The Role of Immersive Virtual Realities: Enhancing Science Learning in Higher Education

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Abstract

Objective: This systematic review aims to map out the role of immersive technologies, specifically virtual and augmented realities (VR and AR), in enhancing learning outcomes within higher education science programs, providing a clearer understanding of their pedagogical value. *Methods*: Leveraging extensive database searches in Scopus and Web of Science, an initial phase of 172 articles was identified. Through a meticulous process of screening based on inclusion and exclusion criteria, this was refined to 33 important articles. These articles were further analyzed to identify distinct structural elements regarding VR and AR interventions and their effects on educational outcomes. *Analysis*: Each study was evaluated for its contribution to pedagogical methods, with a focus on quantifiable changes in student performance and engagement. *Results*: The analysis revealed that immersive technologies are being applied across various stages of the academic crossing, from introductory courses to advanced laboratory work. Particularly, 18 articles demonstrated a significant positive or increased impact on learning outcomes. *Conclusions*: The review confirms that VR and AR possess a transformative potential for higher education, particularly in the sciences. These technologies not only captivate students' interest but also facilitate deeper understanding and retention of complex material. The evidence suggests that VR and AR can substantially enhance the educational experience when implemented thoughtfully. Future research should aim to expand upon these findings, exploring the longitudinal impact of immersive technologies on learning and their potential to democratize education.

1- Introduction

In the ever-evolving landscape of higher education, immersive virtual realities, encompassing technologies such as Virtual Reality (VR) and Augmented Reality (AR), have emerged as transformative tools in the realm of science and engineering education. Within this context, the introduction of these technologies into educational settings, as exemplified by studies conducted by Ferrer et al. [1] and Lasica et al. [2], has significantly reshaped the traditional paradigms of learning. Ferrer and colleagues emphasize the effectiveness of AR in enhancing students' retention of complex subjects, particularly highlighting the immersive nature of AR as a mechanism for more engaging and impactful learning experiences. Similarly, Lasica exposed the evolution of STEM education, where virtual and remote laboratories have begun to assume a central role. Chen et al. [3] further expand our comprehension by illustrating how VR environments can significantly augment cognitive and linguistic development within the scope of language learning.

This insight is complemented by the work of Parong and Mayer [4], who present a nuanced perspective on the efficacy of immersive VR compared to conventional instructional methods, underscoring the focal role of integrating effective learning strategies to harness the full potential of VR. The influence of these technologies extends well beyond the confines of traditional classrooms. For instance, Poce et al. [5] delve into AR's potential for engaging students with university museum collections, highlighting a broader spectrum of applications for AR within educational contexts. Also, Okada et al. [6] delve into the utilization of AR inquiry games as a means of cultivating skills relevant to Responsible Research and Innovation, accentuating AR's capacity to nurture critical thinking and inquiry skills.

The practical applications and challenges associated with immersive technologies come to the forefront in studies conducted by Ho et al. [7] and Küçük Avcı et al. [8]. Ho delved into the domain of 3D animation learning, focusing on the motivational aspects of VR. Meanwhile, Avci contributed valuable insights through a meta-analysis that examines the comparative effectiveness of AR and 3D virtual environments in terms of learning achievement. Taking a different approach, Lamb and Etopio [9] introduce neuroscientific perspectives into the discussion by investigating the cognitive impact of VR within the context of science education. In contrast, Di Natale et al. [10] provide a comprehensive systematic review spanning a decade, underscoring the critical importance of methodological rigor in guiding future research efforts.

Turning our attention back to the focus of the current study, the exploration of AR within diverse educational settings continues to evolve through research initiatives such as those proposed by Claros et al. [11] and Agbo et al. [12], each shedding light on distinct facets of AR's applicability in educational contexts. Similarly, Elfeky & Elbyaly [13] and Bhagat et al. [14] demonstrated the adaptability and versatility of AR in areas as diverse as fashion design and mathematics, respectively. In parallel, the potential of VR as a research tool for investigating design cognition is examined by Neroni et al. [15], while Jdaitawi and Kan'an et al. [16] narrow their focus to assess the effectiveness of AR within the context of special education. Moreover, Coban et al. [17] contributed a valuable meta-analysis that synthesizes the global impact of immersive VR on learning, highlighting its diverse effects across different educational levels and fields of study.

Within the context of the expanding applications of immersive technologies in education, several works provide a multifaceted perspective on the transformative potential of these technologies across diverse educational domains. For example, DeWitt et al. [18] introduced an innovative application of VR that enhances intercultural communication competence. Their study transcends traditional language learning, harnessing VR's immersive capabilities to simulate real-life cultural interactions and scenarios. Cao & Hsu [19] contributed to this discussion with a comprehensive meta-analysis that rigorously evaluates the effectiveness of virtual experiments within educational contexts. Their research underscores the vital role of virtual simulations in offering interactive and secure learning experiences, especially in scientific experiments where real-world execution can be challenging or hazardous.

Expanding on the integration of VR in education, Eutsler & Long [20] investigated its acceptance among preservice teachers. Their study indicates a notable trend toward and positive inclination for integrating VR into science instruction. This reflects a paradigm shift in teaching methodologies and the preparation of future educators for technology-enhanced learning environments. In the context of arts education, Lim [21] explored the role of AR in broadening the horizons of multimodal artistic expression. Their work exemplifies how AR can transcend conventional artistic boundaries, empowering students to engage with art in a more interactive and multidimensional manner. This integration of technology into art education signifies an innovative approach to nurturing creativity and fostering artistic appreciation among students.

Tang et al. [22] offered insights into the impact of new technologies, particularly within the context of virtual medical learning. Their systematic review showed how informatics and virtual platforms are revolutionizing medical education and training, thereby enhancing the delivery and accessibility of medical services and education within virtual settings. Lastly, Figueiredo [23] delved into the emerging concept of the metaverse and its potential implications for rhetorical pedagogy. Their speculative exploration envisions a future where immersive virtual environments, such as the metaverse, could significantly enhance the teaching and learning of the arts and humanities, offering novel, experiential ways to engage with literature and rhetoric.

As evident, the integration of immersive virtual technologies in both educational research and practice has gained substantial attention among researchers and educational institutions. This increasing trend underscores the imperative for a comprehensive evaluation of their influence on a decisive aspect of education, i.e., student performance and engagement. Within this context, our systematic review endeavors to provide a thorough examination of the role played by immersive virtual technologies in shaping student performance/engagement within higher education. To ensure rigor and adherence to best practices, our review follows the PRISMA guidelines, facilitating an all-encompassing literature review to aggregate the existing knowledge.

Our research inquiry, framed using the PICOS approach, is briefly articulated as follows: "How do immersive virtual technologies contribute to the teaching and learning of science and engineering in higher education, and what effects do

they have on student performance and engagement?". The systematic review is structured as follows. In Section 2, we expound upon our methodology, elucidating the PICOS and PRISMA approaches. Additionally, we delineate the various stages and criteria used for the article selection process. Section 3 is dedicated to the presentation of our findings, with particular emphasis on the outcomes of the interventions under scrutiny. In Section 4, we delve into in-depth discussions about identified limitations and offer insightful recommendations for future research endeavors. Finally, Section 5 shows the summary of key insights and conclusions.

2- Methodology

As stated, we employ the PICOS approach—a widely recognized research framework for shaping clear and targeted research inquiries in systematic reviews [24]. The PICOS framework analyses and proposes the research question into five important components (Table 1):

- Population (study group);
- Intervention (treatment or exposure);
- Comparison (reference group involved);
- Outcome (anticipated results);
- Study Design (chosen research methodology).

Table 1. The research question of the presented review is defined according to the PICO approach

P	Population	Students in higher education
I	Intervention	Use of immersive virtual technologies for teaching/learning science and engineering topics
C	Comparison	None
O	Outcome	Impact on performance and engagement
S	Study Design	Systematic Review

This framework is generally valuable for producing precise research questions and promoting study designs that efficiently collect pertinent evidence.

Figure 1 illustrates the methodology adopted in this study, which adheres to the PRISMA guidelines [25] with a specific time frame restriction (2013–2022). This temporal constraint is essential as the research aims to examine the emergence and impact of immersive virtual technologies during the last decade.
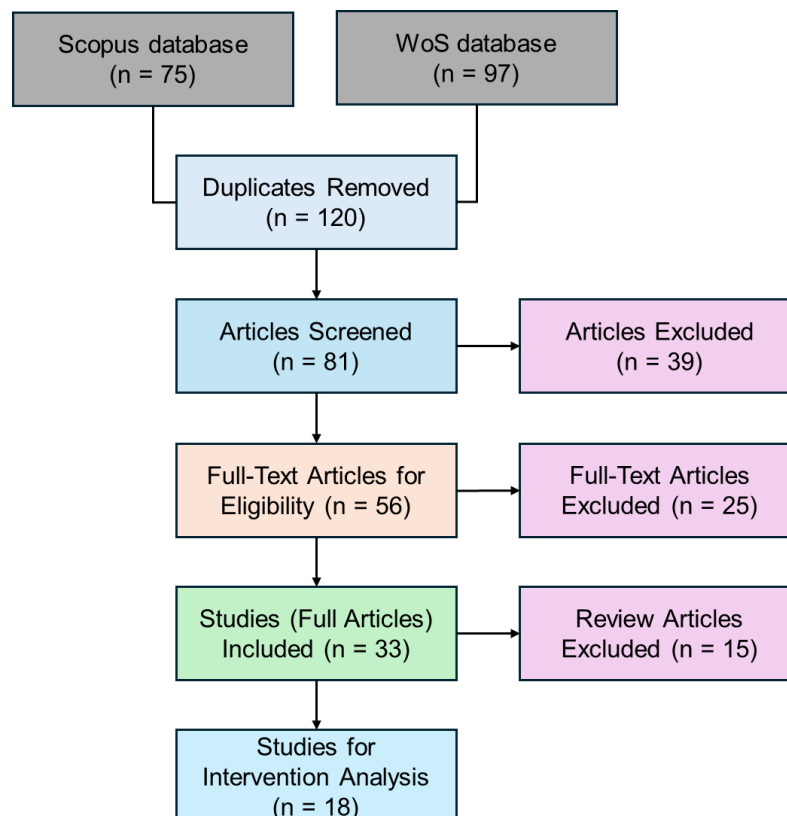

Figure 1. Flowchart of systematic review

2-1- Identification

In May 2023, we searched for articles suitable for inclusion in this review. Our search encompassed two reputable databases, i.e., Scopus and Web of Science (WoS). The search query was constructed to align with the scope of our study, which focuses on.

- "The Role of Immersive Virtual Realities in Enhancing Science Learning in Higher Education."

The outcomes of this query are summarized in Table 2, providing an overview of the articles retrieved during this research endeavor. At this stage, we point out that the analysis is confined to a timeframe spanning from 2013 to 2022. This review specifically omits conference papers and book chapters, focusing solely on works written entirely in English.

Table 2. Type of Query and Associated Results: Timeframe limited to the period between 2013 and 2022. Excludes conference papers and book chapters. Inclusion criteria are restricted to works authored exclusively in English

Database	Query	Results
Scopus	("Virtual Reality" OR "augmented reality" OR "immersive virtual technology") AND ("higher education") AND ("Physics" OR "Science") AND NOT ("High School" OR "Elementary School")	75
WoS	("Virtual Reality" OR "augmented reality" OR "immersive virtual technology") AND ("higher education") AND ("Physics" OR "Science") NOT ("High School" OR "Elementary School")	97

2-2- Screening

Following the elimination of duplicate entries, we proceeded to screen a total of 120 articles by reviewing their titles and abstracts. The screening process was guided by specific keywords, as follows:

- Higher Education Focus: We only included articles related to higher education.

- Immersive Technologies: We considered articles that discussed Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), or Interactive Virtual Technologies (IVT).

- Science or Engineering: We limited our selection to articles centered on science or engineering disciplines.

During this screening process, we excluded 39 articles that did not meet these criteria, leaving us with 81 articles for the next phase of our review. This careful selection ensures the relevance of the articles to our study on the application of immersive technologies in higher education, particularly in science and engineering contexts.

2-3- Eligibility

In the next phase of our systematic review, we distributed the selected articles randomly among our team members for a detailed evaluation of their full texts. Our eligibility criteria, based on both abstracts and conclusions, consisted of three main aspects:

- Relevance to Higher Education: We focused on articles exclusively related to higher education, excluding those about elementary or high school education.

- Immersive Virtual Reality Learning: We examined articles that explored immersive virtual reality learning, analyzing how this technology enhances higher education learning experiences.

- Immersive Virtual Reality Teaching: We also considered articles discussing immersive virtual reality teaching, investigating how educators use immersive technology in higher education instruction.

During this thorough assessment, we excluded 25 articles that did not meet these criteria. Then, 56 articles aligned well with our research goals and were included for the next stage. This meticulous approach ensures the relevance and contribution of the selected articles to our systematic review of immersive virtual reality in higher education.

2-4- Included

In the final phase of our systematic review, we conducted a comprehensive information extraction process on the articles that successfully met our established eligibility criteria. Initially, we had identified 33 articles that were suitable for our study. However, our focus at this stage was on discerning factors that impact student performance, and through this process, we refined our selection to a total of 18 articles. During the information extraction, we applied a set of specific criteria:

- Course Design and Content Planning: We paid close attention to articles that discussed the design and planning of course content. This allowed us to evaluate how instructional materials were developed in a virtual environment to enhance student performance.

- Development of Virtual Environmental Learning Materials: Articles that addressed the creation and utilization of virtual environmental learning materials were of particular interest. These materials play a crucial role in immersive education and have a direct impact on student outcomes.

- Cognitive Load and Time Management: We also considered articles that delved into cognitive load and time management in virtual learning environments. These factors can significantly affect how students engage with educational content and influence their performance.

- Number of Participants: The size of the participant groups in the studies was another factor we considered. Understanding the scope of these studies provided valuable context for interpreting their findings.

Additionally, it is important to note that we excluded 15 review articles at this stage of our review. This decision was made to enable a direct comparison of our outcomes with the findings of previous literature reviews. By excluding these review articles, we ensured that our analysis remained focused on primary research studies, allowing for a more comprehensive and independent evaluation of the factors influencing student performance in virtual learning environments.

3- Results

3-1- Structural Approach

In Figure 1, our systematic review started with the identification of 172 articles from the Scopus and WoS databases that focused on the use of AR or VR in higher education. After duplicates were removed, 120 articles were subjected to a meticulous screening based on title, abstract, and keywords, aligning them with our inclusion criteria. This step resulted in 39 articles being excluded, leaving 81 articles for a detailed full-text evaluation.

The full-text assessment, guided by criteria such as the empirical use of AR or VR technologies and measurable outcomes in performance or engagement, led to the exclusion of 25 more articles for reasons including insufficient empirical data, irrelevance to higher education, or the absence of AR or VR interventions. Consequently, 56 articles were deemed eligible for final data extraction, from which 33 were chosen for an in-depth evaluation, including both quantitative and qualitative research.

These selected articles examined:

- The efficacy of AR and VR interventions, specifically their impact on student performance, measured by assignment completion efficiency, course grades, and task accomplishment abilities, and

- Engagement, indicated by changes in participation, enjoyment, satisfaction, perceived learning value, attendance, course activity involvement, and interest in additional resources.

Out of the 33 full articles, 18 were earmarked for an intensive intervention analysis. This structured literature review process yielded a substantial body of empirical evidence, underscoring the helpful influence of AR and VR interventions on student performance and engagement in higher education. The findings affirm the value of immersive technologies in educational contexts and provide a foundation for further pedagogical research and exploration.

3-2- Interventions Outcomes

The impact of AR and VR interventions in higher education is summarized in Table 3. Of the studies, seven focused on performance: two reported direct improvements, while five noted a broader enhancement in the learning experience. In terms of engagement, out of seven studies, three found positive effects, and four observed general improvements in the educational experience. Additionally, four studies that examined both performance and engagement found one with positive outcomes and three indicating whole beneficial effects. These findings suggest that AR and VR technologies tend to contribute to an enriched learning experience, even when direct improvements in performance and engagement are not always quantifiable.

Table 3 presents a key finding involving the following most important outcomes concerning the impact of AR and VR on performance and engagement in higher education:

- AR technologies applied in science laboratory settings were found to enhance both students' laboratory skills and their attitudes toward physics laboratories, indicating increased performance and engagement.

- The incorporation of AR objects into the educational process led to an increase in both performance and engagement, suggesting these tools may facilitate learning and improve educational outcomes significantly.

- A VR-based approach for delivering feedback on oral presentation skills resulted in a positive impact on performance, showcasing VR's potential for skill-specific improvement.

- The use of a VR platform for conducting lectures showed increased engagement, pointing towards VR's effectiveness in creating immersive lecture experiences.

- The adoption of mobile AR in higher education was associated with increased engagement, indicating that AR can be effectively used on mobile devices to enhance the educational experience.

- Implementing VR in a purpose-designed laboratory environment resulted in a substantial increase in engagement among many students, highlighting VR's scalability and potential to enrich the learning environment.

- The application of AR quizzes for self-assessment in a science education course showed a positive effect on engagement, implying that AR can be a beneficial tool for self-directed learning and assessment.

Table 3. Extracted structural elements with corresponding interventions and measured effect

Stage	Intervention	Variable	Effect	IVT	No. Participants	Ref.
Results	Use of augmented reality (AR) technologies in science laboratories to enhance students' laboratory skills and attitudes toward physics laboratories.	Performance and engagement	Increased	AR	76	Akçayir et al. (2016) [26]
Results	Use of Augmented Reality (AR) objects in the educational process, presumably to facilitate learning and improve educational outcomes.	Performance and engagement	Increased	AR	923	Cabero et al. (2019) [27]
Results	Application of a virtual reality-based task for delivering feedback on oral presentation competence.	Performance	Positive	VR	36	Van Ginkel et al. (2019) [28]
Exploration	This study is the implementation of the virtual reality platform "Mozilla Hubs" for conducting lectures.	Engagement	Increased	VR	24	Hopp et al. (2020) [29]
Reported	Discussed is augmented learning using smart glasses (ALSG), which is proposed as a means to facilitate learning and knowledge acquisition.	Performance	Increased	AR	No specified	Loh & Misselhorn (2020) [30]
Analysis and Interpretation	The application of mobile augmented reality in higher education settings.	Engagement	Increased	AR	215	Stojšić et al. (2020) [31]
Results	Use of an augmented reality application for mobile learning in a course titled "Postal Services Vocation Studies" in the final year of vocational studies at the ICT College of Vocational Studies in Belgrade.	Performance	Increased	AR	22	Radosavljevic (2020) et al. [32]
Evaluated	Use of a 3D reconstruction of the Sanctuary of Delphi as an educational tool, allowing students to engage with the material in a virtual environment.	Performance	Increased	VR	112	Liritzis et al. (2021) [33]
Development and implementation	AR application to enhance the learning of chemical engineering students by providing a practical experience with simulations.	Performance	Positive	AR	No specified	Solmaz et al. (2021) [34]
Evaluated	The virtual reality as a didactic (teaching) resource in higher education settings.	Engagement	Increased	VR	423	Vergara et al. (2021) [35]
Results	Use of mobile augmented reality (AR) glasses during laboratory sessions to provide guidance and timely feedback to students.	Performance	Increased	AR	16	Södervik et al. (2021) [36]
Results	Applied to the two different AR tools, the Microsoft HoloLens and a mobile-based AR application, to teach the anatomy and physiology of the brain.	Performance and engagement	Positive	AR	38	Moro et al. (2021) [37]
Exploration	Use of Virtual Reality (VR) technology to enhance student motivation in a high school science course.	Engagement	Positive	VR	304	Garduño et al. (2021) [38]
Exploration	The use of immersive virtual reality (iVR) simulations as compared to video playback of those simulations.	Performance and engagement	Increased	VR	24	Pande et al. (2021) [39]
Exploration	Conducting three design thinking workshops with interdisciplinary teams of students and lecturers, resulting in the creation of two low-fidelity VR prototypes for educational use.	Engagement	Positive	VR	53	Fromm et al. (2021) [40]
Results	The implementation of VR technology in a purpose-designed laboratory for teaching various subjects.	Engagement	Increased	VR	4833	Marks et al. (2021) [41]
Results	Use of VR as a tool within an introductory physics university course.	Performance	Increased	VR	94	Campos et al. (2021) [42]
Results	Use of Augmented Reality (AR) quizzes for self-assessment in a science education course.	Engagement	Positive	AR	51	Sofianidis et al. (2022) [43]

3-3- Data Analysis

Figure 2 demonstrates the balanced integration of immersive virtual tools in the enhancement of science education within higher education. Both VR and AR have been equally leveraged, each constituting 50% of the technological approaches explored in the studies analyzed. This parity highlights the importance of both VR and AR as complementary technologies that offer distinct yet convergent pathways to enrich the science learning experience in higher education.
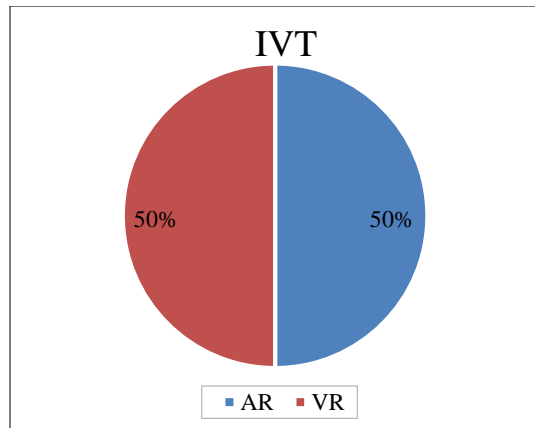
Figure 2. Utilization of Immersive Virtual Tools (IVT) in percentage

Figure 3 illustrates the proportional distribution of two main variables, i.e., Performance and Engagement, and their combined effect. Both Performance and Engagement individually account for 38.89% of the chart, signifying their equal weight in the studies analyzed, while the combined variable, Performance and Engagement (labeled as Perf and Eng), constitutes 22.22%, suggesting a specific focus on the intersection of these two metrics in assessing the efficacy of immersive technologies in enhancing the science learning experience.
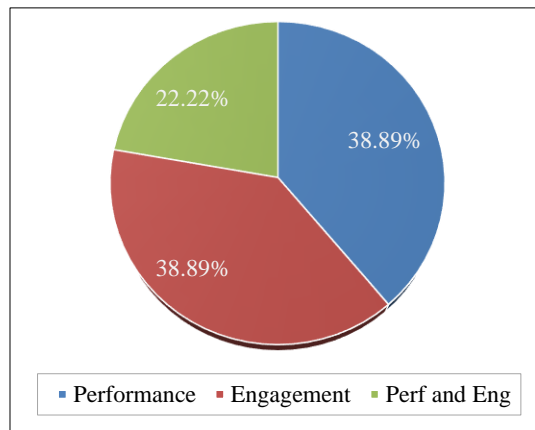

Figure 3. Distribution of Research Focus on Immersive Virtual Tools by Variable in Percentage. It is illustrated by an almost equal emphasis on studying Performance and Engagement individually (each at 38.89%), with a substantial proportion of studies (22.22%) examining the combined impact of Performance and Engagement.

In Figure 4, we present a chart derived from Table 3. This chart primarily highlights the various effects observed following the implementation of VR and AR technologies within educational contexts. We have categorized these outcomes into two distinct categories: 'Increased' representing the majority at 66.67%, and 'Positive' constituting the remaining 33.33%. This visual representation implies that, remarkably, all the observed effects were positive. Furthermore, it underscores that a significant proportion of these effects were notably characterized by an increase in the measured outcomes.
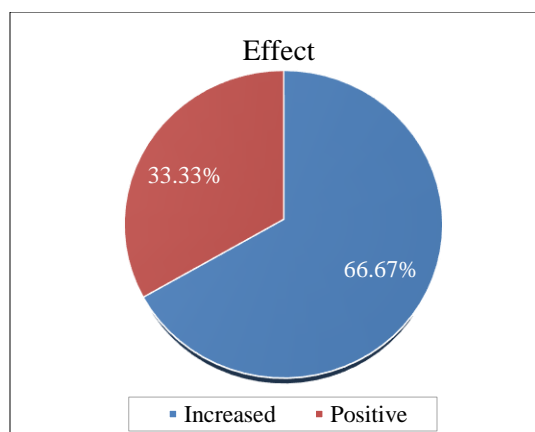

Figure 4. Proportional representation of reported effects from Immersive Virtual Tool Studies. The chart shows that two-thirds of the studies (66.67%) reported an 'Increased' effect in measurable outcomes, while one-third (33.33%) described a 'Positive' qualitative impact on users.

We point out that in the context of the utilization of immersive virtual realities in higher education, the terms "Positive" and "Increased" effects are categorized as:

- Positive Effect: This category signifies that the application of VR and AR technologies in higher education consistently yielded beneficial results. These positive effects might include improvements in student engagement, enhanced understanding of complex concepts, increased motivation, or a more immersive and interactive learning experience. Essentially, a "Positive effect" implies that the utilization of immersive technologies contributed positively to the educational environment without necessarily specifying the magnitude of change.

- Increased Effect: This category indicates a specific subset of positive outcomes. In this case, it suggests that there was a measurable increase or enhancement in the desired educational outcomes. For instance, if students' test scores, knowledge retention, or problem-solving skills significantly improved after using VR or AR technologies, these improvements would fall under the category of "Increased effect." It implies a more pronounced and quantifiable positive impact on student performance or learning outcomes.

3-4- Data Generated

To maintain transparency throughout our study, Figure 5 illustrates the data generation process across various stages, providing a clear overview of our systematic review methodology. For those interested in conducting further research or accessing our dataset, this valuable information is readily available at the following link: *https://doi.org/10.17605/OSF.IO/X945F* (CC-By Attribution 4.0 International).
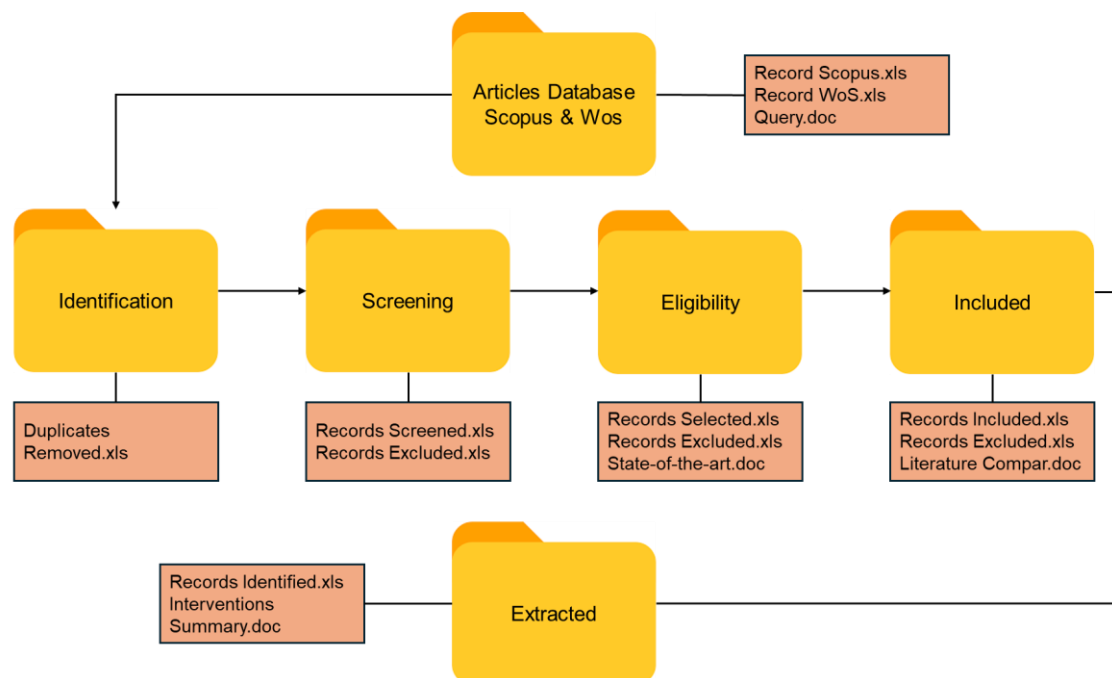

Figure 5. Scheme of generated data for systematic review

3-5- Descriptive Analysis

In our descriptive analysis, categorical variables were quantified and reported as frequencies (Table 4). To investigate the relationships between categorical effects and variables, we utilized chi-square tests, supplemented with Fisher's exact test when necessary due to small sample sizes or other specific conditions. Outcomes of these associations are essential to understand the distribution and correlation of different categorical outcomes. For this study, a p-value of less than 0.05 was established as the threshold for statistical significance, indicating that we can be 95% confident that the observed associations are not due to random chance.

Table 4. Prevalence of Effect and Variable in studies analysed

EFFECT	VR (n = 9) %	AR (n = 9) %	TOTAL (n = 18) %
Increase	66.7	66.7	66.7
Positive	33.3	33.3	33.3
VARIABLE	**VR (n = 9) %**	**AR (n = 9) %**	**TOTAL (n = 18) %**
Performance	33.3	44.4	38.9
Engagement	55.6	22.2	38.9
Performance & Engagement	11.1	33.3	22.2

In Table 4, the distribution of effects is evenly split between VR and AR technologies, with each reporting six instances of Increased and Positive effects, accounting for 66.7% and 33.3% of the interventions, respectively. This balanced distribution implies that VR and AR are equally effective in producing these outcomes in the studied context. The chi-square test results, with a p-value falling above the 0.05 threshold for non-statistical significance. However, the small sample size suggests caution in interpretation, and Fisher's exact test, which is tailored for such data sets, yields a p-value of 0.690. This higher p-value from Fisher's test confirms the finding of a non-statistically significant association.

Also, the results for variables from the statistical analysis indicate that there is no statistically significant association between the type of immersive virtual tool (VR or AR) and the outcomes measured (Performance, Engagement, or both). This is evidenced by the p-values obtained from the chi-square test ($p = 0.297$), Probability Ratio ($p = 0.284$), and Linear-by-Linear Association ($p = 0.764$), all of which are above the conventional threshold of 0.05 for statistical significance. These results suggest that within this sample, the distribution of effects on performance and engagement is not dependent on whether VR or AR technology was used.

4- Discussions

4-1- Intervention Contributions

In this section, we highlight the significant contributions to enhancing student learning experiences, skills development, and attitudes towards their subjects of study:

- Akcayir et al. [26] provided substantial evidence that AR technologies could greatly improve university students' laboratory skills and attitudes toward science laboratories, advocating for AR's integration into educational practices to make laboratory work more interactive and efficient.

- Cabero et al. [27] revealed that AR objects not only increase enjoyment and perceived usefulness of learning materials but also foster high acceptance and motivation levels, which correlate positively with performance. This suggests that AR's role in educational science is multifaceted, affecting both affective and performance outcomes.

- Van Ginkel et al. [28] and Hopp et al. [29] discussed the potential of VR in enhancing feedback mechanisms and engagement in educational settings. The effective use of VR for oral presentation feedback and the use of platforms like Mozilla Hubs for lectures could revolutionize the feedback process and classroom dynamics, emphasizing the scalability and self-regulation benefits of VR.

- Loh & Misselhorn [30] theorized that augmented learning with smart glasses could shift learning from knowing facts to acquiring know-how, especially in STEM fields. This shift could be key in facilitating knowledge transfer and multidisciplinary communication.

- Stojsic et al. [31] addressed the positive attitudes of students towards mobile AR applications, emphasizing the technology's acceptance. The study underscores the need for educational strategies to harness the enthusiasm for AR, particularly in augmented textbooks.

- Radosavljevic et al. [32] demonstrated that AR applications could significantly improve vocational education students' task completion efficiency, suggesting that AR could be a game-changer in vocational training.

- Liritzis et al. [33] showed the effectiveness of 3D virtual reconstruction, particularly in cultural heritage education, suggesting that VR could provide richer, more immersive learning experiences than traditional learning methods.

- Solmaz et al. [34] developed an open-source AR application for chemical engineering education, showcasing AR's potential to create engaging educational environments and promote wider accessibility.

- Vergara et al. [35] evaluated VR's potential as a didactic resource, providing insights into educators' perceptions and highlighting the challenges and advantages of VR integration in academic settings.

- Södervik et al. [36] demonstrated AR's efficacy in guiding laboratory work and improving performance, supporting the notion that AR can enhance hands-on skill development.

- Moro et al. [37] contributed evidence supporting AR in medical education, noting both its advantages and potential drawbacks, and advocating for its supplementary use in teaching.

- Garduño et al. [38] found that VR can significantly boost student motivation in high school science courses, impacting attention, relevance, confidence, and satisfaction.

- Pande et al. [39] highlighted the long-term retention benefits of immersive VR (iVR) simulations over traditional video, suggesting iVR's role in sustaining motivation and self-efficacy.

- Fromm et al. [40] identified VR's unique opportunities for experiential learning, emphasizing the technology's potential to enrich educational curricula and improve learning outcomes.

- Marks & Thomas [41] demonstrated VR technology's positive adoption rates and its ability to enhance laboratory sessions, providing a model for virtual learning integration in higher education.

- Campos et al. [42] showed VR's significant role in enhancing the comprehension of complex concepts like vectors in physics, advocating for VR's inclusion in classroom instruction.

- Sofianidis [43] underscored the advantages of AR in science education, particularly in increasing student engagement and providing interactive learning experiences.

In general, all these studies collectively provide a robust argument for the integration of AR and VR technologies in higher education, underlining the effectiveness of these technologies in enhancing various aspects of the learning experience, from improved engagement and motivation to the development of practical skills and positive attitudes towards learning. The contributions emphasize the necessity of a student-centered approach and the importance of aligning technological interventions with pedagogical objectives to maximize their educational impact.

4-2- Importance of Using Virtual Technologies in Higher Education

The importance of integrating virtual technologies into higher education for the fields of science and engineering is multifaceted and substantial. Hence, we display the following key points:

- Virtual technologies like AR provide students with an interactive environment to practice and master laboratory techniques. They offer realistic simulations that can significantly enhance the acquisition of practical laboratory skills and improve students' proficiency and confidence in performing scientific experiments.

- VR and AR have been shown to foster deeper engagement with course material. These immersive technologies create compelling learning environments that capture students' attention and encourage active participation, which is crucial for retention and understanding in complex scientific and engineering courses.

- VR enables students to virtually access specialized equipment, rare specimens, and unique locations that would otherwise be inaccessible due to logistical, financial, or safety constraints, thus broadening their educational horizons without the need for physical presence.

- In science and engineering, certain concepts can be difficult to grasp through traditional two-dimensional teaching methods. Virtual technologies allow for the three-dimensional visualization of abstract concepts, aiding in students' understanding and leading to better educational outcomes.

- Virtual technologies support personalized education by adapting to different learning styles and paces. They can provide customized feedback and adjust difficulty levels in real time, catering to individual student needs for a more tailored educational experience.

- Beyond technical knowledge, virtual technologies can aid in the development of soft skills such as teamwork, problem-solving, and communication, which are essential for professional success in science and engineering fields.

- Innovative Assessment Methods: AR and VR offer new ways to assess student learning through interactive tasks and simulations. This can lead to more accurate assessments of a student's practical skills and understanding, moving beyond traditional paper-based tests to evaluate competencies in real-world scenarios.

4-3- Comparison with Previous Literature Reviews

In Table 5, we demonstrate that our present systematic review addresses a notable gap in the current literature by providing a focused examination of both AR and VR in the specific context of Science and Engineering education. Unlike previous studies [44-55] that may concentrate on a single technology or a broader educational scope, our systematic review offers a comparative analysis of the impacts of AR and VR on performance and engagement. It delivers nuanced insights into how these technologies can be tailored and implemented to enhance the specialized pedagogical requirements and learning outcomes in these disciplines, thus contributing a more granular perspective to the field of immersive educational technologies.

Table 5. Comparison with previous review papers. P = performance and E = Engagement

Reference	AR	VR	Education	Field	Variable	Effect
Ding & Li (2022) [44]	-	X	Yes	Engineering, and Humanities	P & E	Positive
Mystakidis et al. (2021) [45]	X	-	Yes	Science, Technology, Engineering, and Mathematics (STEM)	No specific	Positive
Rodriguez et al. (2020) [46]	X	-	Yes	Health Sciences	P & E	Positive
Belmonte et al. (2019) [47]	x	-	Yes	Health Education	No specific	Positive
Nesenbergs et al. (2020) [48]	X	X	Yes	General	P & E	Increase
Lucena et al. (2022) [49]	X	X	Yes	Physiotherapy	P	Positive
Luo et al. (2020) [50]	-	X	Yes	General	P & E	No conclusive
Al Farsi et al. (2021) [51]	-	X	Yes	General	P & E	Positive
Papanastasiou et al. (2018) [52]	X	X	Yes	General	P & E	Positive
González-Zamar & Abad-Segura (2020) [53]	-	X	Yes	General	P & E	Positive
Abad-Segura et al. (2020) [54]	X	-	Yes	General	P & E	Positive
Rashid et al. (2021) [55]	-	X	Yes	General	P & E	Increase
This Review	X	X	Yes	Science and Engineering	P & E	Positive and Increase

5- Conclusions

This systematic review has synthesized current research on the integration of immersive virtual technologies into science and engineering education. Our investigation into this expanding field of technological pedagogy reveals several insights:

- The incorporation of VR and AR into higher education serves as a significant enhancer of pedagogical efficacy. These technologies offer rich, interactive experiences that have been shown to improve student engagement and motivation, particularly in disciplines that demand high levels of abstract thinking and practical application. The ability of VR and AR to simulate complex environments and experimental setups provides students with invaluable opportunities to practice and develop skills in a safe, controlled manner, which traditional classroom settings cannot replicate.

- The outcomes underscore the importance of these technologies in facilitating a deeper understanding of complex scientific concepts through visualization and interaction. This is especially crucial in fields such as engineering and physics, where spatial perception and three-dimensional comprehension are critical. The transformative potential of VR and AR in education is further evidenced by the positive impacts on student performance, as demonstrated by various studies included in our review.

- It has also identified critical gaps in the existing literature. While past research has provided a foundation for understanding the benefits of immersive technologies in education, our review highlights the need for more focused studies within the specific context of science and engineering higher education. We address this gap by concentrating on how VR and AR contribute to learning outcomes in these fields, providing a more nuanced understanding of their effects.

Moreover, we have recognized the need for broader inclusivity in research methodologies, advocating for future studies to encompass a wider range of educational settings, languages, and publication types. This is critical for capturing the global scope and diversity of immersive technology applications and for ensuring that the benefits of VR and AR are accessible to a more extensive range of learners.

Finally, as the field continues to evolve, educators, policymakers, and researchers must work collaboratively to harness these technologies' full potential, fostering an educational landscape that is both innovative and inclusive. We hope that this review speeds up such developments, inspiring continued exploration and thoughtful integration of VR and AR into higher education curricula.

5-1- Limitations and Restrictions

This systematic review encountered some limitations during its research process, as follows:

- Volume of Published Literature: The expansive amount of literature on VR and AR in science and engineering education can lead to challenges in comprehensively capturing all pertinent studies, risking the omission of relevant work.

- The creation of search queries and the use of techniques like "snowballing" to identify related studies might overlook significant research due to the inherent limitations of these methods, including potential biases and time constraints.

- By focusing primarily on journal articles published in English, valuable research published in other languages or grey literature, such as conference proceedings, theses, and technical reports that are not indexed in major databases, might be excluded. This criterion can lead to a review that may not fully represent the global scope and diversity of research in the field.

- Given the selection criteria, the systematic review may not completely reflect the variety of educational settings and cultural contexts in which immersive virtual realities are applied, limiting the generalizability of the findings.

5-2- Recommendations for Future Research

To address the above limitations exposed, it is recommended that future research should:

- Consider a more inclusive and expansive literature search, potentially incorporating studies in multiple languages and from grey literature to gain a comprehensive overview of global advancements and applications.

- Employ more exhaustive and varied search strategies that go beyond traditional database querying and snowballing, such as consulting experts in the field and using machine learning algorithms to discover relevant studies.

- Examine the representation of diverse educational and cultural contexts to ensure a more holistic understanding of how immersive virtual realities are used across different regions and educational systems.

- Evaluate the impact of publication bias and explore mechanisms to mitigate its effects to provide a balanced view of the research landscape.

Therefore, by expanding the inclusion criteria and search methodologies, future systematic reviews can present a more accurate and encompassing picture of the role and impact of immersive virtual realities in higher education, particularly in the scopes of science and engineering.

6- Declarations

6-1- Author Contributions

Conceptualization, T.T. and C.V.G.; methodology, C.V.G.; validation, M.G., G.M., and J.V.; formal analysis, C.V.G.; investigation, C.V.G.; resources, T.T.; data curation, T.T.; writing—original draft preparation, C.V.G.; writing—review and editing, C.V.G.; visualization, C.V.G.; supervision, C.V.G.; project administration, T.T.; funding acquisition, T.T. All authors have read and agreed to the published version of the manuscript.

6-2- Data Availability Statement

Data sharing does not apply to this article.

6-3- Funding

6-4- Acknowledgements

6-5- Institutional Review Board Statement

Not applicable.

6-6- Informed Consent Statement

Not applicable.

6-7- Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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