiences and engagement among TVET students.

3.1. Identification and Selection Process

During the identification phase, 265 records were excluded because they did not meet the predefined criteria. The excluded publications comprised systematic reviews, meta-analyses, meta-syntheses, book chapters, non-English language articles, and papers published before 2020. Following this, 127 records proceeded to the screening stage.

In the screening phase, 34 duplicate entries were removed, leaving 93 unique articles for full-text review. Upon assessing these for eligibility, 76 articles were excluded as irrelevant to the research focus, due to a lack of empirical data or misalignment with the study's objectives.

Finally, 17 articles met all inclusion criteria and were selected for quantitative synthesis. These studies were further assessed for methodological rigor and data quality to ensure the integrity and relevance of the findings presented in this review.

This rigorous selection process, illustrated in the PRISMA flow diagram (Figure 2), aligns with established best practices in systematic and scoping reviews (Kraus et al., 2020; Johnson & Christensen, 2020; Tranfield et al., 2003; Moher et al., 2016). It enhances credibility, transparency, and reproducibility, ensuring the final analysis is grounded in high-quality, contextually relevant literature.

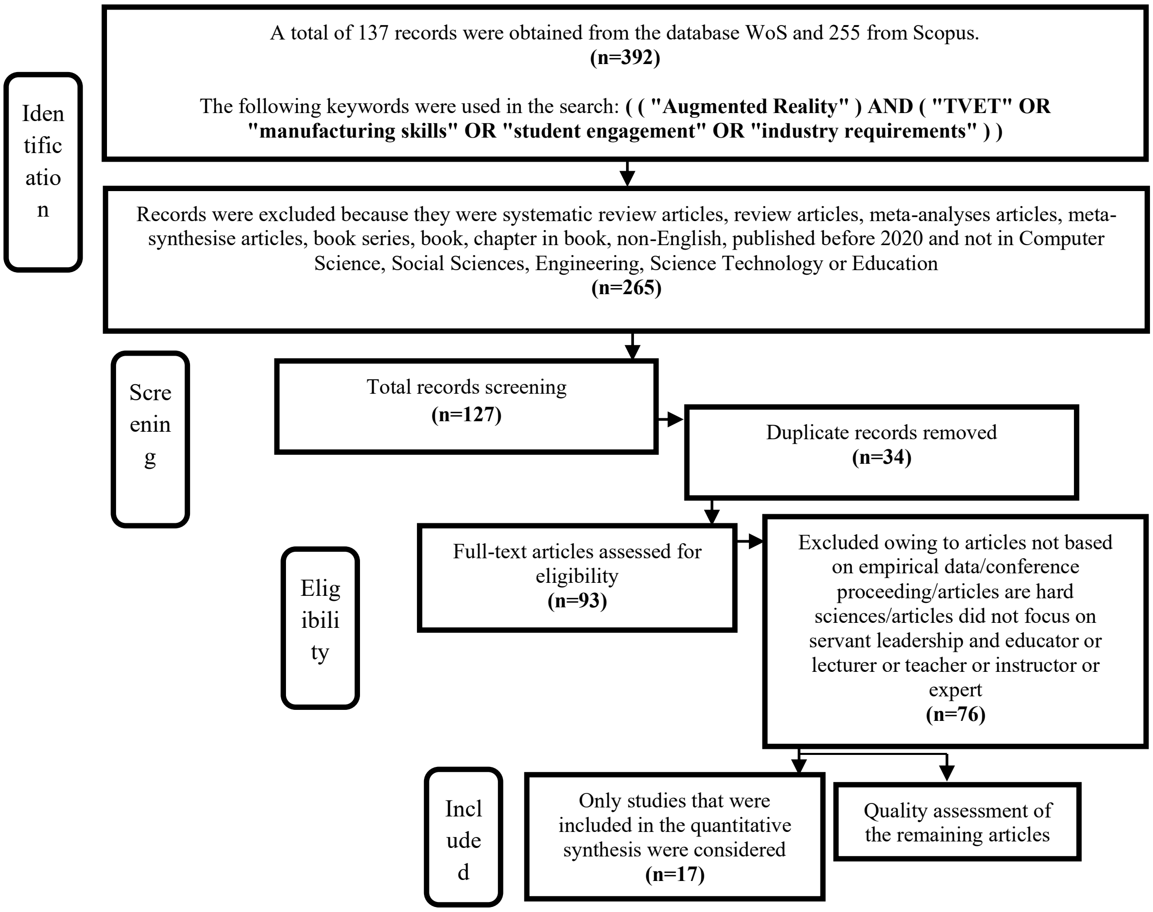

Fig. 2. Flow diagram of research selection process using Preferred Reporting Items for Systematic Reviews (PRISMA) adapted from a study by Moher et al. (2016)

3.2. Main Findings

Based on the established criteria, 17 peer-reviewed articles were selected and analyzed for this scoping review [Lampropoulos & Chen, 2025; Costa et al., 2021; Shkilev et al., 2024; Faria & Miranda, 2024; Althibyani, 2023; Chung et al., 2021; Abdul Hamid et al., 2024; Masneri et al., 2024; Aldaihani, 2023; Villegas-Ch et al., 2024; Rohandi et al., 2024; Lu et al., 2022; Wulansari et al., 2024; Jalil et al., 2024; Liu et al., 2022; Topalska, 2024; Del Moral-Perez et al., 2024].These studies were systematically evaluated and categorized into three overarching themes: Application of AR in Enhancing TVET Learning Experiences; Challenges and Barriers in Implementing AR in TVET Institutions; and Student and Instructor Acceptance of AR Technology in TVET.

3.2.1. Theme 1: Application of AR in Enhancing TVET Learning Experiences

Evidence suggests that AR enhances student engagement, conceptual understanding, and motivation in vocational training contexts (Shkilev et al., 2024; Jalil et al., 2024). AR simulations allow learners to interact with three-dimensional models of machines, circuits, and industrial systems, bridging the gap between theory and practice. For example, Costa et al. (2021) reported that AR-based learning games improved student motivation and performance by promoting hands-on experiences and collaborative problem-solving. Similarly, Jalil et al. (2024) showed that an AR-based chiller system simulation improved students' comprehension of HVAC concepts, which are traditionally challenging to teach through text and diagrams.

From a theoretical perspective, these findings are consistent with Mayer's Cognitive Theory of Multimedia Learning (CTML), which posits that combining verbal and visual modes of information processing enhances comprehension and reduces extraneous cognitive load. AR's capacity to embed interactive elements aligns with CTML principles by supporting dual-channel learning and fostering active cognitive engagement. In practice, this means that vocational students are not merely passive recipients of content but active participants in immersive learning environments.

Furthermore, AR supports experiential learning theory (Kolb, 1984), where learners cycle through concrete experiences, reflective observation, abstract conceptualization, and active experimentation. By simulating authentic industrial processes, AR allows TVET students to practice skills in a low-risk environment, thereby accelerating competence development and self-confidence.

3.2.2. Theme 2: Challenges and Barriers in Implementing AR

Despite its benefits, several critical barriers constrain the integration of AR into TVET. High implementation costs remain the most significant challenge, particularly in resource-constrained institutions (Abdul Hamid et al., 2024). Hardware such as AR headsets, as well as software development and maintenance, require substantial financial investment. Limited institutional budgets often mean that AR adoption is uneven, concentrated in well-funded urban institutions while rural and under-resourced colleges remain excluded.

Another barrier is the shortage of trained instructors, Rohandi et al. (2024) noted that many educators lacked the digital skills necessary to effectively integrate AR into their teaching. Without targeted professional development programs, AR risks being underutilized or misapplied, reducing its effectiveness. Moreover, infrastructural challenges such as unstable internet connectivity and insufficient access to compatible devices further hinder implementation (Liu et al., 2022).

These barriers function as moderating variables in AR adoption, shaping the extent to which AR positively influences learning outcomes. For example, even if AR applications are pedagogically sound, weak infrastructure or limited teacher readiness can dilute their impact. This echoes previous findings in broader digital learning research, which emphasize that technology integration is most successful when accompanied by systemic support, institutional commitment, and capacity-building initiatives.

3.2.3. Theme 3: Student and Instructor Acceptance of AR

Acceptance of AR by students and instructors emerged as a crucial factor mediating its successful implementation. Studies by Lampropoulos & Chen (2025) and Apicella et al. (2022) demonstrated that students with higher digital literacy and prior exposure to interactive technologies were more likely to embrace AR, reporting increased engagement and learning motivation. Conversely, students with limited digital readiness expressed difficulties adapting to AR based tasks.

Instructor acceptance is equally vital. Wulansari et al. (2024) highlighted that teacher readiness directly influenced the effectiveness of AR interventions, with motivated and digitally literate instructors more likely to design engaging, student centered AR activities. In this sense, acceptance functions as a mediating variable, linking AR usage with student outcomes. Without widespread acceptance among both educators and learners, the potential of AR to transform TVET education cannot be fully realized. Overall, the findings suggest that while AR holds substantial potential to enhance learning experiences in TVET, its successful implementation depends on a strategic approach that includes adequate technological infrastructure, instructor training, and institutional commitment. Without addressing these structural and contextual barriers, the transformative promise of AR in vocational education may remain underutilized.

Table 1. Charting the data

Publication	Variables/Construct	Key Finding	Sub-Theme	Theme
Lampropoulos et al. (2022)	Independent: Extended Reality (XR) Mediating: Learning Perception Moderating: System Usability Dependent: Learning Effectiveness, Engagement, Motivation, Learning Outcomes	A validated evaluation tool was developed to assess the educational impact of extended reality applications. Results confirmed that AR and VR significantly improve student engagement, motivation, and learning outcomes, but usability challenges remain.	Impact of digital literacy	Application of AR
Costa et al. (2021)	Independent: Augmented Reality (AR), Mobile Technologies Dependent: Student Engagement, Learning Performance, Game-Based Learning	AR-based location games significantly improved student engagement and motivation in learning astronomy. The study demonstrated that AR enhances hands-on learning and promotes competition among students.	Technical skill development	
Shkilev et al. (2024)	Independent: Augmented Reality (AR), Mobile Learning Mediating: Student Engagement Moderating: Digital Literary Dependent: Interactive Learning, Knowledge Retention, Learning Motivation	AR in mobile learning enhances student engagement, improves knowledge retention, and supports experiential learning. The study highlighted challenges such as technological barriers and the need for revised instructional approaches.	Student engagement	
Faria & Miranda (2024)	Independent: Augmented Reality (AR), Mediating: Guided Inquiry & Pecha Kucha Dependent: Academic Performance, Conceptual Understanding, Student Engagement	AR combined with guided inquiry and Pecha Kucha significantly improved short-term academic performance and conceptual understanding of meiosis. However, long-term retention showed minimal difference compared to traditional methods.	Motivation in learning	
Althibyani (2023)	Independent: Augmented Reality (AR) Mediating: Student Attitudes Moderating: Instructional Design Dependent: Student Engagement, Visualization, Learning Experience	AR significantly improved student engagement, attitude, and visualization skills in learning 3D geometry. Higher completion rates, increased learning time, and improved attitudes were observed in the experimental group.	Technology Integration	
Chung et al. (2021)	Independent: Augmented Reality (AR) Mediating: Group Interaction Moderating: Task Performance Dependent: Collaborative Problem Solving (CPS), Verbal Communication, Attitudes	AR improved collaborative problem-solving efficiency, enhanced group communication and increased engagement in programming tasks. Participants in AR settings had higher task performance and more effective communication.	Technology Integration	
Abdul Hamid et al. (2024)	Independent: Augmented Reality (AR), Skill Training Mediating: TVET Instructors' Perceptions Moderating: Policy and Technology Barriers Dependent: Student Engagement, Technology Adoption Challenges	TVET instructors perceive AR as beneficial for skill training, enhancing students' engagement and practical understanding. However, challenges include technological barriers, instructor expertise, and institutional policy constraints.	Challenges in policy and funding	Challenges in Implementing
Masneri et al. (2024)	Independent: Augmented Reality (AR), Collaborative Learning Mediating: Multi-User Interaction	A collaborative AR application enhanced student engagement and learning experiences by allowing multi-user interactions and integration with	Collaborative Learning	

Publication	Variables/Construct	Key Finding	Sub-Theme	Theme
	Moderating: Learning Environment Dependent: Student Engagement, Learning Experience, Usability, Data Analytics	learning management systems. Teachers and students reported positive feedback on usability and effectiveness.		
Aldaihani (2023)	Independent: Mixed Reality (MR) Dependent: Student Engagement (Behavioral, Cognitive, Emotional)	All mixed reality technologies positively impacted student engagement, with the highest impact from AR and the lowest from AV. AR and VR enhanced cognitive and behavioral engagement, while AV had a weaker effect. Universities should invest in AR tools such as interactive screens and 3D mobile applications to increase student.	Infrastructure constraints	
Rohandi et al. (2024)	Independent: Augmented Reality (AR), Digital Learning Tools Dependent: Student Engagement, Learning Motivation, Conceptual Understanding in Network Topologies	AR-based learning media significantly enhanced student engagement, motivation, and conceptual understanding of network topologies. The interactive 3D visualization allowed students to explore network components virtually, improving practical comprehension.	Infrastructure constraints	
Villegas-Ch et al. (2024)	Independent: Extended Reality (XR) Mediating: Learning Motivation Dependent: Student Engagement, Self-Efficacy, Emotional Response	XR significantly improved student engagement, motivation, and self-efficacy in science and engineering courses. AR increased motivation and relevance perception, while VR enhanced critical thinking and self-efficacy in problem-solving. Emotional responses varied by technology type and implementation context.	Student engagement	Acceptance of AR Technology
Lu et al. (2022)	Independent: Augmented Reality (AR), Flipped Learning, Gamification Dependent: Student Engagement, Learning Attitude, Motivation, Cognitive Load	AR-supported flipped and gamified learning improved student motivation, engagement, and cognitive processing in higher education Chemistry. The study showed positive feedback from students, though implementation challenges remain.	Flipped and Gamified Learning	
Wulansari et al. (2024)	1 Independent: Gamification-Augmented Reality (GAR), Problem-Case Method Dependent: Student Engagement, Critical Thinking, Creative Thinking, Classroom Interactivity	GAR significantly improved vocational students' engagement, critical thinking, and creative thinking. Gamification elements increased participation, while AR facilitated hands-on learning and problem-solving. The experimental group outperformed the control group in classroom interactivity and knowledge retention.	Influence of educator readiness	
Jalil et al. (2024)	Independent: Augmented Reality (AR), Chiller System Simulation Dependent: Student Engagement, Perceived Usefulness, Perceived Ease of Use	AR-based chiller system simulation enhanced student engagement, comprehension of complex HVAC concepts, and overall learning motivation. Students found AR highly useful and easy to use in vocational education settings.	Realistic simulation for training	
Liu et al. (2022)	Independent: Augmented Reality (AR) Mediating: Student Motivation Moderation: Technology Accessibility	AR-based training significantly improved students' engagement in school physical education, enhancing spatial orientation and athletic skills. However, high computational	Barriers in implementation	

Publication	Variables/Construct	Key Finding	Sub-Theme	Theme
	Dependent: Physical Education Training, Student Engagement, Sports Performance, Learning Outcomes	requirements and hardware costs remain challenges for large-scale implementation.		
Topalska (2024)	Independent: Modern Information Technologies Mediating: Teacher Knowledge Moderating: Institutional Barriers Dependent: Technology Integration, Student Engagement	Despite recognizing the benefits of AR and VR in education, Bulgarian teachers face barriers such as limited training, lack of resources, and resistance to technological change. Greater investment in training and infrastructure is necessary to bridge the gap between potential and actual implementation.	Technology Adoption	
Del Moral-Perez et al. (2024)	Independent: Augmented Reality (AR), Artificial Intelligence (AI), Gamification Dependent: Transmedia Skill, Student Engagement, Narrative Creativity	AR and AI-based transmedia game design enhanced student engagement, creativity, and storytelling abilities. It facilitated deeper learning through immersive, interactive challenges.	Technology Adoption	

Based on the findings, a conceptual framework was developed to illustrate the role and integration of AR within the TVET context. This framework synthesizes the three main themes identified in the review: AR application, implementation challenges, student and instructor acceptance, as presented in Figure 3. It serves as a strategic guide for educational institutions and policymakers in formulating effective approaches to support the adoption and sustainability of AR technologies in TVET education.

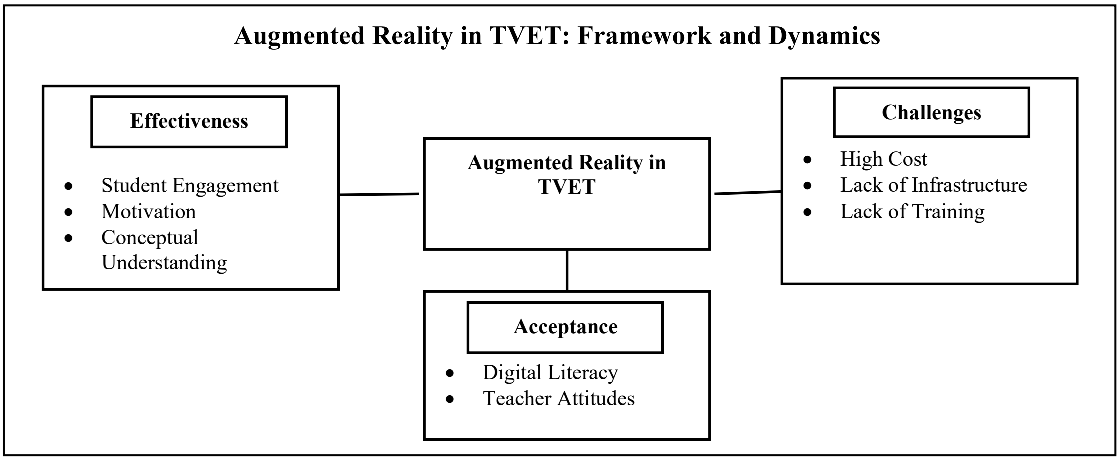

Fig. 3. Conceptual framework on AR in the TVET Context

3.3. Geographical and Temporal Trends

Figure 4 presents the geographical distribution of research studies related to AR in education, as included in this scoping review. The data indicates that prior research was conducted across 10 different countries, with one study each from Russia (Shkilev et al., 2024), Poland (Topalska, 2024), Saudi Arabia (Althibyani, 2023), Kuwait (Aldaihani, 2023), Hong Kong (Lu et al., 2022), Spain (Del Moral-Perez et al., 2024), Greece (Lampropoulos & Chen, 2025); China (Liu et al., 2022), Mexico (Vázquez-Cano et al., 2020), and South Korea (Chung et al., 2021). Additionally, two studies were conducted in Portugal (Costa et al., 2021; Faria & Miranda, 2024) and Indonesia (Wulansari et al., 2024; Rohandi et al., 2024). Notably, the highest concentration of research was found in Malaysia, with three studies included in this review (Masneri et al., 2024; Jalil et al., 2024; Abdul Hamid et al., 2024).

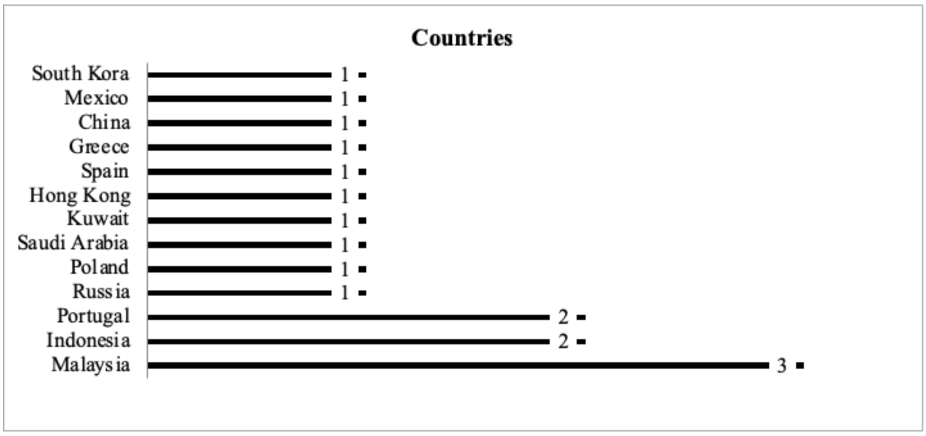

Fig. 4. Number of research studies based on countries

In summary, the number of published articles on this topic has shown a consistent upward trend over the years. Figure 5 illustrates the annual distribution of publications indexed in Web of Science and Scopus from 2020 to 2025. According to the data, one article was published in 2020, followed by two publications in 2021 and one in 2022. In 2023, the number slightly increased to two publications. Notably, a significant surge occurred in 2024, with ten articles published, representing the highest output within the review period. Finally, one article is projected for publication in 2025.

This publication trend directly addresses the second research question concerning the evolution of scholarly interest in AR applications in education. The findings indicate a growing body of research focused on AR's role in enhancing student learning and engagement across diverse educational contexts. The sharp increase in publications, particularly in 2024, highlights the rising relevance and potential impact of AR in current educational contexts, suggesting that this area of research is gaining significant momentum globally.

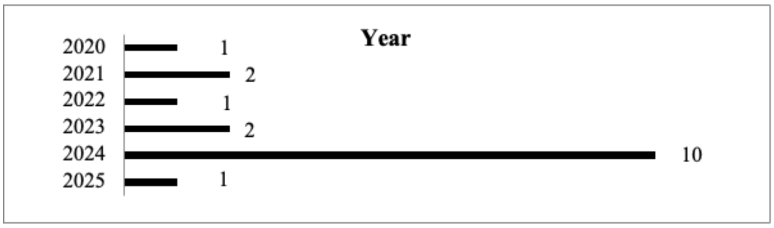

Fig. 5. Year of Publications in WoS and Scopus database

Despite the observed growth in publication volume, research on AR in education remains relatively nascent, particularly in evaluating its effectiveness in enhancing comprehension and knowledge retention. While AR is increasingly recognized as a valuable instructional tool, further empirical investigation is necessary to establish its long-term impact, effective pedagogical integration, and scalability across diverse educational settings.

Another key observation is the geographical concentration of existing studies, with limited exploration of AR implementation across varied socio-cultural and institutional contexts. Compared to the broader body of literature on digital learning technologies, research focusing on AR's unique contribution to student engagement and learning outcomes remains sparse.

These gaps underscore the need for future research to extend beyond current applications. Priorities should include longitudinal studies that assess sustained learning outcomes, comparative analyses with traditional teaching methods, and the development of standardized frameworks to guide AR integration in education. As AR technology improves, robust and context-sensitive evidence is essential to optimize its application and fully harness its potential to transform teaching and learning.

3.4. Discussion

The findings of this study confirm that AR has a notable impact on enhancing students' learning experiences within the TVET sector. However, several implementation challenges must be addressed for AR to achieve long-term effectiveness. Three main themes emerged from the review, each offering a deeper understanding of how AR can be effectively utilized in the TVET education system.

First, the application of AR has been shown to significantly enhance student engagement, conceptual understanding, and the effectiveness of technical skills training (Shkilev et al., 2024; Jalil et al., 2024). These findings are consistent with previous research, which highlights AR's ability to promote active learning and improve student performance in vocational and technical education environments (Costa et al., 2021; Vázquez-Cano et al., 2020).

Nevertheless, the implementation of AR in TVET continues to face considerable obstacles. This study identified high development costs, a shortage of trained instructors, and inadequate infrastructure as key barriers to adoption (Abdul Hamid et al., 2024; Liu et al., 2022; Rohandi et al., 2024). These challenges mirror those found in prior studies, which emphasize the need for institutional investment in digital infrastructure and teacher professional development to employ AR technologies efficiently.

Furthermore, acceptance of AR by students and instructors plays a critical role in its successful integration. The review found that students with higher levels of digital literacy were more likely to adopt AR as a learning tool (Lampropoulos & Chen, 2025), whereas those with limited exposure to technology often struggled to adapt to AR-based learning environments (Apicella et al., 2022). These acceptance factors must be carefully considered when designing AR-based interventions to ensure inclusivity and maximize learning effectiveness.

This study contributes to the progress of digital learning theory by reaffirming that AR positively influences student engagement and learning outcomes in TVET contexts. It also supports theoretical perspectives that suggest interactive technologies can significantly enhance learning, particularly in skills-based training environments. A summary of the reviewed literature and corresponding thematic categories is presented in Table 2.

Table 2. The role of AR in enhancing student learning and engagement

	Independent	Mediating	Dependent
Process	Lampropoulos & Chen (2025) Costa et al. (2021) Shkilev et al. (2024)	Jalil et al. (2024) Abdul Hamid et al. (2024) Rohandi et al. (2024)	Lu et al. (2022)
Outcome	Faria & Miranda (2024) Althibyani (2023) Masneri et al. (2024)	Wulansari et al. (2024) Aldaihani (2023)	Chung et al. (2021)
Enabler	Vizquez-Villegas et al. (2023) Del Moral-Perez et al. (2024)	Liu et al. (2022)	Rohandi et al. (2024)

From a practical perspective, this study highlights the need for TVET institutions to adopt a strategic approach to implementing AR technologies. Key strategies include providing professional development programs for instructors to enhance their competencies in integrating AR into teaching and learning activities; developing interactive and user-friendly AR content to maximize student engagement and improve learning outcomes; and fostering partnerships with industry stakeholders to secure technological support and infrastructure for sustainable AR implementation.

From a policy perspective, the findings suggest that governments and educational authorities must formulate comprehensive policies to facilitate AR integration in TVET education. Recommended actions include allocating grants and special funding schemes to enable TVET institutions to invest in AR technology and related resources; establishing national guidelines and standards to support consistent and effective adoption of AR across TVET programs; and implementing awareness campaigns and training initiatives aimed at increasing the acceptance and readiness of both students and educators in accepting AR-based learning.

3.5. Limitations and Recommendations

Although this study provides a comprehensive overview of the use of AR in TVET education, several limitations must be acknowledged. One primary limitation lies in the scope of the study, as the analysis was based on only 17 selected articles presented in Table 1. Furthermore, majority of the reviewed studies are conceptual or experimental, often conducted in controlled environments rather than real-world educational settings, thus limiting insights into practical, large-scale implementation.

Additionally, this review does not directly evaluate the effectiveness of AR usage in Malaysia or any other specific country context. Instead, it presents a global analysis. As a result, factors such as cultural differences, institutional support structures, and national education policies, which can significantly influence the acceptance and successful integration of AR in TVET, are not fully explored.

Another critical limitation is the lack of longitudinal studies among the articles analyzed. Most studies assessed only the short-term impacts of AR on student engagement and learning outcomes, while the long-term effects on academic performance and graduate employability remain largely undocumented.

To address these limitations and strengthen future research on AR in TVET, several recommendations are proposed:

First, future studies should prioritize field-based research that examines the real-world application of AR in TVET settings. This includes evaluating the long-term effects of AR usage on academic achievement and post-graduation employment outcomes.

Second, comparative studies across different countries are needed to analyze how variations in educational policy, technological infrastructure, and cultural readiness affect AR implementation success.

Third, greater emphasis should be placed on systematic training programs for instructors, as teachers lacking digital competencies may struggle to effectively utilize AR in their teaching. Professional development initiatives and specialized AR training curricula should be strengthened.

Finally, policymakers and educational leaders should actively promote longitudinal research to investigate the sustained impact of AR on student skills development and employability in the evolving job market.

Overall, despite the challenges identified, the findings of this study suggest that strategic initiatives, including continued research, enhanced teacher training, and supportive technology oriented policies, are essential to ensure the successful, scalable, and sustainable integration of AR into TVET education in the future.

3.6. Implications

This study offers significant implications for theory, educational practice, and institutional policy concerning the integration of AR in TVET education.

From a theoretical perspective, the findings support the view that interactive technologies enhance student engagement and learning effectiveness, particularly within technical skills training environments. Moreover, this study helps to understand how mediating variables, such as digital literacy and technology acceptance, influence the success of AR implementation in educational contexts.

From an educational practice perspective, the results indicate that TVET institutions must provide systematic and ongoing professional development for teaching staff to strengthen their competencies in utilizing AR technologies effectively. Furthermore, the integration of AR should be accompanied by the design of interactive, industry-relevant content to ensure students can apply their skills in authentic and meaningful ways.

In terms of institutional policy, the study underscores the importance of investing in technological infrastructure and providing financial support to expand access to AR tools across TVET institutions. Additionally, policymakers should promote and support longitudinal research efforts to evaluate the long-term impact of AR on graduate employability and the evolving needs of industry.

Overall, this study provides valuable direction for educators, institutional leaders, and policymakers in ensuring that the adoption of AR in TVET education is implemented effectively, strategically, and sustainably.

4. Conclusion

This scoping review has provided a comprehensive synthesis of the role of Augmented Reality (AR) in Technical and Vocational Education and Training (TVET). By systematically analyzing 17 peer-reviewed studies, three major themes emerged: the application of AR in enhancing student learning experiences, the challenges and barriers in its implementation, and the acceptance of AR by students and instructors. The findings consistently confirm that AR improves student engagement, motivation, and conceptual understanding, particularly in simulation-based training contexts where theory must be directly applied to practice.

Despite these benefits, the adoption of AR in TVET remains constrained by structural challenges. High implementation costs, limited infrastructure, and a lack of trained instructors represent significant barriers that hinder scalability and sustainability. Moreover, acceptance by students and educators emerged as a crucial mediating factor. Students with higher digital literacy adapt more readily to AR-based environments, while instructors with adequate training and positive attitudes are better positioned to design effective, learner centered AR activities. These findings underscore that AR integration cannot be reduced to technological adoption alone; it requires systemic support, institutional readiness, and long-term investment.

The implications of this study extend beyond pedagogy. For policymakers, the results highlight the urgency of providing financial incentives, national guidelines, and infrastructure support to facilitate AR adoption in TVET. For educators, the findings reinforce the need for continuous professional development and the creation of context-relevant AR content. From an industry perspective, AR-enabled training can bridge skills gaps and prepare a workforce that is agile, digitally competent, and ready for Industry 4.0 environments.

In conclusion, while AR has demonstrated substantial potential to transform TVET, its success depends on collaborative efforts between policymakers, educators, and industry stakeholders. Strategic planning, supportive policy frameworks, and sustained research are essential to ensure that AR is effectively integrated and that vocational students are adequately prepared for the future of work.

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