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INNOVATION IN VOCATIONAL EDUCATION: IMMERSIVE ENVIRONMENTS AND STEAM METHODOLOGIES FOR THE DEVELOPMENT OF TECHNICAL SKILLS: AN INTEGRATIVE REVIEW

INOVAÇÃO NA EDUCAÇÃO PROFISSIONAL: AMBIENTES IMERSIVOS E METODOLOGIAS STEAM PARA O DESENVOLVIMENTO DE COMPETÊNCIAS TÉCNICAS – UMA REVISÃO INTEGRATIVA DE LITERATURA

INNOVACIÓN EN LA EDUCACIÓN PROFESIONAL: ENTORNOS INMERSIVOS Y METODOLOGÍAS STEAM PARA EL DESARROLLO DE HABILIDADES TÉCNICAS—UNA REVISIÓN INTEGRATIVA

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Abstract

This study evaluated the impact of immersive and hybrid learning environments on vocational education, focusing on teaching computer hardware. An integrative review was conducted from 21 October to 9 November, exploring STEAM methodologies, Design Thinking, and technologies like Virtual Reality (VR) and Augmented Reality (AR) that support hands-on learning for digital natives. The research examined how immersive (VR, AR) and hybrid (traditional and digital) environments affect practical hardware education and the role of STEAM, Design Thinking, and virtual classrooms in enhancing these methods. Articles from ACM, ERIC, and ScienceDirect (published since 2020) were selected for relevance and methodological rigor. Findings suggest that immersive environments improve engagement and knowledge retention, especially in technical fields where VR and AR enable safe, simulated practices. STEAM methodologies and Design Thinking encourage problem-solving and creativity, preparing students for professional challenges. However, barriers such as cost and teacher training limit widespread adoption. Despite these challenges, integrating these technologies transforms vocational education, fostering practical skills and motivation. Further research on technological acceptance and long-term effects is recommended to optimize their implementation and effectiveness in education.

Keywords: Immersive learning environments, hybrid learning, vocational education, computer hardware teaching, STEAM methodologies, Virtual Reality, Augmented Reality.

Resumo

Este estudo avaliou o impacto de ambientes de aprendizagem imersivos e híbridos no ensino profissional, centrando-se no ensino de hardware informático. Foi realizada uma revisão integrativa de 21 de outubro a 9 de novembro, explorando metodologias STEAM, Design Thinking e tecnologias como a Realidade Virtual (RV) e a Realidade Aumentada (RA) que apoiam a aprendizagem prática para nativos digitais. A investigação examinou a forma como os ambientes imersivos (RV, RA) e híbridos (tradicionais e digitais) afetam o ensino prático de hardware e o papel do STEAM, do Design Thinking e das salas de aula virtuais na melhoria destes métodos. Foram selecionados artigos do ACM, ERIC e ScienceDirect (publicados desde 2020) pela sua relevância e rigor metodológico. Os resultados sugerem que os ambientes imersivos melhoram o envolvimento e a retenção de conhecimentos, especialmente em domínios técnicos em que a RV e a RA permitem práticas seguras e simuladas. As metodologias STEAM e o Design Thinking incentivam a resolução de problemas e a criatividade, preparando os alunos para os desafios profissionais. No entanto, obstáculos como o custo e a formação dos professores limitam a sua adoção generalizada. Apesar destes desafios, a integração destas tecnologias transforma o ensino profissional, promovendo as competências práticas e a motivação. Recomenda-se mais investigação sobre a aceitação tecnológica e os efeitos a longo prazo para otimizar a sua implementação e eficácia no ensino.

Palavras-chave: Ambientes de aprendizagem imersivos, aprendizagem híbrida, educação profissional, ensino de hardware de computadores, metodologias STEAM, Realidade Virtual, Realidade Aumentada.

Resumen

Este estudio evaluó el impacto de los entornos de aprendizaje inmersivos e híbridos en la formación profesional, centrándose en la enseñanza de hardware informático. Del 21 de octubre al 9 de noviembre se llevó a cabo una revisión integradora, explorando metodologías STEAM, Design Thinking y tecnologías como la Realidad Virtual (RV) y la Realidad Aumentada (RA) que apoyan el aprendizaje práctico para nativos digitales. La investigación examinó cómo los entornos inmersivos (RV, RA) e híbridos (tradicionales y digitales) afectan a la enseñanza práctica de hardware y el papel de STEAM, Design Thinking y las aulas virtuales en la mejora de estos métodos. Se seleccionaron artículos de ACM, ERIC y ScienceDirect (publicados desde 2020) por su relevancia y rigor metodológico. Los hallazgos sugieren que los entornos inmersivos mejoran el compromiso y la retención de conocimientos, especialmente en campos técnicos donde la RV y la RA permiten prácticas seguras y simuladas. Las metodologías STEAM y Design Thinking fomentan la resolución de problemas y la creatividad, preparando a los estudiantes para los retos profesionales. Sin embargo, barreras como el coste y la formación del profesorado limitan su adopción generalizada. A pesar de estos retos, la integración de estas tecnologías transforma la formación profesional, fomentando las habilidades prácticas y la motivación. Se recomienda seguir investigando sobre la aceptación tecnológica y los efectos a largo plazo para optimizar su implantación y eficacia en la educación.

Palabras-clave: Entornos de aprendizaje inmersivos, aprendizaje híbrido, educación profesional, enseñanza de hardware informático, metodologías STEAM, Realidad Virtual, Realidad Aumentada.

1 INTRODUCTION

The rapid advancement of new technologies has significantly transformed education. Immersive learning environments, such as Virtual Reality (VR) and Augmented Reality (AR), as well as hybrid models that integrate traditional and digital elements, provide new pedagogical opportunities. These technologies enhance engagement and interaction, especially for 'digital natives' (Prensky, 2001), offering personalized and practical learning experiences. In vocational education, where practical skills are crucial, immersive and hybrid environments emerge as effective alternatives for teaching computer hardware, promoting knowledge retention and technical competency.

Research on immersive environments and innovative methodologies has expanded, with studies emphasizing the benefits of VR and AR in education. Lampropoulos et al. (2024) highlight the role of affective computing in personalizing immersive learning, increasing student engagement and motivation. Jesionkowska et al. (2020) explore VR and AR in STEAM education, demonstrating how these technologies foster collaboration and technical skill development, essential for future careers.

STEAM methodologies and Design Thinking play a vital role in modern education, enhancing creativity, problem-solving, and innovation (Anderson & Shattuck, 2012). Virtual classrooms further integrate digital elements into pedagogy, reinforcing the impact of hybrid environments (Garrison & Vaughan, 2008). This literature supports investigating how immersive and hybrid environments enhance vocational training in computer hardware.

This study aims to analyse how immersive and hybrid environments contribute to developing practical computer hardware skills in vocational education, focusing on STEAM methodologies, Design Thinking, and virtual classrooms. It examines how VR, AR, and hybrid models impact skill acquisition, assessing engagement, retention, and technical competence in these environments. Additionally, it explores how STEAM methodologies, Design Thinking, and virtual classrooms support immersive learning, evaluating their role in problem-solving and real-world application.

By integrating digital technologies in vocational education, this research deepens the understanding of how immersive and hybrid environments influence technical skill development. It examines the effectiveness of pedagogical innovations like VR, AR, and Design Thinking in preparing students for an increasingly digital job market.

The article follows a structured approach: the introduction contextualizes immersive and hybrid environments in vocational education. The methodology outlines study selection criteria, focusing on systematic reviews and recent articles from ACM, ERIC, and ScienceDirect, which examine STEAM methodologies and Design Thinking in technical education. The results discuss benefits in knowledge retention and technical skill acquisition, alongside challenges such as costs and teacher training. The discussion addresses implications and limitations, while the conclusion reinforces the transformative potential of immersive and hybrid environments, suggesting future research directions. This structure ensures a logical and in-depth exploration of the topic, highlighting its relevance in contemporary education. Given the exploratory and interpretative nature of the topic, this study adopts an integrative literature review approach rather than a scoping review. This methodological choice allows for the synthesis of findings from heterogeneous studies, integrating empirical and conceptual evidence to provide a more nuanced understanding of how immersive and hybrid environments, STEAM methodologies, and Design Thinking intersect in vocational education. Such an approach is particularly relevant in an emerging and fragmented research field, where deep synthesis is more informative than broad mapping.

2 METHOD

This study adopts an integrative literature review approach to investigate and synthesise the available evidence on the use of immersive learning environments, hybrid environments, vocational education, and STEAM methodologies for developing competencies in computer hardware. This methodological choice was guided by the exploratory and interpretative nature of the research, which seeks to synthesise and critically interpret emerging evidence in a rapidly evolving and fragmented field. Unlike a scoping review, which primarily maps the breadth of available studies, the integrative review approach enables a deeper synthesis of findings across different methodological designs, combining empirical, conceptual, and mixed-method contributions to inform future pedagogical innovations. The integrative review allows for the inclusion of studies with various methodological designs, providing a comprehensive and detailed view of the available evidence, which aids in identifying gaps in the literature and formulating new research hypotheses. To strengthen the robustness of the review, the search strategy and inclusion criteria were refined during the process to ensure that the corpus of studies captured the diversity and recency of the field. These adjustments allowed for the incorporation of additional relevant studies and provided a broader evidence base, which is now reflected in the expanded analysis and synthesis presented in the results.

This review focused on articles published since 2020, in English, and followed a systematic process of selection, analysis, and synthesis of data collected from three main databases: ACM, ERIC, and ScienceDirect. A narrative analysis enabled a comprehensive and critical interpretation of the data, considering the most current practices and methodologies in the fields of STEAM education, immersive technologies, and vocational education.

Data collection began with the definition of specific keywords that guided the searches in the databases: [Immersive learning environments], [hybrid environments], [vocational education], [STEAM], and [Computer Hardware]. Based on these keywords, searches were conducted in three academic databases:

1. ACM: This platform provided several articles addressing the main themes. After a preliminary analysis of the results, 25 articles were initially selected for a more detailed evaluation. Of these, and after a second analysis focused on relevance and methodological quality, 10 articles were included in the final review.
2. ERIC (Education Resources Information Center): As a database specialised in education topics, the search resulted in several pertinent articles for this review. Of the identified articles, 2 were considered most relevant to the review's objectives and included in the final analysis.
3. ScienceDirect: The search in this database yielded multiple articles related to the addressed themes. Initially, 7 articles were selected, but after a detailed analysis considering relevance, methodological rigour, and data quality, only 4 articles were retained for the final review.

During the research, adjustments were made to refine the results and increase precision in obtaining studies directly related to the review's objectives. For example, some searches focused on case studies such as "A Case Study on Computer Hardware Diagnostics in Secondary Education," "Virtual Reality in Vocational Education: Improving Hardware Assembly Skills," and "Augmented Reality Tools for Computer Hardware Diagnostics in Secondary Schools," which provided an empirical basis for understanding how virtual and augmented reality can be applied in technical and vocational education.

The inclusion criteria for this review were:

- Articles published between 2020 and 2024, in English.
- Studies addressing the use of immersive and hybrid environments, STEAM methodologies, and technologies applied to teaching computer hardware and vocational education.
- Studies with clear and reproducible methodologies that provided evidence of impact on teaching practices.

Articles were excluded if they:

- Were not available in full text.
- Were duplicates across the databases.
- Addressed the topic tangentially, without a clear focus on education, computer hardware, or STEAM methodologies.

To ensure a rigorous and coherent analysis, each selected article was reviewed and categorised based on methodological quality criteria and relevance to the theme, allowing for a critical interpretation of the state of the art in the studied areas. Content analysis methods were used to identify patterns, emerging themes, and gaps in the literature. The comparative analysis of the selected articles allowed for observing convergences and divergences among the studies, focusing on teaching approaches, obtained results, and implications for vocational education and the development of technical skills.

Thus, after the final selection of articles, a detailed reading and analysis of each study were conducted, focusing on the objectives, methodology, results, and presented limitations. Narrative analysis was chosen as the main approach, allowing for a qualitative synthesis of the findings and offering an interpretation of the emerging themes. This approach enabled exploring not only quantitative evidence but also the pedagogical and contextual implications discussed in each study.

The data were organised into main categories, according to the previously established themes and research questions:

- Immersive and hybrid learning environments: Analysis of studies discussing the implementation of virtual and augmented reality in teaching computer hardware.
- Vocational education: Studies exploring the impact of STEAM methodologies and virtual environments on the acquisition of practical skills.
- Development of competencies in computer hardware: Articles focused on techniques and tools for hardware diagnostics and assembly using AR and VR, exploring how these technologies facilitate students' understanding and motivation.

The categorisation of information facilitated the comparison among studies, allowing for a comparative analysis of methodologies, samples, and conclusions in each. After categorising and analysing the data, the results were synthesised, highlighting the main evidence and best practices identified in the studies. The conclusions were drawn based on the teaching practices identified in the literature, emphasising the importance of immersive technologies and STEAM methodologies for developing technical and problem-solving skills, with a special focus on competencies in computer hardware. This synthesis provides an updated overview of educational practices, identifying the potential of each methodology and areas requiring further investigation.

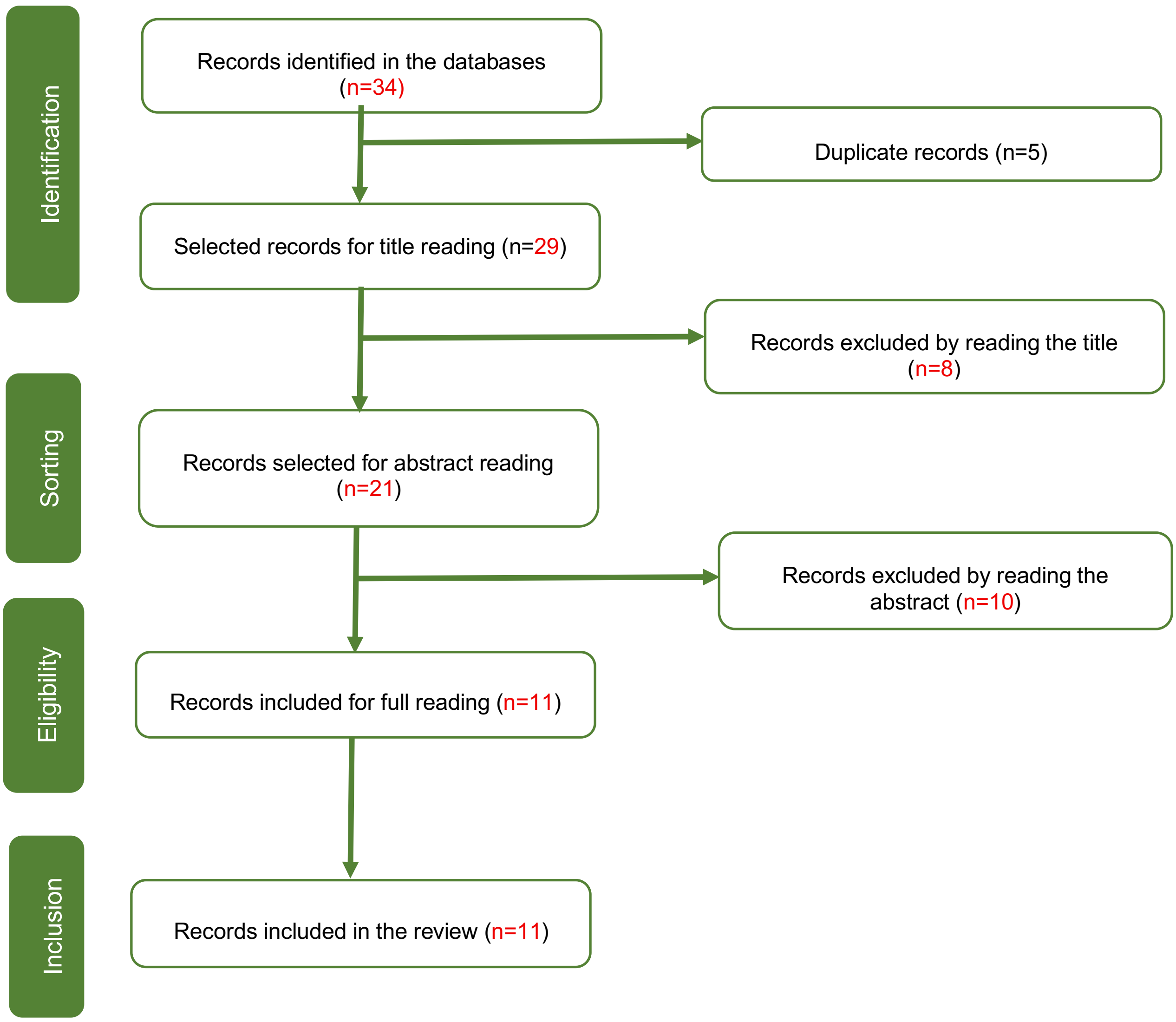
3 RESULTS

This study presents valuable insights into the potential of immersive and hybrid learning environments, particularly Virtual Reality (VR) and Augmented Reality (AR), for enhancing vocational education in computer hardware. However, several limitations must be acknowledged when interpreting the findings. Firstly, the scope of this review was limited to articles published between 2020 and 2024, exclusively in English. Consequently, relevant research published in other languages may have been excluded, potentially limiting the breadth of knowledge encompassed. Broadening the language scope in future reviews would contribute to a more comprehensive, global understanding of the impact of immersive technologies in vocational education.

Of the 34 articles initially identified, 5 duplicates were removed. After a rigorous analysis of the relevance and methodological quality of the studies, 23 articles were excluded for not fully meeting the inclusion criteria. This resulted in the inclusion of a total of 11 studies in the integrative review. The flowchart of the publications selected for inclusion in this integrative review is presented in the following image.

Figura 1

Literature review steps



Additionally, the study relied on data retrieved from three primary databases—ACM, ERIC, and ScienceDirect. While these sources provided relevant material, there remains the possibility that pertinent studies indexed in other databases were overlooked. The focus on only these three repositories might have also excluded relevant industry-specific publications or grey literature, potentially omitting important practical insights. Future research should therefore consider exploring a wider array of academic and industry sources to ensure a more exhaustive literature base. Another critical limitation concerns the methodological diversity of the included studies. The integrative review approach, while allowing for the inclusion of diverse methodological designs, presented challenges in synthesising findings due to variability in research quality. Differences in study designs, sample sizes, and outcome measures limit the generalisation of the results. Moreover, inconsistencies in reporting methodological details hindered comprehensive quality assessments. Although narrative and content analysis provided meaningful insights, the lack of standardised assessment tools tailored for evaluating the educational efficacy of immersive technologies further constrains the conclusions drawn. The development and adoption of standardised evaluation frameworks would therefore facilitate more reliable comparisons across studies and contribute to a robust evidence base.

In this context, several recent studies further strengthen the evidence on the relevance of immersive and hybrid environments for vocational and technical education. Ji et al. (2021) demonstrated that the use of immersive virtual reality in cultural heritage education, despite being applied in a non-technical context, enables the development of transferable skills such as spatial reasoning, problem-solving and collaboration, showing the potential of VR to enhance motivation and active engagement in learning. Yu et al. (2022) introduced a C-STEAM hybrid model that integrates physical and virtual manipulatives, showing how this approach increases inquiry-based learning and the ability to transfer abstract knowledge to practical situations, findings that can be applied to hardware assembly and diagnostics. Cheng et al. (2024) presented the Moon Story project, which combines augmented reality, culturally relevant narratives and generative AI, demonstrating that these hybrid environments improve student motivation, reflective thinking and engagement, which is particularly useful for experiential approaches in STEAM and vocational education. Finally, Lin (2024) proposed and tested a structured methodology for the design of serious games in virtual reality, showing that this strategy allows the safe simulation of complex professional contexts, improves psychomotor skills and supports the acquisition of specific competencies. These studies illustrate the growing scientific interest in immersive, hybrid and AI-supported approaches and their relevance to the development of technical skills in vocational education.

Furthermore, longitudinal data is absent from the current review. While many studies demonstrate the immediate benefits of VR and AR in enhancing engagement and knowledge retention, the long-term effects on skill acquisition, competency retention, and employability remain unclear. Sustained research tracking learners beyond the educational setting is essential for understanding how skills acquired through immersive environments translate into workplace performance. The durability of student motivation and the impact of these technologies on long-term employability should be key focal points in future longitudinal studies.

The implementation of VR and AR technologies in educational settings also faces significant practical challenges. The high costs associated with hardware acquisition, software development, and ongoing maintenance, coupled with the need for specialised teacher training, pose substantial barriers to widespread adoption. Studies by Koutromanos and Kazakou (2023) emphasise that teacher readiness is pivotal for the successful integration of immersive technologies. Many educators lack the specialised training required to effectively incorporate these technologies into their pedagogical practices. Moreover, technological infrastructure, including access to high-performance hardware and reliable software, remains inadequate in many educational institutions. Future research should therefore explore scalable strategies for professional development programmes that equip educators with the necessary skills. Partnerships between educational institutions and technology providers could also address infrastructural challenges, enhancing the scalability of immersive technologies.

The review also highlights gaps in understanding how STEAM methodologies and Design Thinking can be systematically integrated into immersive environments. While these approaches have demonstrated potential in fostering creativity, collaboration, and problem-solving skills, more empirical evidence is needed to substantiate their effectiveness across diverse educational contexts. Moreover, most of the studies reviewed primarily focused on technical disciplines, such as computer hardware, mechanics, and electronics. Future research should investigate the applicability of immersive and hybrid environments across a broader range of vocational subjects, including healthcare, hospitality, and creative industries, to determine their versatility and adaptability. Another area that warrants further exploration is the role of peer collaboration and adaptive assessment in immersive learning environments. Studies should examine how VR and AR platforms can foster collaborative learning among peers and incorporate adaptive assessment systems that adjust learning pathways based on individual progress. Such systems would provide personalised feedback, enhancing the overall learning experience and potentially improving educational outcomes. Additionally, understanding educators' long-term perceptions, experiences, and challenges associated with integrating immersive technologies is critical. These insights are essential for developing sustainable adoption strategies and effective pedagogical frameworks. Lastly, cultural and institutional factors influencing the adoption of immersive technologies should be examined. Adaptation strategies that consider cultural nuances and institutional readiness can significantly enhance the acceptance and effectiveness of VR and AR applications. Future studies could explore how these contextual factors impact the integration of immersive technologies, providing guidelines for culturally responsive and contextually appropriate educational practices.

While this study contributes significantly to the scientific community by deepening the understanding of immersive technologies and STEAM methodologies in vocational education, addressing the identified limitations is essential for advancing research in this field. Longitudinal studies, broadened research scopes, standardised assessment tools, detailed cost-benefit analyses, scalable teacher training programmes, and an exploration of diverse disciplines are all critical areas for future investigation. Such efforts will inform best practices, support the development of innovative educational approaches, and ultimately prepare learners for the demands of an increasingly digital and technologically driven labour market.

The integration of interdisciplinary methodologies and immersive technologies within educational contexts has emerged as a topic of growing interest in contemporary research, primarily due to its potential to prepare students for the challenges of the Fourth Industrial Revolution (Conrad et al., 2024). According to Malele and Ramaboka (2020), the STEAM approach, when combined with AR and VR environments, offers significant potential to transform pedagogical practices by promoting creative learning and innovation. Thus, immersive learning environments and STEAM methodologies have played a crucial role in advancing contemporary education. These environments offer a more engaging and practical educational experience, aligning student learning with real market demands.

AR and VR stand out as technologies that foster not only engagement but also the development of specific competencies. For instance, the study by Lampropoulos et al. (2024) on affective computing in immersive environments highlights the impact of these technologies in personalising learning experiences for individual students. Moreover, the integration of such technologies has proven essential in developing pedagogical methods aimed at promoting student autonomy and innovation.

Malele and Ramaboka (2020) argue that integrating STEAM methodologies with Design Thinking fosters an interdisciplinary pedagogical approach. This approach combines robust technical competencies with creativity, supporting practical, collaborative, and innovation-oriented learning. In contemporary teaching environments, where developing innovative and creative competencies is crucial, Design Thinking serves as a powerful complementary methodology within the STEAM framework. When applied to immersive VR environments, it allows students and educators to co-create highly engaging learning experiences.

These immersive environments provide platforms where students can not only visualise abstract theories but also experiment with them actively, leading to a deeper and more applicable understanding of concepts. Malele and Ramaboka (2020) further emphasise that Design Thinking in VR environments facilitates virtual prototyping and iterative testing. This enables students to experiment with ideas, observe the impact of their actions, and make real-time adjustments without the costs and risks associated with physical environments. Such iterative processes enhance student motivation by granting them the freedom to experiment, which is essential for developing an innovative mindset.

The study by Jantakun et al. (2021) explores the application of Design Thinking in STEAM projects, revealing how this methodology encourages creative exploration and the development of innovative solutions to complex challenges. By introducing a user-centred process, Design Thinking allows students to understand stakeholders' needs, promoting empathy and adaptability. Within the STEAM context, Design Thinking follows an iterative cycle—defining problems, empathising, ideation, prototyping, and testing—guiding students in creating practical and personalised solutions.

3.1. Immersive Learning Environments and Student Engagement

Virtual learning spaces offer students the opportunity to engage with content in ways impractical in the physical world. Thomann and Deutscher (2024) underscore the importance of immersive learning environments in developing technical competencies, showing that VR environments facilitate practical learning and enhance knowledge retention. Ravichandran and Mahapatra (2023) present case studies where VR was successfully applied in vocational training contexts, allowing students to practise skills without the risks associated with real equipment use.

Recent studies deepen this perspective by demonstrating the effectiveness of immersive and hybrid approaches in different educational domains. Ji et al. (2021) developed an immersive VR course for heritage education, showing that these virtual environments, when combined with in-class reflective activities, significantly increase students' motivation, critical thinking and content retention. Importantly, skills such as spatial reasoning and collaboration were shown to transfer to other technical and vocational contexts. Similarly, Yu et al. (2022) designed a hybrid C-STEAM instructional model that integrates physical and virtual manipulatives using Unity 3D. Applied to the study of traditional Chinese wooden arch bridges, this model demonstrated that the combination of physical experimentation and virtual simulation fosters inquiry-based learning, interdisciplinary literacy, and problem-solving skills, with clear potential for vocational education areas like hardware assembly and diagnostics.

In a different application, Cheng et al. (2024) introduced the "Moon Story" mobile system that combines AR, cultural narratives and large language models to teach astronomy. The hybrid experience, integrating outdoor exploration with AR overlays and personalised AI interactions, led to substantial gains in motivation, engagement, and reflective thinking. The study highlights that such approaches could be extended to vocational education and STEAM contexts to teach complex systems and problem-solving. Furthermore, Lin (2024) addressed a major barrier in vocational VR training, the high cost of development, by proposing a prototyping methodology based on Scrum for designing serious games. Through iterative low-fidelity prototyping, the study demonstrated that VR-based serious games can provide realistic and immersive environments for technical skill acquisition, while reducing costs and maintaining strong pedagogical alignment.

The creation of personalised virtual spaces further supports adaptive teaching, enabling content and difficulty levels to be tailored to individual learners' needs. Conrad et al. (2024) highlight that VR provides interactive, gamified experiences, fostering motivational and engaging learning environments that improve student involvement and learning outcomes.

Immersive environments, including VR and AR technologies, create spaces where students can interact with educational content practically and safely. Conrad et al. (2024) conducted a systematic review on VR effectiveness, revealing that VR not only increases student engagement but also enhances learning of specific competencies, such as practical skills and procedural knowledge.

Additionally, immersive environments facilitate knowledge acquisition in areas where traditional practice can be costly or hazardous. Ravichandran and Mahapatra (2023) note that immersive environments provide safe spaces for students to develop and practise technical skills, such as operating industrial or medical equipment, without real-world risks. This approach is particularly relevant in technical education, where practical training is crucial yet challenging in conventional educational settings.

3.2. Hybrid Learning Environments and Extended Reality (XR)

Hybrid learning environments, combining physical and virtual interactions, are becoming increasingly popular in education, providing essential flexibility and adaptability. Extended Reality (XR), encompassing AR, VR, and Mixed Reality (MR), plays a pivotal role in creating these environments. Mula et al. (2024) examine XR applications in industrial contexts, focusing on training and safety, while also highlighting XR's potential for education.

XR facilitates the creation of personalised learning environments that meet specific educational needs, promoting continuous learning and technical skill acquisition, such as hardware development and operation. Hybrid environments also support adaptable teaching practices for diverse learning styles, enabling more inclusive and personalised educational approaches.

Koutromanos and Kazakou (2023) explore the use of AR in smart glasses, enabling students to engage in contextualised, interactive learning activities, enhancing content retention and practical knowledge application. However, challenges related to implementation costs and technological complexity remain significant. The authors note that the acceptance of AR glasses in classrooms depends not only on available resources but also on teacher training in technology.

Mula et al. (2024) further observe that XR technologies have proven effective in industrial and training environments, promoting safe and collaborative interactions adaptable to educational settings. The primary advantage of hybrid environments lies in their ability to create practical experiences that keep students engaged and motivated, regardless of physical learning space limitations.

3.3. Trends and Analysis of Research Themes

Data indicate a growing trend in the number of publications over the analysed period, reflecting increasing interest in using technologies such as VR, AR, and STEAM methodologies in educational contexts. The most frequently addressed theme in the studies is the application of VR and AR in vocational and hardware-related educational contexts, with a focus on immersive environments and student acceptance.

A breakdown of study themes by title shows a diversified research landscape, though some concentrations are evident. Regarding STEAM and Design Thinking, two publications were identified in 2020 and 2021, suggesting initial interest that may have evolved into other approaches in subsequent years. In the area of VR applied to vocational education, three publications were found—one in 2023 and two in 2024—indicating increased research volume and interest.

Table 1

Distribution of the analysed publications by theme and year of publication

Theme	Publications	Year(s)	Titles
STEAM and *Design Thinking*	2	2020, 2021, 2023	– The *Design Thinking* Approach to Students' STEAM Projects (2020) – STEAM Education Using *Design Thinking* Process Through Virtual Communities of Practice (2021) – The Design and Application of C-STEAM Instructional Resources Based on Unity 3D Blending Physical and Virtual Manipulatives (2023)
Virtual Reality (VR) applied to Vocational Education	3	2023, 2024	– Virtual Reality in Vocational Education and Training: Challenges and Possibilities (2023) – How Effective is Immersive VR for Vocational Education? Analyzing Knowledge Gains and Motivational Effects (2024) – Evaluating Effectiveness of Immersive Virtual Reality in Promoting Students' Learning and Engagement (2024) – Serious Game Design and Evaluation Through Prototyping: A Case Study of Developing a Virtual Reality Serious Game for Vocational Education and Training (2025)
Augmented Reality (AR) and Immersive Tools	3	2021, 2022, 2023, 2024	– Examining the Potential of Augmented Reality in the Study of Computer Science at School (2022) – Augmented Reality Smart Glasses Use and Acceptance: A Literature Review (2023) – Improving Higher Education with the Use of Mobile Augmented Reality (MAR): A Case Study (2024) – Scientific and Fantastical: Creating Immersive, Culturally Relevant Learning Experiences with Augmented Reality and Large Language Models (2024) – Constructing Embodied Interaction of Intangible Cultural Heritage Course through Immersive Virtual Reality (2021)
Affective Computing and XR Technologies (Extended Reality)	2	2024	– Affective Computing in Augmented Reality, Virtual Reality, and Immersive Learning Environments (2024) – Extended Reality and Metaverse Technologies for Industrial Training, Safety and Social Interaction (2024)

Similarly, AR and immersive tools showed a comparable trend, with three publications (one in 2022 and two in 2023), highlighting AR's potential for practical learning in educational settings. The field of affective computing and XR technologies (extended reality) was represented by two publications in 2024, reflecting emerging interest in these technologies for enhancing interaction and personalising teaching.

Overall, the analysis reveals that the application of VR and AR in vocational and hardware educational contexts remains the predominant focus, with 50% of the publications addressing these themes. This underscores the significance of immersive and hybrid environments and their role in promoting student engagement and acceptance in technical and vocational learning practices.

In Table 1, we present the distribution of the analysed publications by theme and year of publication, highlighting trends in the application of Virtual Reality (VR), Augmented Reality (AR), STEAM, and Design Thinking in vocational education.

Furthermore, most studies were developed through collaborations among multiple authors, suggesting a multidisciplinary approach to topics involving advanced educational technologies. Despite thematic diversity, VR and AR clearly dominate the field, reaffirming their growing role in transforming vocational education.

4 DISCUSSION

The findings of this study highlight the significant potential of immersive and hybrid environments in enhancing vocational education in computer hardware training. The reviewed studies collectively underscore the capability of VR and AR technologies to offer safe yet realistic environments for students to practise technical skills, thereby overcoming constraints associated with traditional vocational settings, such as safety hazards and high costs (Thomann & Deutscher, 2024; Ravichandran & Mahapatra, 2023). Methodologically, these studies predominantly employ experimental and case-study designs, effectively highlighting immediate gains in learner engagement, motivation, and practical skill acquisition.

However, a critical examination of the reviewed literature reveals methodological limitations and inconsistencies that warrant caution when interpreting and generalising these findings. Notably, studies often vary considerably in design complexity, sample sizes, and evaluation criteria, leading to heterogeneity in outcomes and difficulty in synthesising robust conclusions. Moreover, many studies fail to adequately report methodological procedures, compromising the transparency and replicability of results.

Further complicating the evidence base, several studies highlighted in this review explore diverse contexts beyond strictly vocational education, such as heritage education (Ji et al., 2021) and primary-level STEAM education (Yu et al., 2022; Cheng et al., 2024). While these contributions offer valuable insights into transferable skill development and interdisciplinary competencies, caution is necessary when extrapolating these results directly to vocational hardware education contexts. The transferability of skills such as spatial reasoning and reflective thinking, although promising, requires systematic verification within targeted vocational settings to ensure relevance and applicability.

The evidence consistently demonstrates immediate benefits of VR and AR, including improved accuracy in performing tasks, increased student motivation, and enhanced knowledge retention (Lin, 2024; Conrad et al., 2024). Nonetheless, an important limitation emerges regarding the absence of longitudinal evidence. Existing studies predominantly provide short-term outcomes, leaving significant uncertainty around the durability of skills acquired and their impact on employability and professional practice over time. Therefore, future research should prioritise longitudinal studies tracking learners from educational settings into professional contexts, exploring sustained impacts on career performance and long-term skill retention.

A notable barrier consistently identified in the literature relates to practical implementation challenges, particularly concerning technological infrastructure, teacher preparedness, and cost constraints (Koutromanos & Kazakou, 2023). Many institutions lack the necessary resources or adequately trained educators to effectively implement immersive technologies, significantly limiting their adoption and impact. Addressing these practical constraints through strategic partnerships between educational institutions and technology providers, coupled with targeted professional development initiatives, emerges as a vital recommendation for policy and practice.

Contradictory findings also emerge regarding pedagogical integration, specifically related to the efficacy of integrating STEAM methodologies and Design Thinking with immersive technologies. While several studies highlight their potential to enhance creativity, problem-solving, and user-centred learning experiences (Malele & Ramaboka, 2020; Jantakun et al., 2021), empirical evidence explicitly validating their systematic effectiveness across diverse vocational education contexts remains limited. This gap indicates a clear need for empirical research that systematically evaluates these interdisciplinary methods' effectiveness within immersive vocational training environments.

Another emerging gap identified through this integrative review is the limited exploration of collaborative learning mechanisms and adaptive assessment tools within VR and AR environments. Preliminary evidence indicates significant potential for these technologies to foster cooperative learning and provide personalised feedback, yet detailed empirical studies are sparse. Future research should explicitly address these gaps, exploring how collaborative dynamics and adaptive assessments can optimise the educational effectiveness of immersive technologies in vocational education contexts.

For curriculum designers and educators, the implications are clear: integrating VR and AR should move beyond mere technological adoption towards strategic pedagogical innovation. Emphasis should be placed on tailored instructional strategies, including scaffolding and simulation-based learning, designed specifically for immersive environments. Additionally, curriculum development should systematically incorporate interdisciplinary approaches, such as STEAM and Design Thinking, to foster comprehensive skill development aligned with contemporary labour market demands.

From a policy perspective, investment decisions regarding immersive and hybrid educational technologies should be informed by rigorous cost-benefit analyses, considering not only financial factors but also educational outcomes, learner employability, and educator satisfaction. Policymakers must also prioritise scalable infrastructure development and continuous professional training for educators to ensure sustainable and equitable implementation of immersive educational technologies.

5 CONCLUSION

Immersive technologies and STEAM methodologies have the potential to transform education by creating engaging, interactive, and effective learning environments. The integration of Augmented Reality (AR), Virtual Reality (VR), and Extended Reality (XR) with Design Thinking enhances learning by fostering experimentation, collaboration, and problem-solving. These approaches boost student motivation and engagement while enabling the practical application of knowledge in secure settings. By preparing learners to address complex technological challenges, they promote both cognitive and practical skill development. Ongoing research into technological acceptance and the effectiveness of hybrid methodologies is essential to maximising the potential of these educational innovations.

The methodological strengths of the reviewed studies lie primarily in their innovative use of immersive technologies, rigorous experimentation, and clear demonstration of immediate benefits such as increased motivation and improved technical skills. However, critical methodological weaknesses were also identified, including inconsistencies in study designs, small sample sizes, and varying quality in outcome measures. These issues significantly limit the generalisability of the results. Furthermore, contradictory findings were observed, especially regarding the transferability of competencies from immersive environments to real-world vocational settings, indicating the need for further targeted research.

Despite their advantages, challenges remain. Thomann and Deutscher (2024) note that implementing immersive technologies requires specialised teacher training, which may hinder widespread adoption. Similarly, Ravichandran and Mahapatra (2023) emphasise the need for extensive research on their long-term impact on students' technical and practical competencies. This study highlights the effectiveness of immersive technologies and STEAM methodologies in vocational education, particularly in teaching computer hardware. The combination of VR, AR, and hybrid environments with methodologies such as Design Thinking significantly enhances engagement, collaboration, and problem-solving skills. Mula et al. (2024) stress that these environments provide safe and adaptable spaces for acquiring technical competencies, equipping students for the challenges of the Fourth Industrial Revolution.

However, the quality and generalisability of evidence in the existing literature remain variable. Many studies rely heavily on short-term, experimental, or case study approaches, providing limited insights into long-term outcomes and real-world applicability. Consequently, the current evidence base, while promising, must be interpreted cautiously, particularly concerning the sustained educational impact and skill transfer to professional environments.

Emerging research gaps include the absence of longitudinal studies, limited exploration of adaptive assessment mechanisms, and insufficient attention to cultural and institutional contexts affecting technology adoption. These gaps present critical avenues for future research aimed at enhancing educational practices.

To overcome identified challenges such as technological infrastructure deficits and insufficient teacher training, targeted investments and supportive educational policies are required. Strategic partnerships between educational institutions and technology providers could significantly mitigate these barriers, facilitating broader adoption.

For educators and curriculum designers, these findings imply a need to develop and integrate specific pedagogical strategies tailored for immersive learning environments. Policymakers must consider detailed cost-benefit analyses to inform funding decisions and infrastructural investments, ensuring sustainable and equitable access to immersive technologies.

Future research directions must therefore address several critical areas. Longitudinal studies tracking students beyond their formal education into professional contexts are essential to evaluate the enduring impacts of immersive technologies on employability and long-term competency retention. Additionally, extending the research scope to include multilingual and international sources will offer a more comprehensive and culturally nuanced understanding of immersive technologies' educational potential.

Developing standardised assessment tools specifically designed for immersive learning environments is crucial to facilitate more robust comparisons across studies and enhance the reliability of educational outcomes. Further exploration of peer collaboration dynamics and adaptive assessment systems in VR and AR could significantly optimise personalised learning experiences.

Research should also systematically explore the applicability of immersive and hybrid learning environments across various vocational fields, including healthcare, hospitality, and creative industries, to determine broader adaptability and effectiveness. Lastly, detailed analyses of educators' long-term experiences and institutional readiness will provide critical insights into sustainable adoption strategies, supporting educators and institutions in effectively implementing these innovative educational practices.

While this review significantly contributes to understanding immersive technologies and STEAM methodologies in vocational education, addressing identified methodological weaknesses and research gaps is vital. Continued scholarly investigation into these areas will inform evidence-based pedagogical practices and policy decisions, ultimately ensuring that education systems adequately prepare learners to navigate and excel in a digitally sophisticated and technologically evolving professional landscape.

6 LIMITATIONS OF THE STUDY

This study provides valuable insights into the potential of immersive and hybrid learning environments, particularly Virtual Reality (VR) and Augmented Reality (AR), for vocational education in computer hardware. However, several limitations must be acknowledged to contextualise the findings and guide future research.

First, the scope of the review was restricted to articles published between 2020 and 2024 and written in English. This criterion, while ensuring recency and relevance, may have excluded significant research conducted in other languages. Expanding future reviews to include multilingual sources and studies from a wider range of geographical contexts would strengthen the global perspective on immersive technologies in vocational education.

A second limitation concerns the reliance on three primary databases: ACM, ERIC, and ScienceDirect. While these repositories provide high-quality scholarly material, this focus might have excluded relevant studies from other databases or grey literature. Consequently, potentially valuable contributions from industry reports and non-indexed publications may not have been captured.

The heterogeneity of research designs also posed significant challenges for synthesising findings. Differences in methodologies, participant groups, and assessment tools made it difficult to directly compare results across studies. For this reason, the review emphasises the identification of patterns and overarching implications rather than drawing definitive causal conclusions.

This section intentionally avoids duplicating the detailed pedagogical implications already addressed in the conclusion. Instead, it highlights areas where evidence remains insufficient or fragmented, signalling opportunities for further investigation.

Another notable limitation relates to the absence of standardised tools for evaluating immersive learning environments. Without such frameworks, comparisons across studies become inconsistent, reducing the reliability of the evidence base. Similarly, longitudinal evidence remains scarce. While the reviewed studies consistently report short-term benefits, such as increased engagement and knowledge retention, there is little empirical data on how these technologies influence long-term skill transfer, employability outcomes, and sustained learner motivation.

Practical barriers to the implementation of immersive technologies also persist. High costs associated with hardware, software development, and maintenance, alongside the need for specialised teacher training, continue to hinder broad and equitable adoption in educational settings. Furthermore, limited research has been conducted on how cultural and institutional factors, as well as adaptive assessment systems and peer collaboration mechanisms, affect the scalability and effectiveness of immersive learning strategies.

Addressing these limitations will require comprehensive and multidisciplinary approaches. Future studies should prioritise broader multilingual reviews, longitudinal research designs, the development of standardised assessment frameworks, scalable teacher training initiatives, and detailed cost-benefit analyses. In addition, expanding the scope of research to explore the applicability of immersive and hybrid learning environments across diverse vocational domains, such as healthcare, hospitality, and creative industries, will be essential to determine their broader adaptability and impact.

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