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Augmented Reality and education: a comprehensive review and analysis of methodological considerations in empirical studies

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Abstract

Augmented reality (AR) has been gaining attention in the field of education due to its potential to enhance learning experiences. However, the use of AR in education is still relatively new, and empirical studies examining its effectiveness are limited. This review paper provides a comprehensive analysis of the methodological considerations in empirical studies that have investigated the use of AR in education. In this paper, 23 articles out of 134 articles were gathered from publishers database including Scopus, Science Direct, Springer, Taylor Francis, and Web of Science outlaying the detailed analysis of knowledge-based tests and methodologies essential for studying AR in education. The review paper further highlights the challenges and limitations of conducting such studies and also examines the outcomes and implications of empirical studies to date, providing insights into the effectiveness of AR in STEM courses. The analysis revealed that engineering education is more extensively explored compared to architecture. Additionally, mobile-based devices and AR marker-based technology are more commonly used in current studies than other AR-based devices and technologies, while probability sampling technique and pretest and post-test evaluation technique are more frequently followed by authors. Thus, based on the findings, the paper concludes with recommendations for future research directions and methodological considerations to be taken into account in empirical studies of AR in education. This review aims to provide a valuable resource for researchers and educators interested in incorporating AR technology in educational settings.

KEYWORDS: AR in Education, Augmented Reality, Education, Learning Environment.

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1. Introduction

The importance of education for a nation's development cannot be overstated. Likewise, in order to achieve the status of a developed nation, citizens must actively participate and have access to education. However, the traditional method of learning may not be sufficient in the modern world. In addition, with the advancements in technology and society's modernization, new and effective learning methods have become a necessity (Kaufmann, 2003). In order to appeal to a large number of students, educational institutions need to transform in response to new trends. However, (Pierson,2001) argues that despite their prevalence, traditional educational approaches provide several obstacles for pupils, hindering their academic success. Additional challenges include constraints on the quantity of study materials, limited opportunities for personalized instruction, and scheduling constraints for sessions. E-learning and personalised online education provides students with more flexibility and accessibility, resulting in advantageous outcomes. These strategies enable students to learn at their own pace, provide them with access to a wide variety of study tools, and provide them with personalized attention; all of these things contribute to an improved learning experience for the students.

The timely and appropriate adoption and use of necessary information is crucial for optimizing efficiency in educational and professional settings, particularly in the face of a dynamic and diverse knowledge landscape (Singhal et al., 2012). Hence, immersive technologies serve as a means to overcome

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the gap between students and education. Furthermore, the use of immersive technology-based methodologies in the educational setting enhances learner engagement, attractiveness, motivation, realism, and significance (Nischelwitzer et al., 2007).

Likewise, immersive technologies are those that allow a user to see or interact with an artificial or simulated environment. It allows the user to have the experience of being immersed in the digital world. Through integrating the digital environment with individuals sound, vision and even contact, immersive technology has revolutionized the digital experience. Immersive technology is comprised of two principal technologies: virtual reality (VR) and augmented reality (AR).

VR technology enables individuals to fully engage within a simulated environment, which may include a wholly fictitious realm or an accurate representation of the real world. The experience may include auditory, visual, and touch modalities on some occasions. According to Elmqaddem (2019), the level of immersion experienced in virtual environments may be similar to that of the physical world. The present investigation assessed the academic achievement of nursing students throughout their childbirth education course, as reported by Chang et al. (2022). In addition to serving as a kind of VR, AR system allow users the capability to see three-dimensional images by overlaying virtual data over a real-time video feed. To use these technologies, it is necessary to own a headset, smart phone, or tablet.

AR embellishes the physical environment by putting digital data over it. AR does not completely recreate artificial surroundings to replace actual ones, unlike VR. When used in conjunction with an existing environment, AR may add audio, visuals, and video. Because AR doesn't really require a head- mounted display, it gives users greater freedom and opens up more marketing opportunities, even if VR is more immersive. AR creates a link between the physical world and the mind (Azuma, 1997).

AR emerged as a promising technology to bridge the gap between students and educational learning techniques because it provides interaction, which is sometimes required in the learning process. AR overlays the digital content on the real environment, helping students understand the concepts (Osadchyi et al., 2021). Unlike VR, AR does not create an entire virtual world to replace the real one (Pavithra et al., 2020). Furthermore, AR can improve the effectiveness and appeal of in-class learning for students in the real world (Du¨nser & Hornecker, 2007).

1.1 Augmented Reality in Education

Education is a fundamental aspect of personal and societal development. In the 21st century, STEM (Science, Technology, Engineering, and Mathematics) subjects have become increasingly important in shaping the global landscape. However, many students find STEM subjects to be challenging, which can hinder their academic progress and future career opportunities (Mystakidis et al., 2022). The ability to comprehend these subjects and perform well in them depends on various factors, including memory retention, comprehension of the subject matter, spatial ability, critical thinking, cognitive load, and more. Thus, it is essential to understand the underlying factors that influence students' learning and academic success in STEM subjects. This research paper aims to explore and analyze these factors to provide insights into enhancing students' STEM education. While augmented reality AR) technology is increasingly being adopted in various sectors of education, there is a need for further investigation into its effectiveness as a teaching and learning tool. Previous research studies have demonstrated that participants generally have positive attitudes towards AR systems in educational settings. However, there is still a lack of comprehensive research on the integration of AR technology in teaching and learning, and the potential benefits it can bring to both teachers and students. Specifically, there is a need to examine how the use of AR technology can improve the teaching of subjects that require visualization, compared to traditional methods of instruction. This highlights the need for additional research in this area to help educators better understand the potential of AR technology to enhance the learning experience for students.

As the demand for online education grows, AR offers a plethora of potential outcomes as well as several benefits for improving the learning and teaching environment. For instance, AR has the capacity to: (a) encourage, fascinate, and involve students in investigating course materials from various perspectives; (b) assist in the teaching of subjects where students could not realistically gain their own experience (for example, in subjects like geography, astronomy, etc.); (c) improve coordination between students and instructors; (d) nurture student insight and creative ability; (e) aid students in taking charge of their education at their own speed and along their own way; and (f) develop a genuine educational environment for learning that accommodates different styles of learning (Yuen et al., 2011).

The objective of this research is to recognize the prevailing developments of AR in education by assessing the responses to the below research questions:

1. Which subject area or target area is in trend for AR educational applications?
2. What is the most commonly utilized type of AR device in educational settings?
3. Which type of AR technology is most commonly used in educational applications?
4. Which type of sampling technique is most commonly used in educational applications?
5. What type of evaluation technique is adopted by AR applications?

2. Methodology

2.1 Identification of relevant papers

The database has an enormous number of articles, making it a challenging task to select the relevant ones. It is imperative to carefully choose articles that illustrate the application of AR technology in different fields of education and how it has been utilized to enhance various contexts. These articles must demonstrate the functions and advantages of the AR technology employed in order to provide a comprehensive understanding of its potential.

To ensure that the selection process is thorough and accurate, certain criteria/ guidelines must be followed. In this study, a meticulous approach is followed for selecting articles, beginning with a list of specific points that we consider essential for article selection. The selection process must include articles that showcase how AR technology has been used in various fields, such as STEM education, medicine, and architecture. These articles must provide detailed explanations of the AR technology used and how it has improved the particular field. Additionally, they must describe the benefits of using AR technology and how it has impacted various contexts, including the efficiency and effectiveness of tasks.

Furthermore, the articles considered for the study must be recent and up-to-date, reflecting the latest advancements in AR technology in the field of education. They must also have a clear and concise structure, making it easy for readers to comprehend the information presented. The articles must be published in reputable journals and have undergone rigorous peer review processes to ensure their accuracy and reliability.

Overall, the selection of articles is a critical aspect of any research study. By following specific criteria and guidelines, we can ensure that the articles selected provide a comprehensive understanding of how AR technology has been utilized in various fields and its potential for the future.

1. Online databases such as Scopus, Science Direct, Springer, Taylor Francis, and Web of Science were used for searching the articles that discussed immersive technology (AR) in education.
2. The articles were gathered from Google Scholar, which was published between 2017 and 2023.
3. The keywords used for searching the articles were: “augmented reality in education”, “augmented reality”, “current technologies in education”, “learning environment augmented reality”, “augmented reality trends”.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is the tool used for this literature review as this tool offers an organized and standardized approach for conducting and reporting systematic reviews. It employs data extraction, analysis, and review (filter, identify, and eligibility criteria) of the relevant literature. The selection criteria (Figure 1) for relevant articles.

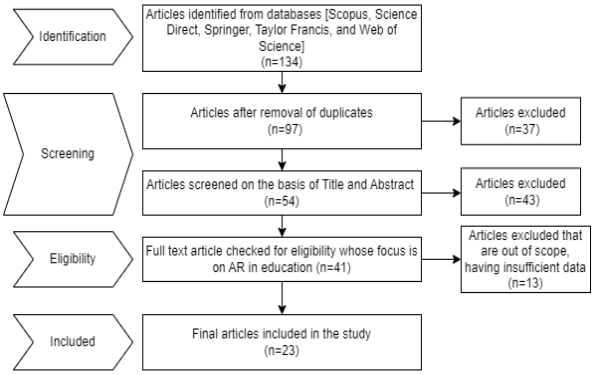

Figure 1 - PRISMA Flowchart for Study Selection.

2.2 Selection of relevant articles

The process of selecting articles for inclusion in a research study can be challenging, as there may be a large number of articles available from various sources. In this particular study, initially 134 articles were identified from different databases. However, not all of these articles were deemed relevant for inclusion in the study. After careful consideration and evaluation, 23 articles were finally selected that met the criteria and were included in the study. Specific inclusion and exclusion criteria were established (Table 1) to guide the selection process of relevant articles. Only articles that met the specific criteria were included in the study. The careful selection process ensured the study’s accuracy and credibility, and it allowed for meaningful conclusions to be drawn from the available evidence.

Inclusion Criteria	Exclusion Criteria
AR articles that discussed the development of an application wereincluded.	AR articles that are not related to education in AR were excluded.
Articles must be published between 2017 and 2023.	Not written in English.
Articles using AR technology in education were only included.	Articles using other technologies like Virtual Reality (VR), MixedReality (MR) were excluded.
Articles that evaluated parameters were included.	Articles that did not mentioned the type of AR technology were excluded.

Table 1 - Inclusion and Exclusion Criteria.

2.3 Data Visualization

By using data visualization techniques, data becomes more accessible and easier to interpret, which allows for better understanding of the implications of the results and drawing conclusions about the research findings. Overall, data visualization is a crucial aspect of the results and discussion section, as it helps to clarify and simplify the information presented, making it easier to comprehend and engage with the research.

3. Literature Review

The study examines the existing research on AR technology and its effectiveness in enhancing education. Through the discussion (Table 2, at the end of the paper), the study identifies potential AR applications in various sectors of education. The primary objective of this review is to evaluate the benefits of AR technology and how it can be used to improve teaching and learning outcomes.

4. Analysis and Discussions

In the Results and Discussion section, the data is presented using visual aids such as charts and graphs. These visualizations are a powerful tool for conveying information in a clear and concise manner, allowing readers to quickly and easily understand the data being presented.

RQ1: Which subject area or target area is in trend for AR educational applications?

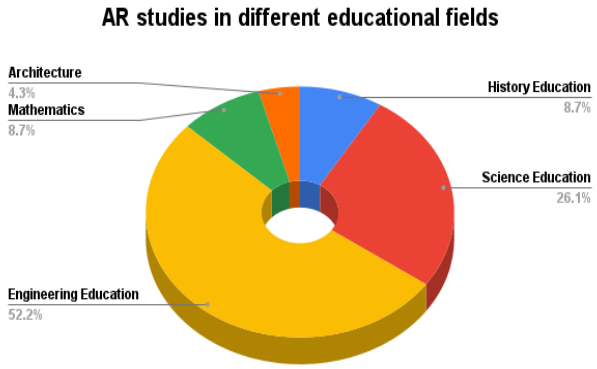

Figure 2 - AR articles in different educational fields.

The result (Figure 2) provides insights into the distribution of AR studies across various educational fields, including science, mathematics, history, architecture, and engineering education. The data shows that engineering education is the most popular area with 52.2%, while science education comes in second with 26.1%. Both history and mathematics education have an equal percentage of 8.7%. Architecture education has the lowest percentage at 4.3%, indicating that further exploration and research are necessary in this area.

RQ2: Which type of AR device is most commonly used in educational applications?

The result (Figure 3) depicts various types of AR devices utilized in the education sector. These devices create a simulated environment that enables users to interact with the application. Mobile-based devices 40% are the most preferred and commonly used devices due to their

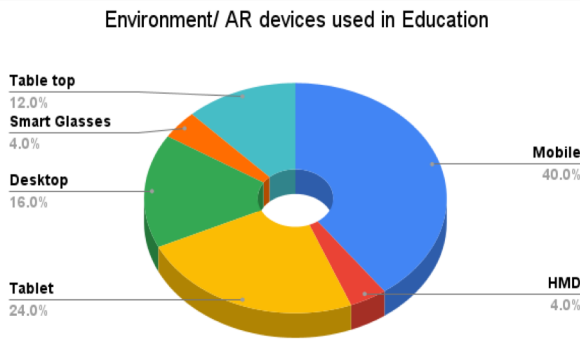

Figure 3 - AR devices used in different educational fields.

accessibility and ease of use. Tablet-based devices 24% rank second in usage frequency. Desktop devices account for 16%, and table-top devices account for 12% of the devices used. Smart-glasses 4% and HMD 4% are used the least due to the potential risk of eye strain that arises from focusing on a close-up screen for an extended period, leading to headaches, dry eyes, and blurred vision.

RQ3: Which type of AR technology is most commonly used in educational applications?

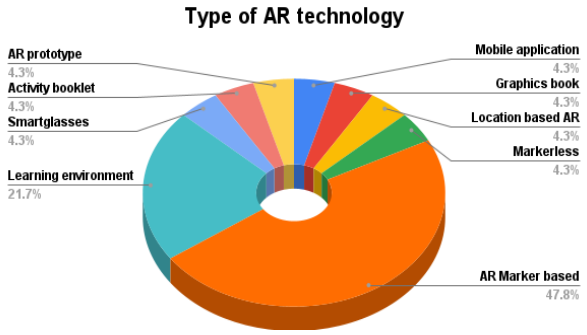

Figure 4 - Different types of AR technologies used in different educational fields.

The types of technologies used in the applications (Figure 4), with marker-based technology being the most used, accounting for 47.8% of the applications. This is due to the accuracy and reliability it provides, as the markers are easily recognizable by AR software, allowing for precise tracking of their position and orientation in 3D space. The learning environment is the second most used technology, with a percentage of 21.7%. Other technologies, such as activity booklets, graphics books, location-based AR, smart glasses, markerless AR, and AR prototypes, are used less frequently, each with a percentage of 4.3%. It indicates that there is a need for further exploration of these technologies, as they offer great flexibility and lower costs.

RQ4: Which type of sampling technique is most commonly used in educational applications?

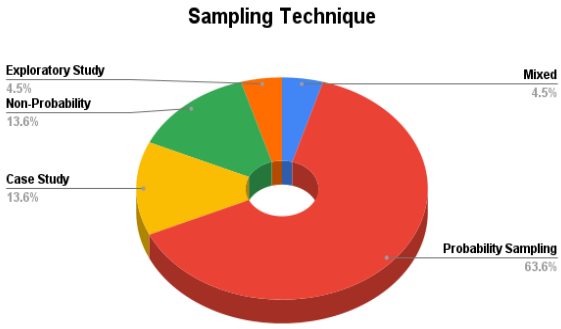

Figure 5 - Different types of Sampling techniques used in sample analysis in different educational fields.

The different types of sampling techniques used in research articles (Figure 5). Probability sampling is the most commonly used technique, with a percentage of 63.6%, as it involves selecting samples randomly and reduces bias. Non-probability sampling and case studies are used by 13.6% of the authors, while mixed and exploratory studies are performed by 4.5% of the authors each. The diagram provides valuable insights into the sampling techniques used in research articles.

RQ5: What type of evaluation technique is adopted by AR applications?

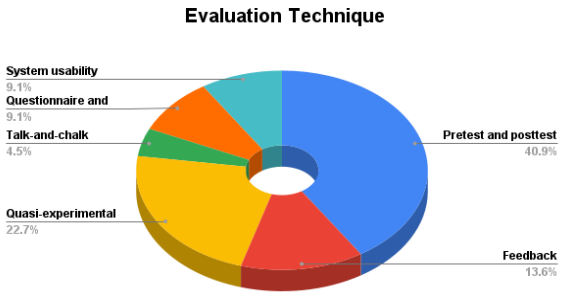

Figure 6 - Evaluation techniques used for sample analysis different educational fields.

The various evaluation techniques used in AR applications are illustrated (Figure 6). The pretest and post-test technique is the most commonly used, preferred by 40.9% of the authors. Another popular evaluation technique is the quasi-experimental pretest/post-test method, which is also used by 40.9% of the authors. Feedback questionnaires are used by 13.6% of the authors, while questionnaires and System Usability Survey (SUS) techniques are used by 9.1% of the population.

6. Conclusion & Future Scope

AR makes it easier for students to comprehend, evaluate, and recall information without tiring them out. Because it helps students enhance their memory, spatial ability, learning, and critical thinking, AR is quite popular among students. Augmented reality has the potential to enhance instructional materials and assist pupils in better comprehending difficult topics. Using AR, children may enjoy games while also studying, which prevents them from becoming bored.

According to the findings of this study, the application of technology that utilizes augmented reality can enhance classroom instruction in a range of subject areas. AR features and helpful apps can serve as motivation for students to learn and help them enhance their visualizing skills. Also, the features might assist instructors in making topics understandable to students. Participants and learners who demonstrated interest in integrating AR in their educational processes provided favorable feedback on the technology's application. Their affirmative feedback is significant because it demonstrates that students are eager to use augmented reality tools to actively participate in their academics. However, the research analysis reveals that the majority of the limitations are due to technical difficulties. These restrictions will be overcome, duplicated, and improved as more study on the use of AR in education is conducted. When the potential of these technologies is more extensively investigated, the useful qualities of AR can start being widely utilized in many educational fields, which will increase the effectiveness of the teaching and learning process.

Within this continuously developing domain, several unsolved issues and various aspects pertaining to the use of AR technology need additional investigation. There are some limitations associated with this approach. In the context of the study, it was seen that a significant proportion of individuals engaged in an AR learning activity had positive opinions on the efficacy of AR tools. However, it was noted that these participants did not perceive the AR tools to be as beneficial as their conventional textbooks. The use of AR technology for the purpose of information gathering posed a considerable challenge for them. Although the AR tool is user-friendly, it necessitates a certain amount of time for image transmission, word recognition, and subsequent text decryption. The frequency of replication research on AR is increasing. Nevertheless, Malaysia is gradually adopting this kind of technology, namely within the realm of education. To enhance pedagogical approaches within the national educational system and enhance the effectiveness of instructional practices, it is essential for a greater number of scholars in the realm of education to investigate the potential of AR. Further research should be conducted on the mobile augmented reality (MAR) system, a new technological

advancement that involves the integration of a smartphone application with the AR platform.

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Table 2 – Literature review.

Research Studies	Target	Topic	Parameter	Environment/ AR devices used	Type of AR technology	Sampling Technique	Sample Size	Evaluation Technique	Summary
Nagata et al. (2017)	History Education	Territorial information	Learning skills	Mobile	AR based mobile application	Mixed Sampling	143, Primary School Students	Pretest and posttest	Students productivity in the learning process were enhanced and interaction between students and learning materials were encouraged.
Hung et al. (2017)	Science Education	6 Bacteria	Learning performance and memory retention	HMD	AR based graphic book	Probability Sampling	72, Primary School Students	Pretest and posttest	The book provides youngsters with an empirical and hands-on method to discover and learn about bacteria.
Efstathiou et al. (2018)	History Education	Neolithic historical site	Conceptual knowledge and historical compassion	Tablet	Location based AR	Case study	53, Primary School Students	Pretest and posttest	When compared to a regular field trip, the AR technique proved more effective in developing students historical compassion and conceptual knowledge.
Reyes et al. (2018)	Engineering Education	Resistive Circuit Topology	Conceptual understanding	Mobile	AR based Markerless application	Non-Probability Sampling	60, Engineering Students	Feedback Questionnaire	The system aids the userin comprehending & contrasting the theoretical and experimental values of the parameters of a given circuit. Studentscan modify the existing topologies as well as propose new ones.
Omar et al. (2018)	Engineering Education	Fundamental of Engineering Drawing course	Student mental rotation and 3-dimensional development skills	Mobile and Tablet	AR Marker based application	Non-Probability Sampling	60, Engineering Students	Quasi-experimental pretest/ posttest	TPSVT:R and PSVT:D these two set of tests were used in pre and posttest and results show that student performance and visualization was improved.
Singh et al. (2019)	Engineering Education	Oscilloscope and Function Generator	Impact of AR intervention on student laboratory skills, cognitive load, and learning motivation	Desktop	AR based learning environment	Probability Sampling	60, Engineering Students	Pretest and posttest	ARLE is an effective tool in reducing the cognitive load of students while operating laboratory equipment.
Sagayam et al. (2019)	Engineering Education	3D Gearbox Model	Comprehension of the interaction of gears during a gear shift	Tablet	AR Marker based application	Probability Sampling	30, Engineering Students	Talk-and-chalk techniques compared with AR	A 3D model of a gearbox was developed, in which five separate sets of markers were developed for each gear. These markers ought to interact with the system more quickly upon recognition.

Omar et al. (2019)	Engineering Education	Orthographic Projection	Spatial Visualization Skills	Mobile	AR Marker based application	Non-Probability Sampling	60, Engineering Students	Pretest and posttest	Due to the significance of the PSVT:R, mental rotation abilities were assessed.
Thees et al. (2020)	Science Education	Heat Conduction	Extraneous cognitive processing	Smart Glasses	AR based smart glasses	Probability Sampling	74, Undergraduate Students	Quasi-experimental pretest/post test	AR technology was successfully used to transform basic laboratory environments from divided source to unified presentational format with live data visualizations. However, superfluous processing was reduced throughout the performance.
AlNajdi et al. (2020)	Engineering Education	Buzz-Boards	Learning Effectiveness	Tablet	AR-based learning environment	Probability Sampling	36, Engineering Students	Feedback Questionnaire	Results showed that the PVM with AR technique was more effective to the paper-based approach in terms of learning achievement, enjoyment of learning activities, and utility.
Sahin et al. (2020)	Science Education	"Solar System and Beyond" module	Academic achievements and Attitude	Desktop	AR-based activity booklet	Probability Sampling	100, Secondary School Students	Quasi-experimental pretest/post test	The research revealed a significant and moderate correlation between the academic achievement and attitudes of the experimental cohort of pupils.
Sharma et al. (2020)	Engineering Education	Ohm's law	Interaction and innovation	Desktop	AR Marker based application	Probability Sampling	40, Engineering Students	Feedback Questionnaire	Students find AR Ohm application to be more interactive and innovative, which leads them to an easier conception of the topic.
Russo et al. (2021)	Architecture, Engineering & Construction	Architecture	Democratization Process	Mobile	AR Marker based application	Not Specified	Not Specified	Not Specified	The whole AR process progression in architecture, from the conception stage to its application was underlined.
Faridi et al. (2021)	Science Education	Magnetic field, Electromagnetic waves, Maxwell's equations, Fleming's rules	Critical Thinking and Learning Gain	Mobile	AR-based learning environment	Probability Sampling	80, Engineering Students	Pretest and posttest	The AR experience enhanced students understanding of abstract physics concepts by aiding them in visualizing them.
Gargrish et al. (2021)	Mathematics Education	Vector addition, position vector, direction ratios, cross and dot	Memory retention abilities and learning	Table top	AR Marker based application	Probability Sampling	80, Polytechnic Students	Quasi-experimental pretest/post	Results revealed that memory retention capacities of students had improved even after 2 and 4 weeks of learning after using

		product						test	AR based GLA.
Arici et al. (2021)	Science Education	"Sun, earth and moon", "Solar system and eclipses" and "solar system and beyond"	Perceived learning, attitude, experience, and interest	Tablet	AR-based learning environment	Probability Sampling	40, Secondary School Students	Questionnaire and interview method	Space 4D application was developed and result shows that student interest and motivation towards the subjects have increased.
Kumar et al. (2021)	Engineering Education	Embedded System	System usability, learning experience	Table top	AR Marker based application	Exploratory Study	20, Professionals	System usability survey (SUS)	AR-based scaffolds were developed after their usability was tested with faculty members, and it was found that their total usability rating was 79.5%, which qualifies them for continued use with students for exploratory work.
Kaur et al. (2022)	Engineering Education	Stability Analysis of Linear Control System	Comparative difference between Mobile and Table top variant	Table top and mobile	AR Marker based application	Probability Sampling	60, Engineering Students	Questionnaire and interview method	Students potential for spatial visualization in real time is influenced which additionally, aids in improving concept comprehension in relation to a better understanding of the topics.
Portillo et al. (2022)	Science Education	Acid–base reactions, chemical elements and chemical bonds	Learning Outcome	Tablet	AR Marker based application	Probability Sampling	124, Secondary School Students	Pretest and posttest	The study determined the utility of an AR based learning activity for mastering fundamental chemical concepts as well as the appeal of immersion learning for students.
Dutta et al. (2022)	Engineering Education	K-maps	System Usability	Mobile	AR Marker based application	Probability Sampling	90, Engineering Students	System usability survey (SUS)	Students were divided into two groups: keypad-based MAR groups and marker-based MAR groups. The results suggested that the keypad-based MAR program had greater SUS and HARUS scores compared to the marker-based MAR application, indicating that it had better interaction with users.

Tuli et al. (2022)	Engineering Education	Electronics laboratory Manual	Student learning attitude and their attitude towards AR technology	Mobile	AR Marker based application	Probability Sampling	107, Engineering Students	Quasi-experimental pretest/ posttest	ARLM was developed, and results display an optimistic relationship between students academic achievement and their learning attitude towards the technology.
Shore et al. (2023)	Engineering Education	Building project	Involvement and imagination	Mobile	AR prototype	Case Study	60, Engineering Students	Pretest and posttest	The outcomes show that during a simulated design conference, students can perceive structures more quickly, precisely, and with more assurance with AR than they do with their traditional paper designs.