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Barriers and Enablers to Adopting Virtual Reality in Lower Secondary STEAM Curricula

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Abstract

This study investigates the barriers and enablers to VR integration in middle school STEAM curricula, addressing a notable gap in the existing literature. A systematic literature review and qualitative synthesis were conducted, supported by bibliometric analysis, to examine key concepts, including technological barriers, teacher training needs, and policy interventions. Data were extracted and coded to ensure a comprehensive analysis of academic publications, emphasizing VR-driven educational outcomes and systemic challenges. Findings reveal that technological limitations, such as high costs and infrastructure deficits, alongside insufficient teacher training and institutional resistance, are significant barriers. Enabling factors include targeted professional development, collaborative platforms, and policy reforms that enhance accessibility and scalability. Case studies highlight VR's potential to transform STEAM education when supported by inclusive strategies and cost-effective technologies. This study underscores the importance of aligning policy, training, and infrastructure to ensure sustainable VR integration.

Keywords: Virtual reality (VR), STEAM education, educational technology, student engagement, teacher training, and interdisciplinary learning

1. Introduction

Virtual Reality (VR) has emerged as a revolutionary educational tool, especially in the STEAM (science, technology, engineering, arts, and mathematics) fields. Through its immersive and interactive learning environments, virtual reality (VR) encourages more engagement and makes it easier to understand complicated concepts. For instance, Vázquez & Palencia (2024) showed how VR improves spatial reasoning and geometry problem-solving abilities. Lin et al. (2024) emphasized how technology might help kids with learning impairments by giving abstract ideas a concrete form. Despite these advantages, a number of contextual and systemic issues have prevented VR from being widely used in lower secondary STEAM curricula. Expensive equipment prices, inadequate technology infrastructure, and a lack of teacher preparation hamper adoption of VR. Institutional reluctance and challenges in integrating VR content with current curricula exacerbate these barriers, according to studies like Wang (2024) and Ravichandran & Mahapatra (2023). These difficulties are further compounded by ethical considerations like the digital divide and health issues like VR sickness (Ozgun & Sadık, 2023; Chalkiadakis et al., 2024).

A multifaceted strategy including legislation changes, technology improvements, and systemic support for educators is needed to overcome these obstacles. On the other hand, facilitating elements like focused professional development, sophisticated writing tools, and encouraging legislative frameworks play a crucial role in encouraging VR integration. For example, Tafazoli (2024) emphasizes how professional development helps teachers become more confident and have better skill sets, while partnerships and collaborative platforms facilitate resource sharing and innovation (Oubahssi et al., 2024). Furthermore, Shankar et al.'s (2023) investigation of transdisciplinary VR applications shows how it might promote critical thinking and creativity in STEAM education.

This study aims to identify and evaluate the obstacles and facilitators to VR adoption in lower secondary STEAM curricula. To overcome these obstacles and promote fair, efficient, and long-lasting VR integration in international educational contexts, it attempts to synthesize results from case studies and current research.

This study aims to investigate the primary barriers hindering the adoption of Virtual Reality (VR) in lower secondary STEAM curricula, focusing on technological, institutional, and teacher-related challenges. It explores enabling factors such as teacher training, policy reforms, and technological advancements that support VR integration. Additionally, the study examines successful case studies of VR implementation to identify best practices for addressing systemic challenges. By synthesizing these insights, the research seeks to develop actionable recommendations to promote equitable and sustainable VR use in STEAM education, fostering broader accessibility and effectiveness in middle school learning environments.

This study seeks to answer key questions: What are the primary barriers to adopting VR in lower secondary STEAM curricula? What enabling factors support its integration? How can successful case studies inform strategies for overcoming challenges? Finally, what policy, training, and technological interventions are needed to foster equitable and sustainable access to VR in STEAM education?

2. Theoretical Framework

The theoretical framework for this study is grounded in the Technology Acceptance Model (TAM) (Su & Li, 2021), Constructivist Learning Theory (Shah, 2019; Bada, 2015), and Diffusion of Innovations Theory (Dearing & Cox, 2018; García-Avilés, 2020). Together, these theories provide a comprehensive lens to understand the barriers and enablers of adopting Virtual Reality (VR) in lower secondary STEAM curricula. Based on VR's promise to improve engagement, comprehension, and collaboration, the Technology Acceptance Model (TAM) emphasizes how perceived utility, technical support, user training, and simplicity of use affect teachers' and students' desire to accept the technology. Constructivist learning theory, which emphasizes active knowledge production through experiential learning and lets students explore and work together in interactive environments, is in line with virtual reality's immersive qualities. Lastly, the Diffusion of Innovations Theory provides techniques to overcome opposition and expedite implementation, explaining that institutional preparation, governmental backing, and professional development are necessary for VR acceptance.

3. Literature Gap and Significance

An important turning point in a student's academic career is middle school. Students start to establish their interests and goals throughout this time of major cognitive and social growth (Yun, 2023). These early years are greatly influenced by STEAM education. STEAM courses give students the critical thinking, problem-solving, creativity, and teamwork abilities they need to succeed in the workforce of the twenty-first century (MacCallum, 2021; Hawkinson, 2024). Virtual reality (VR) has the potential to greatly improve the learning process in middle school STEAM programs, making these disciplines more interesting and available to a larger group of pupils (Hawkinson, 2024). Virtual Reality (VR) adoption in lower secondary STEAM curricula faces significant unexplored barriers. Existing research often overlooks systemic issues like institutional resistance, teacher training deficits, and curriculum misalignment. Moreover, enabling factors such as professional development and policy reforms lack comprehensive frameworks addressing these challenges holistically. This study fills the gap by analyzing barriers and enablers, focusing on middle school STEAM education. It offers actionable strategies and

replicable best practices for policymakers and educators, contributing to equitable and sustainable VR integration globally.

4. Research Hypotheses

This study examines factors influencing the adoption of virtual reality (VR) in lower secondary STEAM education. It hypothesizes that institutional barriers, including high costs and limited infrastructure (H1), and teacher-related issues like inadequate professional development and resistance to technology (H2), hinder VR integration. Conversely, enabling factors such as targeted teacher training, collaborative platforms, and supportive policies (H3) are expected to facilitate successful adoption. Additionally, advancements in affordable technologies and equitable policy reforms are proposed to enhance VR accessibility and sustainability (H4). Together, these hypotheses explore challenges and opportunities for incorporating VR into STEAM curricula effectively.

5. Methodology

5.1 Conceptual Framework Development

A conceptual framework was developed using literature analysis and concept mapping to refine key aspects of VR integration, such as infrastructure, teacher training, and policy alignment. Relationships between barriers and enablers were analyzed to overcome challenges and enhance STEAM education. A systematic literature review and qualitative synthesis examined VR's impact on engagement, critical thinking, and interdisciplinary learning. Bibliometric analysis highlighted trends, enablers, and challenges, showcasing VR's transformative potential while addressing constraints like technology, teacher readiness, and policy alignment.

5.2 Evaluation of VR Integration in STEAM Curricula

The evaluation process involved a systematic review conducted in adherence to PRISMA criteria across multiple academic databases, including Google Scholar, PubMed, Scopus, Web of Science, JSTOR, and ProQuest. Boolean search terms and targeted keywords such as "Virtual Reality," "STEAM education," "barriers," and "enablers" were used to identify relevant studies published between 2013 and 2024. The review prioritized original research and recent studies exploring VR's role in enhancing critical thinking, problem-solving, and student engagement in STEAM contexts. The findings emphasized VR's potential to create inclusive, interdisciplinary educational frameworks aligned with modern pedagogical and technological advancements.

5.3 Inclusion Criteria for Qualitative Synthesis

The qualitative synthesis focused on original research articles published in English in reputable journals or conference proceedings, excluding theses, and dissertations. Selected studies explored VR integration in middle school STEAM education, highlighting its impact on fostering engagement, critical thinking, and interdisciplinary collaboration. Additionally, studies that examined enabling factors like teacher training, technological infrastructure, and policy alignment were included to ensure a comprehensive analysis of barriers and enablers. This approach ensured that the synthesis provided actionable insights into creating equitable and sustainable educational practices leveraging VR technology.

5.4 Article Selection Process

A total of 1350 documents were found from several databases, and their relevancy was assessed using title and keyword in the first stage. A number of 250 articles remained after 650 duplicates and 450 ineligible records were removed. The abstracts of these papers were examined for relevant information related to the topic to vet them further. Item failure to meet the predefined inclusion criteria was eliminated during the final screening. 67 articles were chosen and evaluated for qualitative synthesis because of this stepwise selection procedure, as shown in Figure 1.

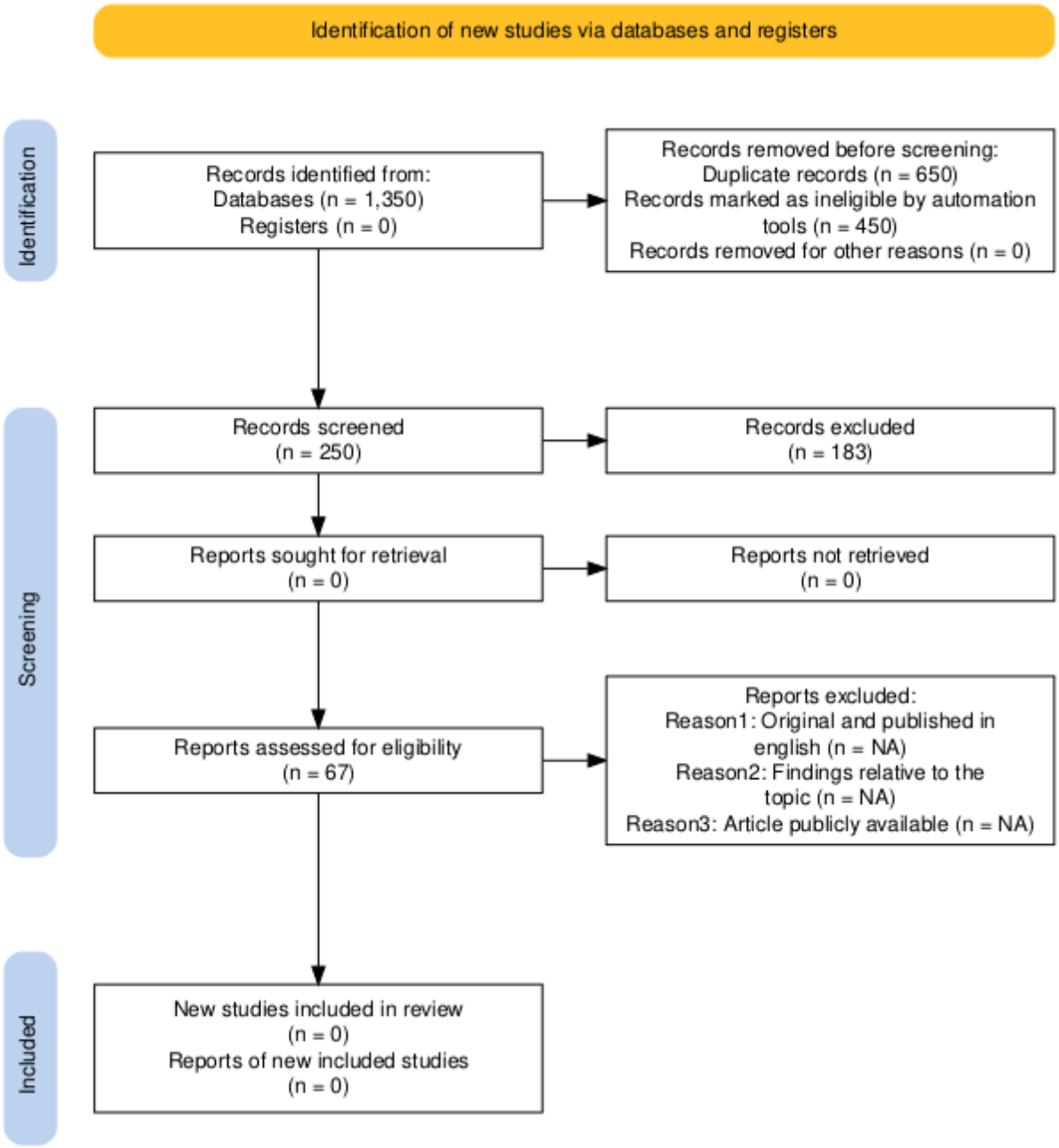

Figure 1. Identification of new studies via databases and registers (PRISMA diagram) (Haddaway et al., 2020)

5.5 Data Extraction and Data Analysis

A systematic data extraction process was employed to examine the integration of virtual reality (VR) in lower secondary STEAM curricula. Relevant information, including authorship, theoretical frameworks, research methods, findings, and limitations, was documented using a structured Excel sheet for reliability and comprehensiveness. A mixed-methods approach combined regression analysis to evaluate VR's impact on academic achievement, engagement, and accessibility with co-occurrence analysis to identify research trends. Thematic and content analyses explored barriers like infrastructure and teacher training while addressing ethical concerns like the digital divide. These analyses provided actionable insights to overcome systemic challenges and promote VR adoption.

5.6 Ethical Considerations

Throughout the study, ethical considerations were rigorously upheld. Data privacy was ensured by anonymizing personal information, and all sources were appropriately credited in

adherence to copyright laws (Ducato, 2020; Hornuf et al., 2023). The research followed ethical guidelines for implementing VR in education, critically evaluating potential biases, risks, and accessibility concerns associated with immersive technologies. These measures ensured a responsible approach to addressing systemic barriers while fostering equitable and sustainable VR integration in STEAM curricula.

6. Findings

6.1 Article Publishing Trends Between 2013 and 2024

Figure 2 shows the annual distribution of publications from 2013 to 2024, highlighting an increasing trend in research activity. The field saw minimal contributions in its early years, with only one publication each in 2013, 2018, and 2019. A noticeable rise began in 2020 with seven publications, followed by consistent growth, peaking at 15 in 2023. This surge reflects heightened interest, likely driven by advancements in technology and educational practices. A slight decline to 11 publications in 2024 suggests stabilization in the field. Overall, the figure demonstrates the evolving nature of research in this area, emphasizing its growing relevance (Figure 2).

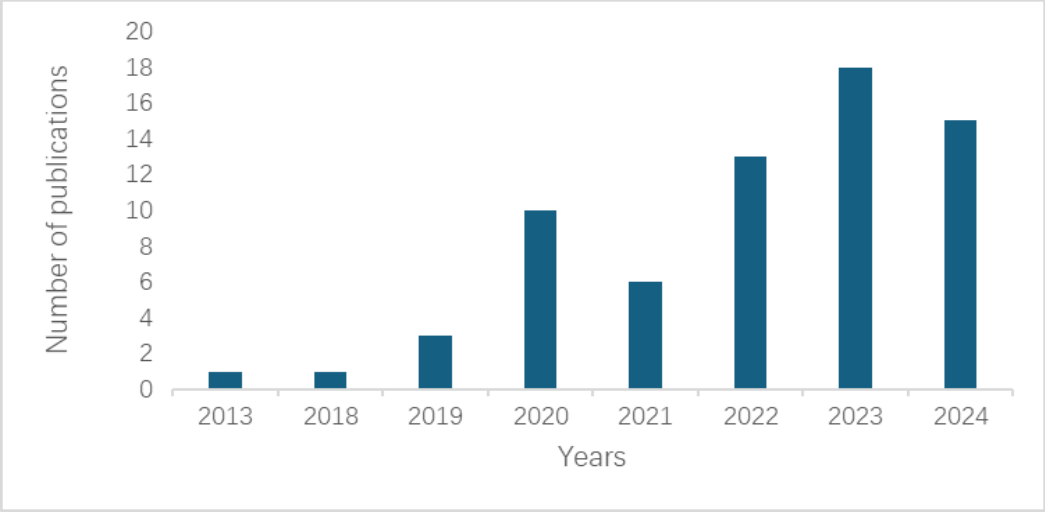

Figure 2. Trends in Publications on Sustainable Education and Youth Entrepreneurship (2013-2024)

6.2 Citation Frequency of Key Studies in VR and STEAM Research

The contributions of different authors are highlighted in Figure 3, which displays a broad variety of publication or citation numbers. With more than 2,000 citations, Merchant et al. (2014) stands out as having had a substantial impact on the field. Notable contributions with comparatively large citation counts are also displayed by other writers, such Zingraff (2020) and Maas & Hughes (2020), demonstrating their significance in furthering the field of study. However, most authors have fewer citations, which suggests that their work is either new or specialized. This distribution highlights the diversity and increasing engagement in this developing discipline, while also highlighting the importance of foundational studies.

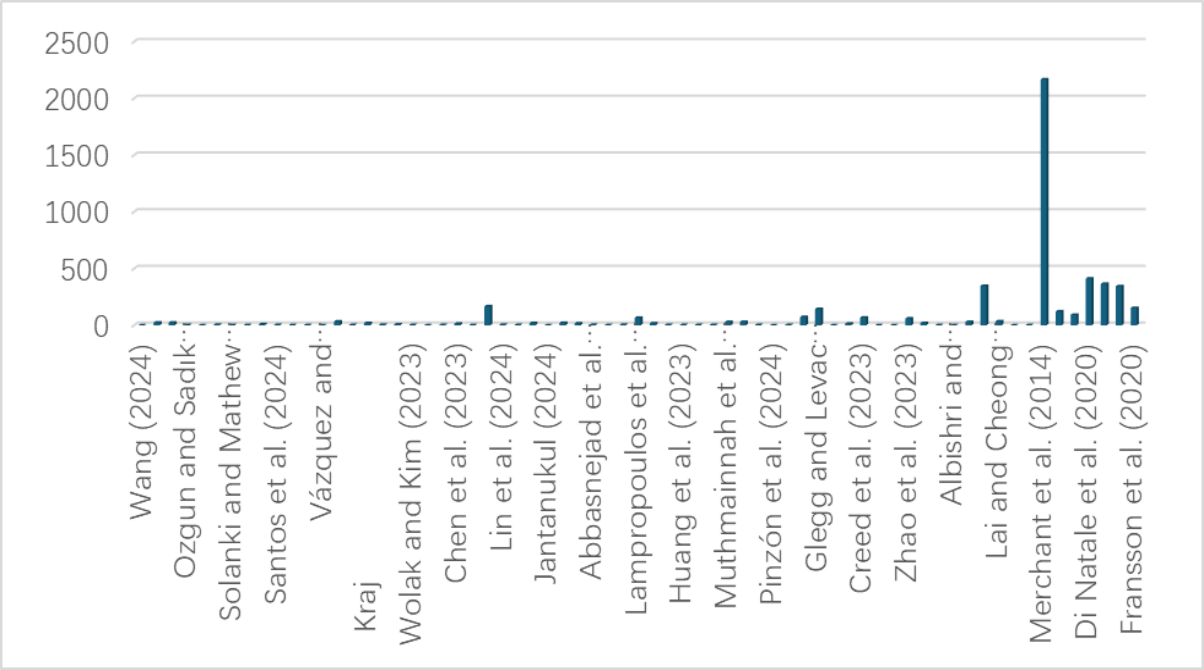

Figure 3. Author Contributions and Citation Impact in VR and STEAM Research

6.3 Exploring Barriers and Enablers to Virtual Reality Adoption in STEAM Education: A Methodological Perspective

Research on Virtual Reality (VR) in education employs diverse methodologies to investigate its adoption and impacts. Like those by Al-Oudat & Altamimi (2022), quantitative studies utilize frameworks such as the Technology Acceptance Model (TAM) to examine adoption factors. Mixed-methods approach, seen in Wang (2024), integrate surveys and interviews to explore educator perceptions and infrastructure needs. Systematic reviews, like Pirker and Dengel (2021), synthesize trends and barriers, while experimental designs, such as Abbasnejad et al. (2022), assess VR's effectiveness in STEAM education. These methodologies underscore the importance of policies, teacher training, and robust technological infrastructure for successful VR integration.

6.4 Key Findings in Adopting Virtual Reality in Lower Secondary STEAM Curricula: A Comprehensive Overview

6.4.1 Impact on Student Engagement and Learning Outcomes

Studies such as Wang (2024) and Vázquez & Palencia (2024) demonstrate that VR significantly enhances student engagement, motivation, and comprehension of complex concepts. VR environments promote cognitive, affective, and behavioral engagement by making abstract concepts tangible and encouraging critical thinking and problem-solving. Applications in subjects like geometry and STEM highlight VR's ability to bridge theoretical and practical knowledge, improving academic performance and essential skills development. The immersive nature of VR fosters deeper learning and helps students connect to content more meaningfully.

6.4.2 Barriers to VR Adoption in STEAM Education

Significant challenges hinder VR integration in STEAM classrooms. High costs of equipment and content development, insufficient teacher training, and limited technical infrastructure remain major barriers, as noted in studies such as Al-Oudat & Altamimi (2022) and Lin et al. (2024). Other concerns include health risks like VR sickness, reduced student-teacher interaction, and challenges aligning VR content with established curricula (Ozgun & Sadık, 2023). Organizational resistance and insufficient administrative support further complicate adoption. These issues are particularly pronounced in under-resourced and developing regions.

6.4.3 Technological and Design Aspects of VR

Studies like Baek (2020) and Jantanukul (2024) emphasize that VR's immersive, interactive, and

realistic design features significantly influence user perceptions. Positive attributes such as realism and interactivity foster motivation, while concerns about usability, performance, and adaptability raise challenges. Effective VR design requires careful consideration of both engagement factors and potential drawbacks, including issues like immersion-related anxiety or cognitive overload.

6.4.4 Teacher Autonomy and Professional Development

Teacher autonomy and training are pivotal for successful VR adoption. Du et al. (2022) and Oubahssi et al. (2024) emphasize the need for tailored training programs that foster teacher confidence and equip them with the skills to integrate VR into lessons effectively. Advanced authoring tools and resources that streamline VR content creation are critical to empowering educators and supporting adoption in diverse classroom contexts.

6.4.5 Ethical and Equity Considerations

Chalkiadakis et al. (2024) and Creed et al. (2023) highlight the ethical and equity concerns surrounding VR adoption. Issues like the digital divide, unequal access to resources, and privacy risks need to be addressed to ensure equitable adoption. Accessibility barriers for students with disabilities and underserved populations are particularly pressing, underscoring the need for inclusive design and policy measures.

6.4.6 Navigating Health, Safety, and Interdisciplinary Opportunities in VR Adoption

Virtual Reality (VR) adoption in education faces significant health and ethical challenges. Prolonged use can cause VR sickness, especially in younger students, as highlighted by Ozgun & Sadık (2023). Ethical concerns such as data privacy, algorithmic bias, and the digital divide further complicate integration. Clear guidelines for safe use, equitable access, and inclusive design are vital for sustainable implementation. Additionally, VR's interdisciplinary potential, particularly when combined with Augmented Reality (AR) and Mixed Reality (MR), fosters collaborative learning. Shankar et al. (2023) highlights how such integration enhances STEM education, promoting teamwork, creativity, and critical thinking.

6.4.7 Context-Specific Challenges and Opportunities

Regional factors, such as those discussed by Pinzón et al. (2024) and Swargiary (2023), play a crucial role in shaping VR adoption. In resource-constrained settings, challenges like limited infrastructure, inadequate funding, and cultural resistance to new technologies are significant. However, tailored solutions, such as localized VR content and affordable hardware, present opportunities to overcome these barriers and ensure wider adoption.

6.4.8 Policy and Strategic Implications

Successful VR integration requires systemic approaches involving collaboration between educators, policymakers, and technologists. Tailored strategies addressing cost, accessibility, and training gaps are critical for maximizing VR's transformative potential in STEAM education. Policies that support infrastructure development, professional training, and inclusive practices can help VR revolutionize teaching and learning, equipping students with essential skills for 21st-century challenges.

6.5 Addressing Barriers to Virtual Reality Integration in STEAM Education

The research studies of adoption of Virtual Reality (VR) in STEAM education faces multiple challenges that limit its transformative potential. Contextual and methodological constraints, such as geographic specificity and reliance on cross-sectional designs, restrict the generalizability of findings. Studies like Wang (2024) and Du et al. (2022) emphasize the need for longitudinal and multi-contextual research to assess VR's adaptability across diverse settings. Technological and design challenges, including high costs, limited infrastructure, and usability issues, further hinder integration, as noted by Lin et al. (2024). The lack of teacher training and professional development programs is another persistent barrier, with studies advocating for advanced tools and structured frameworks to empower educators. Ethical concerns, such as privacy, inclusivity, and health risks like VR sickness, require urgent attention. Future directions emphasize interdisciplinary collaboration, policy reform, and cost-effective solutions to overcome these barriers. Addressing these challenges is essential to unlocking VR's potential for innovation and inclusivity in education.

7. Discussion

7.1 Trends and Methodological Challenges in Virtual Reality Research

The integration of Virtual Reality (VR) into lower secondary STEAM education has gained significant scholarly attention, as reflected in the increasing number of studies exploring its pedagogical impact. However, research in this field often encounters methodological challenges, such as limited geographic and cultural contexts, small sample sizes, and reliance on cross-sectional data. Studies like Wang (2024) and Du et al. (2022) demonstrate promising outcomes but are constrained by single-region scopes, limiting generalizability. Future research should prioritize longitudinal designs and cross-cultural investigations to evaluate VR's sustained impacts and adaptability in diverse educational environments.

7.2 Technological and Design Limitations

Technological barriers remain a significant challenge for VR adoption. High equipment costs, limited infrastructure, and usability concerns hinder widespread implementation. As noted by Ravichandran and Mahapatra (2023) and Lin et al. (2024), scalability and cost-effective solutions are critical to overcoming these obstacles. Furthermore, VR systems often lack accessibility and adaptability, which impacts their effectiveness in meeting diverse student needs. Addressing these limitations through innovative system designs and technical improvements is essential to ensure VR's broader integration in STEAM curricula.

7.3 Teacher Training, Professional Development, and Individual Barriers

The role of teacher training in successful VR integration cannot be overstated. Studies such as those by Baek (2020) and Oubahssi et al. (2024) highlight the lack of structured professional development programs and advanced authoring tools for educators. Tafazoli (2024) further underscores the challenge of individual teacher resistance, insufficient technological proficiency, and systemic institutional constraints as barriers to adopting computer-assisted technologies, including CALL in Iran. While professional development opportunities enhance teacher confidence and skillsets, they alone cannot address broader contextual barriers. These findings highlight the critical need for multi-level interventions, including institutional support and systemic policy changes, to empower teachers with the tools and motivation needed to integrate VR effectively into their teaching.

7.4 Navigating Health, Safety, and Interdisciplinary Opportunities in VR Adoption

Virtual Reality (VR) adoption in education faces significant health and ethical challenges. Prolonged use can cause VR sickness, especially in younger students, as highlighted by Ozgun & Sadık (2023). Ethical concerns such as data privacy, algorithmic bias, and the digital divide further complicate integration. Clear guidelines for safe use, equitable access, and inclusive design are vital for sustainable implementation. Additionally, VR's interdisciplinary potential, particularly when combined with Augmented Reality (AR) and Mixed Reality (MR), fosters collaborative learning. Shankar et al. (2023) highlights how such integration enhances STEM education, promoting teamwork, creativity, and critical thinking.

7.5 Transformative Potential of Virtual Reality in Enhancing Educational Engagement and Learning Outcomes (Case Studies)

Virtual Reality (VR) has demonstrated immense potential in educational settings, as illustrated by notable case studies. It has proven transformative in educational settings, enhancing engagement, comprehension, and interdisciplinary learning across various disciplines. Leong et al. (2024) illustrated the impact of VR through Google Expeditions, which enabled students to take virtual field trips, such as exploring ancient Rome, fostering a deeper understanding of historical and cultural contexts. Mondly VR transformed language learning by immersing students in virtual environments, improving motivation and fluency. Similarly, VR-based physics simulations allowed students to visualize abstract concepts, significantly boosting their interest and comprehension in STEM education. These cases underscore the interactive and inclusive nature of VR in fostering critical thinking. Kluge et al. (2022) highlighted the University of Newcastle's use of extended reality (XR) in disciplines like procedural training and criminology. Despite challenges such as infrastructure limitations and cost constraints, the initiative demonstrated VR's capacity for hands-on, safe learning experiences. Interdisciplinary collaboration and iterative software development proved crucial for successful implementation. Zakaria et al. (2020) further emphasized VR's role in primary science education in Malaysia, using immersive tools

like Google Expeditions to improve concept retention and engagement. Similarly, McGrath et al. (2010) demonstrated VR's ability to simplify complex physics concepts. Together, these examples showcase VR's potential to revolutionize education through innovative, scalable approaches.

7.6 Policy Implications and Strategic Directions

Policy barriers, including insufficient institutional support and misaligned curricula, further restrict VR adoption. Studies like Lin et al. (2024) and Santos et al. (2024) emphasize the need for strategic collaborations among policymakers, educators, and technologists. Tafazoli (2024) reinforces the importance of multi-level interventions, particularly in addressing systemic country-level challenges and institutional constraints, which are critical for the successful integration of educational technologies. Policies should address infrastructure gaps, funding models, and equitable access to ensure VR can be adopted at scale. The role of public-private partnerships in driving innovation and accessibility is also critical to realizing VR's potential in STEAM education.

8. Implications of this Study

8.1 Theoretical Implications

By analyzing systemic obstacles like teacher opposition and infrastructure deficiencies with facilitators like professional development and supportive policies, this study contributes to the theoretical understanding of VR integration in lower secondary STEAM education. Future educational research will be guided by the framework it offers for tackling accessibility issues and the digital divide while promoting participation, critical thinking, and interdisciplinary learning.

8.2 Practical Implications

Through scalable teacher training, equitable access programs, and affordable infrastructure, this study addresses systemic constraints and offers practical ways for incorporating VR into STEAM education (Baek, 2020; Ravichandran & Mahapatra, 2023). Policymakers, educators, and technologists can find useful solutions to promote the sustainable and equitable adoption of VR by aligning VR technologies with curricula, which creates engaging and effective learning environments (Huang et al., 2023; Lin et al., 2024).

9. Conclusion

The revolutionary potential of virtual reality (VR) in lower secondary STEAM education is examined in this study, with a focus on how it might improve interdisciplinary learning, engagement, and critical thinking. It draws attention to the significance of professional development, policy alignment, and equal resource access by tackling obstacles including technical restrictions and teacher-related difficulties. The study fills in holes in the literature by concentrating on STEAM instruction in middle schools, which is frequently disregarded in VR research. Actionable tactics for long-term VR integration are provided by the useful suggestions from case studies. To ensure that VR's potential for inclusive and future-ready education is realized, future research should investigate creative frameworks to address systemic issues.

10. Limitations and Future Research Directions

This study is constrained by its dependence on prior research, which may cause it to miss recent advancements or regional differences in VR usage. Other academic levels and fields are left out of the middle school STEAM education focus. Subsequent investigations ought to delve into the enduring effects of virtual reality on educational results in various settings, with a focus on reasonably priced technology, educator preparation, and legislative structures for fair and sustainable incorporation (Merchant et al., 2013; Campos et al., 2022).

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Ethics Statement

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. No ethical approval was required as this is a systematic review article with no new data collection on site, on animals or human beings.

Conflict of Interest

There is no conflict of interest with me about this review article. The study is self-funded, and all sources of financial support have been disclosed.

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