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Integration of Virtual Reality and Augmented Reality into STEAM Education: A Meta-Analysis

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Abstract
Integration of Virtual Reality (VR) and Augmented Reality (AR) into the teaching of science, technology, engineering, arts, and mathematics (STEAM) has become so popular because of the impact on teaching and learning process. This meta-analysis explores the effects of VR and AR technologies in STEAM education based on a chain of studies undertaken over five years. The study analyses the impact of immersive technologies on student engagement, concept mastery, and skill development in various fields of science and technology. Research findings from various studies indicate that VR and AR support experiential learning by providing an immersive and interactive environment, which enables complex problem solving, creativity, and participation. In other words, VR provides a totally immersive experience that increases spatial consciousness and procedural abilities, but AR improves interaction with the physical environment and the real world. However, VR and AR effectiveness depends upon the level of education and the subject area and method of implementation. It is indicated that the results of the application of VR and AR show significant differences, as in most cases, VR offers deep experiences, whereas AR offers much opportunity to learn about the situation. The special emphasis of research is placed on intentional use of technology and strategies for education. It has identified some key areas that require further study to enhance the application of VR and AR technology in education and to have a higher impact on learning outcomes.

Keywords: Virtual reality, augmented reality, STEAM education, meta-analysis and learning outcomes.

1. Introduction

Integration of VR and AR in STEAM education is one of the imperative transformations in the education sector within the 21st century. These technologies can influence educational experiences because they provide a realistic, interactive, and interactive environment that goes further than the traditional classroom barriers. Teachers and researchers are exploring how virtual reality and augmented reality can foster STEAM education and pointing out the need to establish the impact of these technologies on educational goals. Virtual reality is an online space that uses a head-mounted display or other specific apparatus through which users experience an interactive 3D world. The innovation has been used for people to relate with the virtual world in the most realistic and abstract, as well as imaginative, simulated experience (Coban et al., 2022). Conversely, AR enhances the perception of the environment by the user through superimposing digital information into the physical world via a smartphone, tablet, or AR glasses (Addar & Yuldrm, 2023). Both VR and AR open a door to great educational potential in STEAM subjects that have a practical foundation. STEAM education brings together scientific investigation, technological ingenuity, engineering design, creative art, and mathematical reasoning.

The objective is to have an in-depth knowledge of the topics and be ready to critically analyse the problems with which they will be confronted. VR and AR are believed to be very effective tools for improving STEAM education because they create engaging learning experiences that can greatly affect participation, understanding, and students' skill development. Improved student participation has been seen with the inclusion of VR and AR in the education sector. It has been argued that research shows that there is the possibility of providing highly interactive learning experiences that immerse students in the environments usually impossible or even ineffective (Chistyakov et al., 2023). For instance, for complex concepts, VR simulation can take students to historical events, distant planets or small worlds where they can understand what is going on through their direct interaction. Similar, virtual information can be attached to real objects in order to improve the access of theoretical concepts, participation, and deepen interconnectivity between education and realistic scenarios (Velarde-Camaqui, 2024).

VR and AR sustain the users and enhance learning, which further enhances acquiring new skills. Immersive nature of VR offers students a 3D platform where they can practice even the most complex scientific and mathematical concepts to enhance spatial understanding and procedural skills. AR allows the student to connect the theoretical with practice and better understand the concept in real-life contexts as it provides information on real-time contextual grounds (Li, 2023). Gülhan and Hamash (2024), hold that the inclusion of VR and AR in project-based learning and teamwork enhances creativity and problem-solving skills. Both VR and AR have great potential in STEAM education but how they function depends on academic levels, subjects, and application. Studies on the integration of data also propose that VR is much more immersive and AR enhances context in different scenarios (Chang, 2022; Hanid, 2020). For example, it has been very successful in engineering and physics fields where spatial understanding is a prime requirement. On the other hand, AR has demonstrated major benefits in mixing theoretical knowledge with practical experience in areas like biology and geography (Yu, 2023). That means the choice between VR and AR should be made in specific educational goals and environments.

With that in view, the objective of this meta-analysis is an evaluation of the effectiveness of VR and AR technologies through the use of quantitative data analysis extracted from many studies carried out over the course of the past decade. In general, the general objective of the study would be to provide comprehensive understanding into the educational value gained by studying the effect of influence on student engagement, knowledge and performance in the various STEAM-related areas. The primary aim will be to exhibit the possible changes and constraints of VR and AR, offering advice as to how it can best be used and implemented. Also, the study identified significant gaps in current research on the integration of VR and AR technologies into educational environments and proposed a future route for improvement. Thus, the integration of VR and AR in STEAM education is considered to be one of the greatest leaps in educational technology. This interactive tool has shown potential in enhancing experiences with an increase in engagement, depth of conceptual understanding, and better skill improvement. However, the functionality of these technologies is otherwise different on different levels of education, disciplines, and method used. Based on an in-depth review of available evidence, this meta-analysis aims to give an in-depth overview of the incorporation of VR and AR into STEAM education and guide further research and applications to improve their impact on educational results.

2. Research Questions

- What are the effects of VR and AR on the participation and understanding of students in STEAM methods?
- What tactics can be used to integrate VR and AR into project-based learning to improve students' problem-solving and creativity skills?
- What are the differences between VR and AR educational results based on the level of education and subject matter in the STEAM framework?

3. Methodology

The objective of this meta-analysis is to assess the impact of virtual reality (VR) and augmented reality (AR) technologies on improving the STEAM (Science, Technology, Engineering, Arts, and Mathematics) education system. The methodology section describes some concrete criteria, i.e., collection, extraction, and synthesis processes, and the statistical methods utilized for the estimation of the impact of VR and AR technologies on different educational metrics. The research is in line with PRISMA 2020 publication selection principles to give an exhaustive and unprejudiced strategy. On the basis of these standards, the research endeavours to comprehend specifically how immersive technologies enhance educational processes and outcomes of learning in STEAM subjects.

3.1 Inclusion and Exclusion Criteria: Inclusion and Exclusion Criteria were also defined evidently to confirm the validity and worthiness of the studies selected to examine the utilization of VR and AR in STEAM education. 41 studies out of 89 reviewed during January 2020 to August 2024 were included upon undergoing a proper evaluation process. The studies selected were primarily quantitative empirical research, such as randomized controlled trials, quasi-experimental studies, and studies with clearly defined experimental and control groups. This focus on empirical research ensured that the findings provided measurable results in terms of the impact of VR and AR on student motivation and knowledge acquisition in STEAM subjects. These were accompanied by mixed-method studies that combined qualitative evidence with quantitative findings and thus gave a better overall picture of the practical and situational nature of VR and AR use in educational settings. Studies that lacked sufficient quantitative analysis, however, were excluded because they did not meet the necessary standards for strong empirical comparison. Besides, exclusively research on VR and AR pertaining to STEAM education was looked at. Non-STEAM subject research or research that touched upon other categories of educational technology, such as mobile learning programs or e-learning platforms, was not taken into account (Gülhan, 2024; Li et al., 2023). Hidayat and Wardat (2024) remained persistent in data analysis by selecting research articles that appeared only in the English language for ensuring linguistic consistency and availability in global academic exchange.

3.2 Search Strategy: A thorough searching strategy is adopted to determine appropriate articles. The literature study adopts various academic database platforms of PubMed, ERIC, Scopus, Science Network, and Google Scholar among others, with an elaborative educational as well as technological research material (Kim et al., 2024). The study incorporated several selected keywords and terms based on VR, AR and STEAM education with respect to their impact on student achievement. Terms that involve "virtual reality", "augmented reality", "STEAM education", "student engagement", "conceptual understanding", and "21st century skill development" found in Leavy (2023), and Zhang et al. (2022), debates. Titles and summaries of studies identified were used as a reference to decide their relevance. The original text of the article has been reviewed to decide about eligibility. Chang et al. (2022), exclude duplicate studies and only include those that meet all criteria in the final review.

3.3 Data Extraction: Data extraction refers to a systematic process of extracting data from selected studies. Methods, sample size, education background, and subjects under research were targeted. The ones include information concerning the adoption of VR and AR technology and evaluation of educational results concerning particular issues (Coban et al., 2022; Sanz Camero et al., 2023). Data was collected on the factors of the following namely, engagement of pupils, awareness of concepts and enhancement of skills. The above technologies were grouped in different sub-disciplines so that there was something to be used in comparative analysis with different research works. Impact size for every research was also calculated just to check for the significant difference VR & AR cause to the output of studies. This was achieved by using standard mean differences and probability ratios as needed (Kalemkuş & Kalemkuş, 2023).

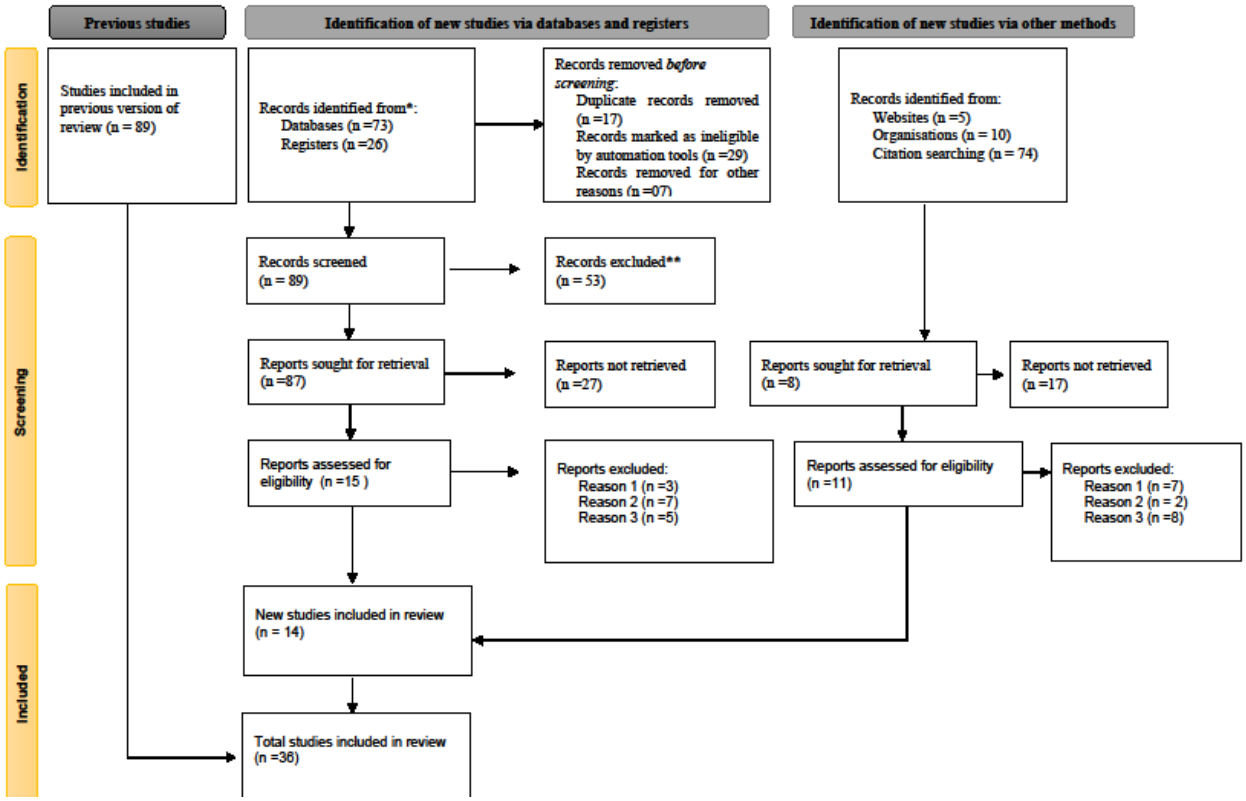
3.4 Data Synthesis and Analysis: The integration of findings of different studies into overall conclusions is synthesis data. Meta-analysis was performed by using software packages, namely Comprehensive Meta-Analysis (CMA) and RevMan. Dong et al. (2023) uses the random effects model to capture heterogeneity among studies for better estimates of effect size concerning VR and AR in the STEAM curriculum. To establish the variability in the research, I2 statistics used to evaluate proportion of variance explained by inter-research variability were applied to assess heterogeneity levels in the study. If a high heterogeneity is suggested, the study may need subgroup analysis or sensitivity analysis. For instance, the Chang et al. (2022) study on their work utilized funnel maps and Egger tests for evaluating publication bias. This phase tested whether publication bias could be a source of influence in the outcomes of the meta-analysis conducted by Qiu et al. (2024).

3.5 Sensitivity and Subgroup Analyses: In addition to the aim of evaluating the robustness of the study findings and maintaining its validity, sensitivity analysis was done. The goal behind doing the analysis was

checking the study's effectiveness based on dropping off studies having higher degrees of bias or outlier findings (Avera & Yaldrim, 2023). The analysis involved subgroup levels by level of education in addition to subjects considered and by the use of VR or AR application. It aided in exploring the effectiveness based on other influencing elements through the utilization of the used VR and AR technologies (Kalemkuş & Kalemkuş, 2023, Marii & Lavicza, 2024).

3.6 Reporting and Interpretation: Results from the meta-analysis were reported according to the guidelines of the preferred components for system review and meta-analysis reporting (PRISMA). The findings are interpreted based on the potential impact on STEAM education and the potential of VR and AR to improve educational experiences (Erduran et al., 2024; Perales & Aróstegui, 2024). This evaluation also pinpointed the limitations of current research and provided suggestions for future research on the potential improvement of the integration of these technologies in educational settings. This guarantees that an all-rounded assessment of VR and AR technologies is given in STEAM education, provides useful insights into their effectiveness, and influences future research and practices in the field.

Figure 1: PRISMA 2020 flow diagram showing Meta-Analysis Literature Reviews approach which included and excluded searches of databases, registers and other sources.



4. Technological Foundations of Virtual Reality & Augmented Reality into STEAM Education

Virtual reality (VR) and augmented reality (AR) are advanced technologies that are being used more and more in education, especially in STEAM disciplines. These technologies provide immersive learning experiences that can assist students in understanding difficult concepts better and enhancing their learning (Cao, 2023; Dong et al., 2023). VR enables users to interact with completely virtual worlds through headsets and motion sensors, providing alternate realities (Cromley et al., 2023). Conversely, AR imposes digital content upon the real world, which one can experience through mobile devices or AR glasses (Hidayat, 2024). Both VR and AR depend on cutting-edge technologies such as sensors, cameras, and computer vision in order to design interactive experiences (Gülhan, 2024; Xu, 2022). While VR completely immerses people in a virtual environment, AR combines digital information with the physical world (Gamez-Tone et al., 2023; Chang et al., 2022). VR devices usually consist of high-definition screens, spatial audio, and motion tracking for a more immersive experience (Coban, 2022). AR, on the other hand, usually superimposes digital information over real-world environments with mobile phones or AR glasses (Li et al., 2023; Velarde-Camaqui et al., 2024). Recent developments in VR

and AR hardware involve increased processing speeds and better sensors, whereas software developments aim to advance user interaction and overall experience (Leavy et al., 2023; Marii et al., 2024).

5. Impact of Virtual Reality & Augmented Reality on STEAM Education

The application of virtual reality (VR) and augmented reality (AR) in STEAM education has been shown to enhance learning in an extraordinary manner. The two technologies provide a real-time, interactive experience that the conventional methods of instruction might not be able to provide. Avader and Yarrow (1923) studied the impact of VR and AR in STEM education, showing that they effectively boost interest and understanding of STEM subjects by simulating complex processes and phenomena (Coban et al., 2022; Yu et al., 2022). Chang et al. (2022) conducted a decade-long study, finding that AR positively influenced school-level education outcomes by increasing student engagement and achievement. This concurs with Li et al. (2023) and Hanid et al. (2020), whose findings showed enhanced pupil engagement and outcomes in schools making use of AR apps. Dong et al. (2023) posited that AR and VR can be made simpler with STEM education. Chistyakov et al. (2023) further emphasized the potential of project-based learning through the aid of VR and AR, where interaction and immersion are encouraged to yield more effective learning and, consequently, improve the quality of STEAM education (Cromley, 2023; Hidayat, 2024).

6. Immersive Learning and Engagement in STEAM Education through Augmented & Virtual Reality

Virtual reality and augmented reality enhance the student's engagement in learning and result in more engaging educational experiences (Hidayat & Wardat, 2024). The technologies, using interactive and hands-on learning environments, can attract the attention of students and drive them to learn more (Cao 2023, Zhaoetal.2022). Immersive learning environments allow students to engage with materials that traditional approaches cannot accomplish (Dong et al., 2023; Leavy et al., 2023). VR can be applied in the replication of scientific experiments and historical events so that students can have practical experiences which enhance their knowledge (Cromley et al., 2023). Coban et al. (2022) researched on the analysis of how immersive VR enhances learning and its effectiveness in offering interactive learning experiences. Engaged learning not only brings students into focus but also enables active participation and enhances the recall of information (Kalemkuş & Kalemkuş, 2023). Hanid et al. (2020) highlights the fact that AR can upgrade learning methods by providing more interactive and contextual information in order to make students much more involved in the subject. Current studies (Games-Ton and Ordia, 2023; Milara and Ordia, 2024) also report that both VR and AR can enhance an experience of STEAM education and create an interactive learning atmosphere.

7. Use of AR & VR in STEAM Education for Conceptual Understanding and Skill Development

The use of VR and AR in teaching improves students' comprehension of ideas as well as develops skill acquisition according to Hanid and Li 2023. With these technologies, students have a better way to understand complex concepts abstractly by interactive and visual approaches (Cao, 2023; Xu et al., 2022). Use virtual reality simulations in order to recreate scientific phenomena or engineering processes so that students can see and experiment with concepts that are very hard to be represented physically in a classroom (Gomez-Tone et al., 2023; Lampropoulos et al., 2022). Li et al. (2023) also researched the effect of AR on university performance, which improved the understanding of complicated subjects using interactive graphics. In 2022, Xu et al. studied the effect of AR on scientific education and found that it enhanced the understanding of the students by using stimulating and interactive resources (Hidayat & Wardat, 2024). It has been supported by Chistyakov et al. in the year 2023 that the importance of practical experience learning can be created with the help of Augmented Reality and Virtual Reality for STEAM education with emphasis on the fact that this would provide better trainings (Erduran et al., 2024). Dong et al., (2023) learnt that Virtual reality and augmented reality enhance the effectiveness of the courses in STEM stream since they were studying "Use of Augmented reality (XR) in Learning Context" in the year 2023. These conclusions point towards an improvement of learning through virtual and augmented reality since they are highly interactive, immersive, and make the experiences better for learners in the areas of STEAM.

8. Variability in Effectiveness of Virtual Reality and Augmented Reality in Education

Even though VR and AR have several benefits, the effect of VR and AR on education can be different due to a variety of reasons (Coban et al., 2022; Dong et al., 2023). The quality of the technology, the design of the educational content, and the context affect the efficiency of these technologies (Cromley et al., 2023; Chang et al., 2022). According to Avadar and Keldim, 2023, some factors that may affect advantages in VR and AR include readiness of educational level and the way technology supports educational goals (Leavy and et al., 2023). Avadar and Keldim (2023) carried out a meta-analysis on the application of AR in scientific education. They mention the diversity in their performances regarding academics, while variation in the structure of intervention along with its actual practice shows variations in AR application with varied success cases in

practice. According to Hiddaat & Wardat, 2024 and Xu et al., 2022, Yu says there should be an observation towards understanding contextual factors while exploring heterogeneity in terms of effect over the result of learning as the result of implementation for educational effects of using AR, according to Yu (2023). This will, however depend on proper integration within the curriculum and synchronization towards very accurate learning objectives such as stated in Erduran et al., 2024; Milara & Ordua, 2024. According to Dong et al. (2023), AR and VR can improve science and technology teaching as it was also indicated in Avdar and Yldrm's (2023), study on the application of augmented reality (XR) in education. These findings suggest that VR and AR can enhance learning by increasing interaction and immersion, thereby improving educational experiences in STEAM subjects (Gamez-Tone et al., 2023; Marii et al., 2024).

9. Critical Analysis and Future Directions

An in-depth analysis of recent studies shows promising potential and significant challenges for the integration of VR and AR technologies into education. Although there are opportunities to improve the process of teaching (Coban et al., 2022), the challenge of cost, availability and the need for effective teaching techniques remains. High costs for VR and AR devices and the technical expertise required to use them could prevent their widespread use (Avdar & Yldrm, 2023). Furthermore, these technologies need to be carefully integrated into existing curriculums to ensure they are consistent with educational goals and improve learning experiences (Kamek & Karamsh, 2023). Ayanwale et al. (2024) examined the effect of trust in AI-powered educational tools on STEAM teachers, stressing the importance of teacher preparedness and trust in the successful integration of new technologies.

This is in line with Marii and Lavicza's research (2024), which emphasizes the importance of providing professional training and assistance to teachers in the integration of new technologies into their teaching methods. Future research should focus on addressing current limitations and finding innovative ways of integrating VR and AR into educational environments (Gülhan, 2024). This involves the development of plans to improve the accessibility and affordability of these technologies and the establishment of standards for their use (Erduran, Guilfoyle et al., 2024). In addition, further research is needed to examine the long-term effects of VR and AR on education outcomes and determine effective methods for managing differences in their effectiveness (Leavy et al., 2023). Dong et al. (2023), examined the use of extended reality (XR) in education. They discovered that virtual reality and augmented reality can enhance the effectiveness of STEM education. These results suggest that VR and AR may improve STEAM learning by increasing interaction and immersion, which ultimately improves learning experiences (Li et al., 2023).

Finally, VR and AR have a significant impact on STEAM education by providing immersive and interactive learning experiences that improve participation, understanding of concepts and skills development. However, its effectiveness may vary depending on factors such as technological quality, educational content design and use context. A thorough analysis of recent research reveals the benefits and challenges of these technologies. Future objectives should focus on overcoming these obstacles and discovering creative strategies to integrate VR and AR effectively into educational environments.

10. Results & Discussion

This meta-analysis of literature reviews the impact of virtual and augmented reality technologies on STEAM education, particularly in terms of learning outcomes, participation and conceptual understanding. The following sections present important findings of selected studies and examine their impacts.

10.1 Results

Table 1: Showing the essential aspects of each study, allowing for a clear overview of the integration of VR and AR technologies in STEAM education.

Study	Technology	Impact	Key Findings
Ayanwale et al. (2024)	AI-based Educational Technologies	Trust in technologies	Teachers' trust in AI technologies positively influences their integration into STEAM education.
Cao (2023)	AR and VR	Mathematics learning	AR and VR significantly improve students' understanding and engagement in Mathematics.
Çavdar & Yıldırım (2023)	Mixed, AR, and VR	STEM Education	Comprehensive benefits in STEM education; bibliometric analysis shows growing integration of immersive technologies.
Chang et al. (2022)	Augmented Reality	Educational outcomes	Meta-analysis shows AR enhances learning experiences and outcomes across various

			educational contexts over ten years.
Chistyakov et al. (2023)	Project-based Learning	Science and STEAM Education	Project-based learning enhances engagement and understanding in science and STEAM disciplines.
Coban et al. (2022)	Immersive Virtual Reality	Learning effectiveness	Immersive VR significantly boosts learning retention and student engagement compared to traditional methods.
Cromley et al. (2023)	Virtual Reality	STEM learning	VR provides broad benefits across STEM education, including improved understanding and skill application.
Dong et al. (2023)	Extended Reality	Teaching effectiveness	Extensive review indicates XR improves teaching effectiveness through enhanced student engagement and collaboration.
Erduran et al. (2024)	Cross-Curricular Collaboration	Argumentation skills	Cross-curricular integration enhances argumentation skills in STEAM contexts, promoting deeper learning.
Gomez-Tone et al. (2023)	AR and Immersive VR	Spatial skills training	AR and VR significantly enhance spatial skills in university-level STEAM students.
Gülhan (2024)	Hands-On Workshops	Teacher collaboration	PLC workshops in STEAM foster collaborative practices and professional growth among teachers.
Hamash et al. (2024)	Flow State Model	Student engagement	New models for achieving flow states in STEAM education enhance students' focus and learning outcomes.
Hanid et al. (2020)	Augmented Reality	Learning strategies	AR technologies improve student learning strategies, leading to better academic performance.
Hidayat & Wardat (2024)	Augmented Reality	Learning effectiveness	Systematic review shows AR enhances understanding and retention in STEM education.
Kalemkuş & Kalemkuş (2023)	Augmented Reality	Academic achievement	Use of AR applications significantly improves academic achievement in science education.
Kim et al. (2024)	Literature Review	STEAM education development	Review highlights key developments and trends in STEAM education in Korea, emphasizing technology integration.
Laksmiwati et al. (2024)	Hybrid Learning Environment	Teacher innovation	Hybrid learning fosters teacher innovation through design heuristics in engineering and STEAM contexts.
Lampropoulos et al. (2022)	AR and VR	Public perspectives	Public sentiment towards AR and VR in education is generally positive, with an emphasis on their potential benefits.
Leavy et al. (2023)	Emerging Technologies	Technology prevalence	Systematic review shows increasing prevalence of emerging technologies in STEAM education across various settings.
Li et al. (2023)	Augmented Reality	Academic achievement	AR positively affects academic achievement in higher secondary level education, enhancing engagement and learning.
Malagrida et al. (2024)	Responsible Research and Innovation	STEAM competencies	Focus on competencies supports responsible innovation in STEAM education.
Maričić & Lavicza (2024)	Emerging Technology Integration	Student engagement	Emerging technology significantly enhances student engagement in STEAM learning environments.
Martins & Baptista (2024)	Integrated STEAM Education	Teacher PCK development	Professional development in integrated STEAM contributes to enhancing teachers' pedagogical content knowledge.
Milara & Orduña (2024)	STEAM Pedagogies	Teaching effectiveness	Challenges and strategies in STEAM pedagogies impact teaching effectiveness and student learning outcomes.
Montés et al. (2024)	STEAM∀ H	Higher education	Redefining STEAM to include all humanity enhances inclusivity and relevance in higher

			education.
Nyaaba et al. (2024)	Inclusive STEAM Education	Sustainable education	Emphasizing STEAM education from the start leads to more inclusive and sustainable educational practices.
Perales & Aróstegui (2024)	STEAM Approach	Educational outcomes	Implementation of the STEAM approach has significant educational, social, and economic consequences.
Qiu et al. (2024)	Virtual Reality	EFL learning	VR enhances English as a Foreign Language (EFL) learning outcomes significantly.
Sanz-Camarero et al. (2023)	Integrated STEAM Education	Arts education	Integrated STEAM education positively impacts arts education, promoting creativity and interdisciplinary skills.
Su et al. (2024)	STEAM in Early Childhood	Early education development	STEAM integration in early childhood education fosters holistic development and early engagement in STEM fields.
Sun & Saleh (2024)	STEAM Activities	Equity in education	Strategies for promoting equity in STEAM education significantly enhance student participation and success.
Velarde-Camaqui et al. (2024)	EduAR Platform	Augmented Reality	The EduAR platform enhances STEAM education through interactive AR experiences, improving engagement.
Xu et al. (2022)	Augmented Reality	Science learning	AR effectively enhances science learning outcomes, influenced by various moderating factors.
Yu (2023)	Augmented Reality	Educational outcomes	A decade-long analysis shows AR's consistent positive effects on educational outcomes across disciplines.
Zhang et al. (2022)	Augmented Reality	K-12 education	Systematic review indicates AR significantly improves educational outcomes in K-12 settings.

10.1.1 Impact of AR and VR on Educational Outcomes

In exploring the effects of virtual reality and Augmented Reality on education in STEAM, different aspects of learning results, participation, and understanding, this meta-analysis considers everything. In this regard, numerous studies have established the fact that VR and AR promote highly enhanced learning results when it comes to STEAM subjects. According to Dong et al. (2023), the interactive nature that is associated with VR and AR can improve the outcomes of students' academic activities in STEM fields by imitating content. Similarly, Li et al. (2023) had revealed that AR technologies enhance higher secondary education by understanding at the level of academic performances through interactive simulations. A great advantage has been realized in the field of engagement for VR and AR. Avdar and Yoldrm, (2023) has revealed that motivation and students' participation enhanced if they involve teaching with AR enhancement instead of conventional teaching techniques. This is in agreement with results from Chang et al. (2022), as the statistical analysis showed the fact that AR apps promote a high involvement of students in any educational activity and enhance efficiency and fun while learning experience.

Conceptual understanding of VR and AR technology has been fully tested. Xu et al. (2022), emphasized that AR applications allow a student to see the conceptual scientific idea and improve a student's ability to hold more information. Additionally, Marii and Lavicza, (2024), cited how this new technology infusion in the STEAM curriculum allows learning of the material and cultivates critical thinking, where students are ready for usage in practice. In general, this meta-analysis concludes that inclusion of VR and AR in STEAM education has significant effects on outcomes in learning, participation, and understanding concepts, as evidenced by impressive results from these studies. This field could be the location for further research in better ways to improve educational methods through the incorporation of these technologies.

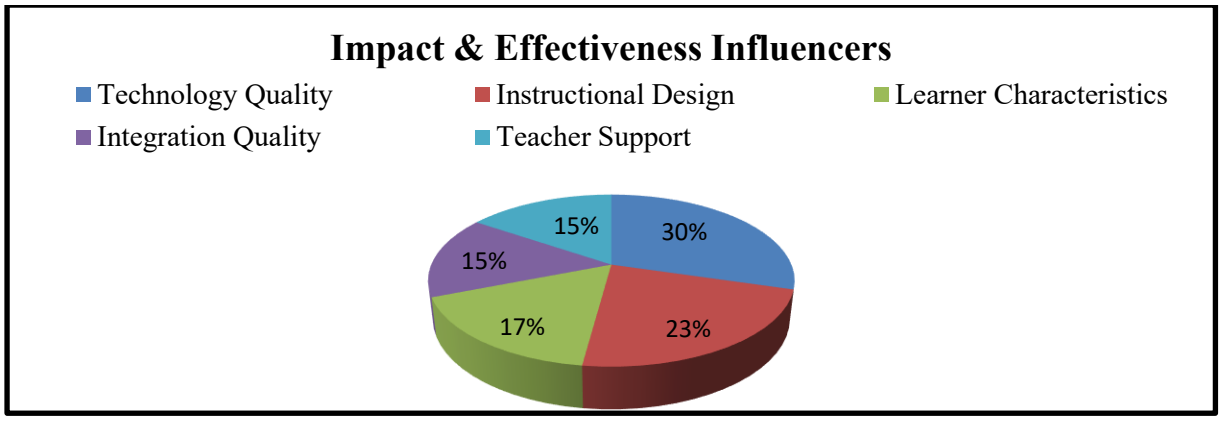
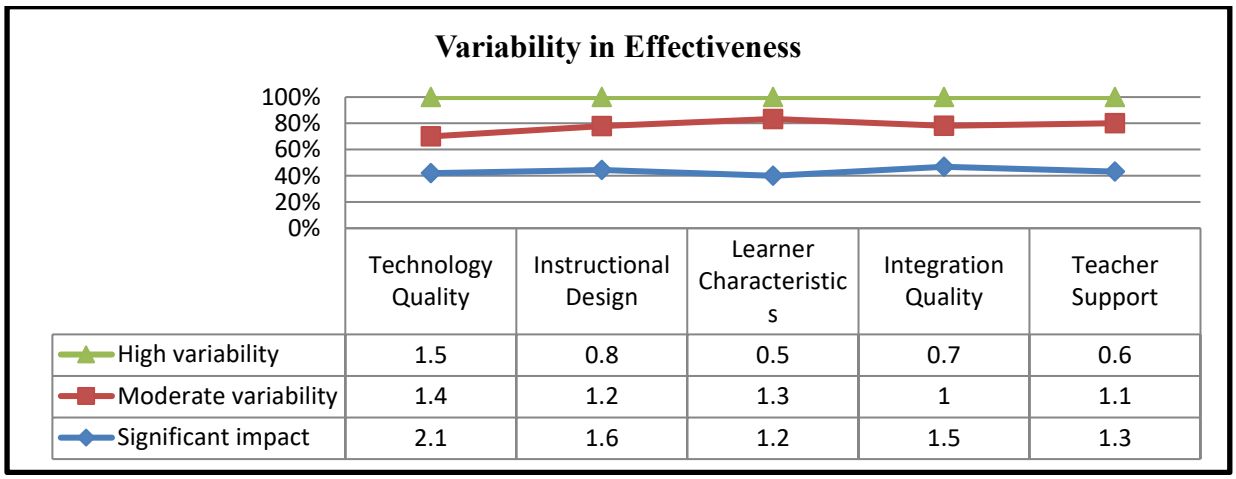


Figure 2: Illustrating the factors impacting & influencing the effectiveness of AR and VR technologies in STEAM Education.

10.1.2 Variability in Effectiveness

It is varying in terms of involvement depending on the implementation of VR and AR. According to Vladar and Irodim, students who used AR technology showed a higher level of motivation in comparison with others using conventional means, but such an effect can be strongly related to the structure of the lesson and its content. This is confirmed by Chang et al. (2022), who showed that AR applications usually increase the engagement of students, but this depends on educational tasks and settings. Therefore, it means that involvement depends not only on technology, but also on teaching methods and past experience of students. Changes in influence of VR and AR on conceptual understanding are also reflected. Xu et al. (2022) highlighted that through AR apps, students visualize ideas behind intricate science concepts which may enhance better understanding and memory. Such technologies can, however not benefit each student, primarily those with no basic skills. This includes the extent to which such technologies can be embedded within the present curricula by teachers to affect their ability to influence critical thinking skills.

Overall, VR and AR technology integrated in STEAM education has enormous potential in terms of improvement of results of learning, participation and understanding. However, differences in the effectiveness of its use and impact in various situations and with the population of students point to further research directions. Harnessing these subtleties will be crucial in terms of optimizing use of VR and AR in an educational environment and making all students able to take full advantage of these modern tools.



	Technology Quality	Instructional Design	Learner Characteristics	Integration Quality	Teacher Support
High variability	1.5	0.8	0.5	0.7	0.6
Moderate variability	1.4	1.2	1.3	1	1.1
Significant impact	2.1	1.6	1.2	1.5	1.3

Figure 3: Showing the level of variability for each factor affecting the effectiveness of AR and VR technologies.in STEAM Education.

10.1.3 Teacher Trust and Professional Development

The main aspects for integrating virtual reality and augmented reality well into STEAM education lies in the teachers' competence in the use of technologies, in conjunction with their training in these areas. According to Ayanwale et al., (2024), "Teachers need to appropriately integrate AI-based educational technologies into STEAM education.". The trust of teachers in technology will affect its effectiveness and reliability, which affects the adoption and use of these technologies. If teachers believe in the benefits of technology, they are more likely to use it actively and implement it in teaching methods. Professional growth is very essential. Martins and

Baptista (2024) also stated, that professional development in an integrated education on STEAM strongly increased the PCK knowledge in a teacher's teaching set. Such professional development exactly provides educators with the level of training required to facilitate effective application of innovative technologies into the learning settings. Another related point, which has also been made, is the one in which Gülhan (2024), pointed out, that "interactive workshops along with teamwork boosted teachers' development and developed new teaching approaches like VR and AR.". In addition, Marii and Lavicza, in their paper (2024) assert that student involvement augments directly with new technologies. More professionally developed teachers are likely to use those technologies better, hence benefiting their students' education.

Teachers should, therefore, be more confident in the VR and AR technologies and receive comprehensive training to take advantage of them. This improvement will be in the ability of teachers to use immersive technologies as well as reinforce quality learning experiences within students.

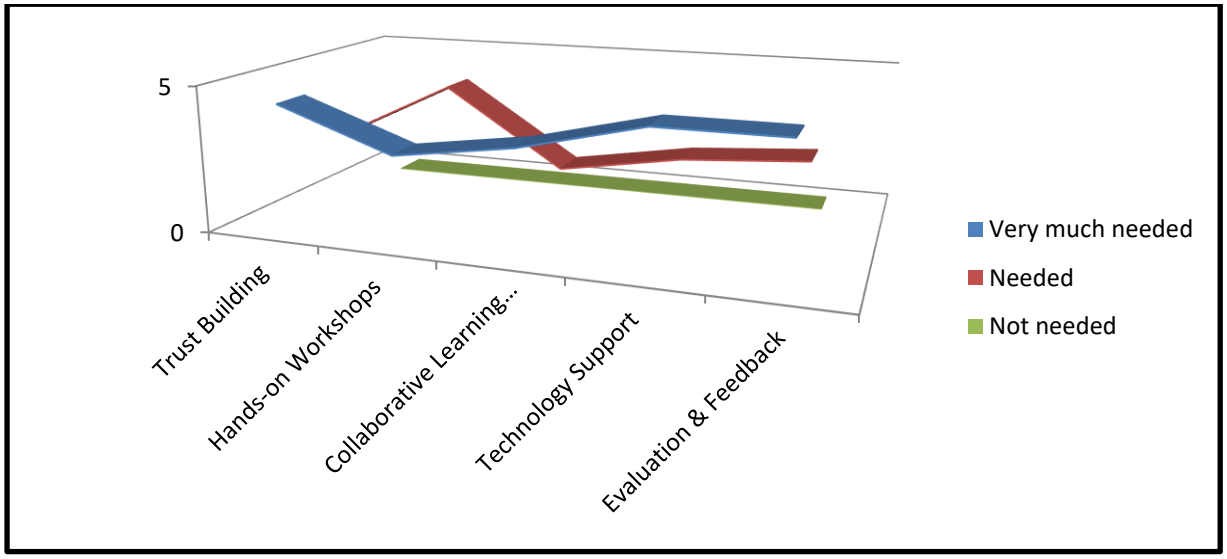


Figure 4: Showing the relative importance of different professional development needs for effective implementation of AR and VR technologies in STEAM Education.

10.1.4 Cross-Curricular Collaboration & Innovation through Engagement and Immersive Learning

Collaboration and creativity in the diverse fields of specialization are very essential for STEAM education. Immersive and engaging learning experiences emanate from effective VR and AR technologies. The amalgamation of diverse disciplines enhances gaining a better understanding and better educational experience among the students. According to Erduran et al. (2024), the work on various subjects enhances the capability of the STEAM field in arguing and then leads to profound learning. This collaboration encourages the application of what has been learned from different disciplines and facilitates the integration of complex ideas in a holistic manner. In addition, Chistyakov et al. (2023), suggest that project-based learning, which is likely to cut across a few disciplines, is bound to increase participation and comprehension of science and STEAM education and emphasizes collaborative learning methods. Immersive technologies offer very unique opportunities for creating conditions for creative learning and teaching and education. According to Dong et al. (2023), there is an expansion in reality that increases the intensity and collaboration of students resulting from the increase in efficacy towards education. This practical approach fosters the gap between purely hypothetical ideas and the use of real world and increases enthusiasm and involvement in the process. Coban et al. (2022), further supports the understanding that immersive VR enhances retention of learning and promotes participation better than traditional methods, and it reveals the possibility for immersive learning environments to revolutionize the education experience.

The effects of AR and VR on students' engagement have been extensively discussed. According to Cao (2023), AR and VR have dramatically changed the game in terms of students' mastery and engagement in mathematics. Conversely, Chang et al. (2022) discovered that AR has enabled favourable learning outcomes and experiences within various educational environments over the last decade. These findings unlock the potential for immersive technologies to use in the learning environment, including making it more participatory and creative. Generally, cooperation efforts in diverse fields, blended with these immersive technologies like AR and VR, can significantly enhance participation, understanding, and students' achievements in the overall competencies in the STEAM fields. Teachers should prepare students for the real world by fostering collaboration while creating dynamic learning spaces using creative techniques that lead to instructive techniques.

10.2 Discussion

The above studies give a thorough review of how integrating AR and VR technologies can influence STEAM learning, highlighting their ability to improve student engagement, enhance conceptual understanding, and support immersive learning. Nevertheless, they also point to the challenges that come with such integration, such as the provision of proper teacher training, high-quality instructional design, and contextualisation in effective implementation of the technologies in educational settings.

10.2.1 Effectiveness and Impact of AR & VR on STEAM Education: The uniform outcomes of different studies result in the conclusion that augmented reality (AR) and virtual reality (VR) can well engage students and improve their conceptual knowledge. Chang et al. (2022) and Xu et al. (2022) present strong evidence that AR has a beneficial impact on learning by enhancing understanding and boosting involvement in complicated topics. Similarly, Coban et al. (2022) observes that VR creates extremely immersive learning environments, resulting in enhanced experiential learning. However, Dong et al. (2023) point out the variable effectiveness of such technologies, noting that implementation and context determine their success. The contrast in the quality of technology, instructional design, and the extent to which teachers receive support plays a crucial role in the performance of AR and VR within educational environments. This indicates that although AR and VR are highly potent, their performance is greatly subject to different variables such as the level of use, preparation of teachers, and the nature of learning activities themselves (Çavdar & Yıldırım, 2023). Thus, in order to optimize the advantages of AR and VR, it is crucial to take into account these factors and make sure that the technology as well as teaching strategies are adequately appropriate for students' and teachers' needs.

10.2.2 Teacher Trust and Professional Development: Ayanwale et al. (2024) point out that among the most important conditions for effectively embedding augmented reality (AR) and virtual reality (VR) in learning spaces is the competence and capacity development of teachers. Teachers should be able to make effective use of these new tools, since their utilization has a direct bearing on student engagement and academic performance (Dong et al., 2023). To establish this ability, teachers ought to engage in interactive professional development programs. Such courses promote teamwork and collaboration among instructors, making them better equipped to integrate AR and VR into teaching (Gülhan, 2024). Such collaboration corresponds with the awareness that effective implementation of new technology in education relies on adequate support and training of teachers (Chang et al., 2022). By investing in teacher professional development, teachers can acquire the skills and confidence needed to effectively utilize AR and VR in their classrooms. Such an investment not only rewards the teachers but also enhances the learning experience of the students, making it more engaging, authentic, and immersive. Finally, giving training to teachers so that they become equipped to maximize the usage of these technologies creates better learning conditions and more accurately prepares students to meet the challenge of the modern digital world.

10.2.3 Engagement and Immersive Learning in the context of STEAM Education: For Marii and Lavicza (2024), students are most effectively engaged when learning with the aid of virtual reality (VR) and augmented reality (AR) technologies, as these make highly interactive and immersive environments for learning. AR and VR give learners the kind of experience that engages them, opening up complex ideas to be more achievable and fun. These technologies allow students to achieve a state of flow, complete immersion, and concentrated attention on their learning activities, implying that immersion technologies can greatly improve the learning process (Hamash et al., 2024). This is particularly significant in STEAM education, which focuses on hands-on engagement and intrinsic motivation for achievement. Through the promotion of curiosity and active engagement, AR and VR not only enhance comprehension but also encourage critical thinking and creativity. As teachers increasingly investigate and employ these technologies, the more evident it is that they provide richer, more immersive learning experiences. In the end, VR and AR are revolutionizing the way students engage with the world of information, preparing them for greater success in a rapidly changing digital age. These developments guarantee that students are not just learning information but actually applying problem-solving and creative processes, which are required skills in the contemporary world.

10.2.4 Cross-Curricular Collaboration and Innovation: Erduran et al. (2024), have indicated the possibility of positive impacts of AR and VR on encouraging cooperation and innovation for STEAM education. These technologies have made possible, Laksmiwati et al. (2024), integrating different disciplines with new ways of developing creativity. For example, the potential of AR and VR might be tapped to simulate involved processes or cross-cutting subjects in order for students to better understand STEAM concepts and apply those concepts better. In principle, then, the merging of these AR and VR applications into a single package, as such, offers very significant gains in STEAM education by way of significantly enhanced participation, concept appropriation, and related academic outcomes. However, qualities of technology, teaching design, and support by teachers are greatly influencing its competence. Varieties of the results have established that all these factors are to be considered deeply so that full potential of AR and VR is achieved. Research in future should further follow

the investigation of successful implementing strategies while overcoming challenges faced at the stage of incorporation in daily practice of education. AR and VR have helped teachers to enhance learning and training in STEAM by focusing on teacher training and environmental factors.

10.2.5 Practical Challenges in Streaming AR and VR into STEAM Education: Streaming AR and VR into STEAM education does come with some technical limitations. Foremost among them is the expense and technical know-how of installing AR and VR technology, which would be a budgetary burden on schools in terms of procuring equipment and facilitating internet infrastructure. A second issue would be a lack of teacher training for integrating these technologies into the curriculum (Papadakis, 2022). Teachers may not understand how to build powerful and pedagogically valuable AR/VR experiences that are aligned with instructional needs (Zourmpakis et al., 2023). Second, content creation in AR/VR takes time and money, which reduces the likelihood of its adoption on a big scale (Kalogiannakis & Papadakis, 2020). In addition, there are concerns about the inclusiveness and accessibility of AR/VR tools for students with different learning needs (Papadakis et al., 2022). Teachers and developers must collaborate in creating low-cost, adaptive, and pedagogically sound AR/VR material in order to address these issues and provide equal access to such tools for all learners (Zourmpakis et al., 2023).

11. Conclusion with Recommendations

This evaluation has brought out that VR and AR technologies have great potential in enhancing the outcomes of learning in STEAM education in terms of improved learning, engagement, and conceptual understanding. Different studies have also come out on how these technologies can enhance immersive interactive learning environments and deep learning experiences. This study shows that AR and VR success relies on some variables: quality of technology, instruction design, and teacher support. On this issue, the following are some recommendations.

- **Invest in Professional Development:** Invest in priority professional development programs for teachers, which will make the work of teachers easier, increase their confidence and competence in the use of AR and VR in educational institutions, while building trust through practical workshops and cooperation.
- **Improve the quality and integration of technology:** Schools and colleges have to focus on acquiring top quality AR and VR tools, which are in synchronization with the educational objectives. In order to ensure these technologies can be well adapted with the existing teaching method so that the outcome of learning can be improved as a result.
- **Promote collaborative learning environments:** Promote collaborative learning environments by encouraging teamwork among students through inter-disciplinary projects using AR and VR technology. This technology can improve approaches in teaching by incorporating more than one subject, and thus better creativity and solving of problems.
- **Assist in the development of educational materials:** Teachers need support and guidelines for creating effective learning content that incorporates AR and VR features. In this respect, techniques of preparing interactive content and activity, which would help in deeper and meaningful learning, also have to be developed.
- **Evaluation and necessary changes on the basis of feedback:** Organizations should have procedures in place to determine the success of their integration of AR and VR technologies. Methods for getting teachers and students' feedback while trying to improve the efficiency of such technologies in school can be very effective in refining and improving.
- **To encourage continuous research:** The continuity of research is vital in identifying the long-run effects of AR and VR on success in STEAM education. Future trends that include technology with education should incorporate the distinctive learning environment and characteristics of learners.

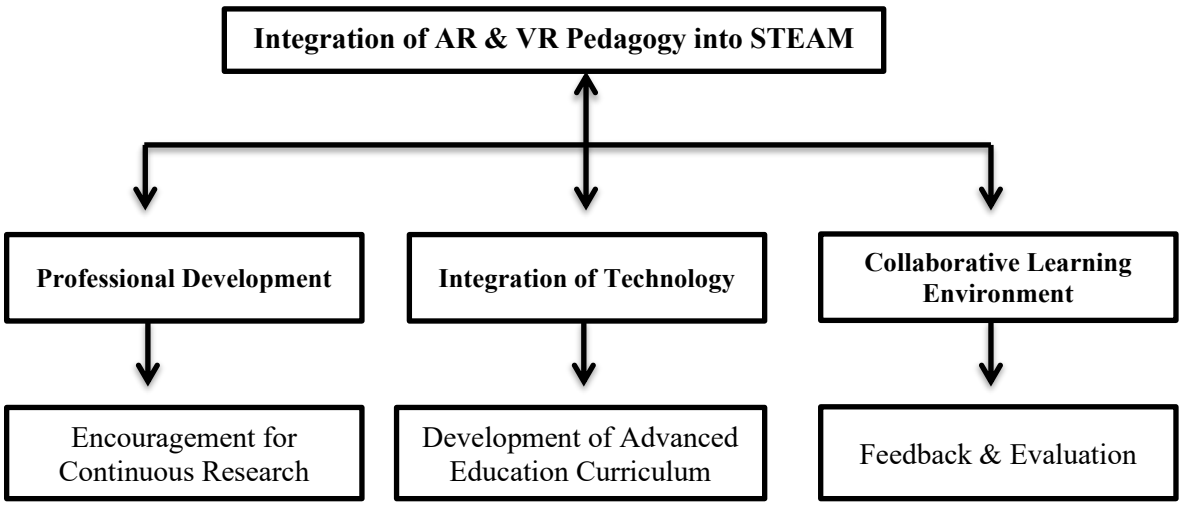


Figure 5: Showing key recommendations with regard to integration of Augmented Reality and Virtual Reality into STEAM education.

- Educators can realize the maximum potential of AR and VR technologies by implementing the above suggestions, with the long-term objective of enhancing STEAM learning processes and equipping students to handle upcoming challenges. Current advancements in VR and AR tools, particularly in Western settings, provide valuable lessons regarding how these tools are being leveraged to transform education. For instance, interactive VR spaces are already being employed in countries like the United States and the UK to offer virtual science laboratories and simulations where students may test complex ideas safely and interactively. AR technologies such as those incorporated into mobile devices are used to enhance real-world learning by overlaying interactive elements on top of actual objects, enriching biology, engineering, and math lessons. These developments capture the global potential of AR and VR to not only boost the interest and engagement of STEAM education but also provide students with the problem-solving and technological skills of the future. With the integration of these advancements, educators around the world can widen the reach and influence of their teaching methods.

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Data Availability Statement

Integration of Virtual Reality and Augmented Reality into STEAM Education: A Meta-Analysis

All the secondary data including PRISMA 2020 framework table and data transcription table supporting the findings of this Meta-Analysis are available upon reasonable request. Researchers interested in accessing the data for scholarly purposes may contact directly the corresponding author for further information and to discuss the terms of data sharing.

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