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A Systematic Literature Review on Types of Augmented Reality (AR) Technologies and Learning Strategies for Problem-Solving

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Abstract. Augmented reality (AR) technology has gained popularity among educators over the past decade in line with the development of Industrial Revolution 4.0 and the 21st century learning concept. Previous studies have provided evidence that students' engagement in AR, in general, facilitates the development of problem-solving skills required in the field of education. However, there has been a lack of systematic research on the correlation between AR technologies and learning strategies, as well as the problem-solving methods utilized. Therefore, this study aimed to examine types of AR technologies utilized and their integration with learning strategies and problem-solving methods employed in education. The methodology of this study involved employing the preferred reporting items for systematic reviews and meta-analyses (PRISMA) approach, based on references from reputable online databases, namely Web of Science, Scopus, and ScienceDirect. The study analyzed publications from 2018 to 2023, with a total of 14 selected articles (N = 14). The findings show that the most popular type of AR technology was marker-based AR. In addition, the most dominant learning strategy was problem-based learning (PBL), with the specific problem-solving approach being the computational thinking approach. In conclusion, these findings will provide guidance regarding the types of AR technologies that have been integrated with learning strategies and problem-solving methods. By identifying the limitations of the analyzed AR technologies and learning strategies, new research opportunities can emerge, focusing on integrating emerging AR technologies with problem-solving methods that may be more effective in the learning process.

Keywords: augmented reality in education; augmented reality technology; learning strategies; problem-solving

1. Introduction

Technology is one of the main drivers shaping the landscape of the education field in the present time, and it consistently has a profound impact on learning strategies. Aligned with the era of Industrial Revolution 4.0, characterized by rapid technological advancements, the education system now prioritizes the mastery of technology skills in 21st century teaching and learning, which is technology oriented. Numerous innovations are emerging in response to today's rapid technological advancements. Augmented reality (AR) is one such technological innovation that is garnering growing attention and popularity across diverse domains, including the field of education. The AR environment brings a new learning experience to students and offers opportunities for utilization in technology-assisted learning (Tan et al., 2022).

AR is a technology that allows users to experience virtual content in 2D or 3D form. According to Azuma (1997), this technology has three important characteristics, namely having overlaid virtual elements in the real world, real-time interaction, and the ability to appear in 3D form. Through AR technology, students can experience a different type of learning by incorporating a combination of objects, including text, images, and animations. By incorporating AR in education, students can enjoy a captivating digital experience that is unmatched by traditional teaching methods (Phakamach et al., 2022). Moreover, AR technology facilitates more efficient student interaction with intricate materials outside of regular school hours and textbooks (Sun et al., 2023). Additionally, it empowers teachers to tailor content according to individual students' learning styles (Childs et al., 2023). Thus, it can be inferred that incorporating AR into education enhances the teaching and learning process, rendering it more interactive, engaging, and enjoyable (Yusof et al., 2022).

Apart from the popular appeal of AR, which can captivate students' interest and motivation during AR technology usage, it is also considered a strategy that can enhance students' ability to solve problems during the learning process (Guntur & Setyaningrum, 2021). Problem-solving skills are among the essential skills required by students to face the era of Industrial Revolution 4.0. Various approaches are utilized in the problem-solving process in learning. These include problem-solving methods in mathematics through the Polya model (Polya, 1957), computational thinking as a process for problem-solving in education (Hsu et al., 2018; Wing, 2006), and problem-solving in geometry topics through the Van Hiele model (Fuys et al., 1988).

Among the subjects that require effective problem-solving skills is mathematics, especially in topics with abstract content, such as geometry. Previous studies have shown that geometry topics contain abstract concepts that are challenging for students to comprehend, as visualization and reasoning skills are involved in the problem-solving process. Therefore, technologies such as AR are viable options for addressing this matter. As important as the role of technology is in the world of education, it is equally important to examine how technology can assist students in their learning. In their study, Hanid et al. (2022) observed an improvement in visualization and problem-solving skills in geometry topics when utilizing AR applications based on computational thinking methods. This opinion is consistent with Sung and Black (2020), who stated that computational thinking in problem-solving for geometry topics in mathematics can help enhance mathematical knowledge. Specifically, this systematic literature review aimed to explore the subsequent research questions:

1. What types of AR technologies are implemented to assist the learning process?
2. What learning strategies are used with the integration of AR technologies?
3. Are there specific problem-solving methods utilized in conjunction with the learning strategies mentioned above?

1.1 Implications and Contributions of the Research

This study emphasizes the transformative role of AR technologies in fostering problem-solving abilities in line with 21st century educational advancements. It highlights a significant gap in current research, notably the lack of systematic studies linking specific AR technologies with precise learning strategies and problem-solving techniques. This research gap presents an opportunity for future work to explore the integration of emerging AR technologies with innovative learning strategies, potentially reshaping educational methods to offer more interactive, engaging, and personalized learning experiences tailored to a diverse range of learner needs and preferences.

Additionally, the findings provide crucial insights for the development of future AR educational applications. By identifying effective AR technologies and their compatibility with certain learning strategies, the study offers a valuable guide for developers and educators in creating AR tools that are not only technologically sophisticated but also pedagogically sound, aiming to improve students' problem-solving skills.

In summary, the review posits AR as a key driver in the evolution of educational experiences, integrating advanced technologies with established learning strategies. The study not only sheds light on the current utilization of AR in education but also paves the way for future research and development efforts to fully leverage the potential of AR to enhance educational outcomes and equip learners with vital problem-solving capabilities.

2. Literature Review

2.1 Types of Augmented Reality Technologies

AR is a technology that allows virtual objects to merge with the real world and coexist in the same location simultaneously (Akçayır & Akçayır, 2017). Various types of AR technologies have been implemented in the field of education, such as marker-based AR, markerless-based AR, location-based AR, and object recognition AR (Samir et al., 2018). Marker-based AR, often referred to as image recognition, depends on identifying specific markers or user-defined images to operate. This form of AR requires a marker to trigger an augmentation. These markers are unique patterns that cameras can readily recognize and process. They are visually distinct from their surrounding environment. Markerless-based AR scans the real environment for recognizable geometric features, such as flat surfaces like floors, and generates virtual digital content accordingly. Location-based AR utilizes position or location data generated by mobile devices, global positioning systems (GPS), or any part of the real environment to determine the locations and targets. It then generates and displays digital media virtually. Among the popular examples of this type of AR technology is Pokémon GO, where characters can move within the environment based on their location. Object recognition AR, on the other hand, scans real-world physical objects and then generates and displays digital media layers virtually.

The benefits of AR are recognized as key drivers promoting its application in education. One notable advantage is the ability of AR technology to support students in cognitive processes, especially by improving their visualization skills (Hanid et al., 2022). The incorporation of AR technology in the classroom leads to a boost in students' interest and problem-solving abilities during the learning process. Moreover, it enables students to interact and collaborate more effectively. With these advantages, it will prepare students for success in the future.

2.2 Learning Strategies

According to Gagné (1985), learning strategies refer to the organization of cognitive functions aimed at assisting students in understanding and problem-solving. Learning strategies can also be defined as procedures and approaches used contextually with planned objectives to assimilate new knowledge to achieve meaningful learning (Muelas & Navarro, 2015). Stakeholders in education must strategically plan, implement, and assess effective learning approaches to improve the quality of education (Nasir et al., 2023). Previous studies have identified that learning strategies incorporating AR technology include game-based learning (GBL), inquiry-based learning (IBL), conceptual learning, and peer learning. AR-based learning strategies are crucial, offering students innovative ways to engage in their learning environment by utilizing various devices. The interaction between students and between teachers and students fosters a collaborative environment that boosts students' motivation to learn (Sampaio & Almeida, 2016).

Prensky (2001) introduced digital game-based learning, stating that gaming elements exist when engaging in activities for entertainment or enjoyment, which can indirectly facilitate the learning process. Digital game-based learning is a student-centered learning strategy that can produce quality, active, and collaborative learners as well as assist students facing challenges in learning at the early stages (Vlachopoulos & Makri, 2017). According to Rozali and Abd Halim (2020), IBL is a student-centered learning strategy involving questioning and curiosity, where students actively seek answers. This learning strategy involves the inquiry process, existing knowledge aspects, motivation, and critical thinking (Prayogi et al., 2018). Students actively engage in discussions and explore activities given by the teachers. Contextual learning, according to Dewey (1916), means that students will learn effectively if what they are learning is related to what is happening in their environment. Lastly, peer learning refers to the acquisition of knowledge and skills through mutual assistance and support among individuals within similar social groups who collaborate to facilitate each other's learning process (Topping, 2005).

2.3 Problem-Solving in Learning

One of the essential skills and curriculum requirements in 21st century learning is problem-solving. Problem-solving is a high-level cognitive process that necessitates proficiency in more fundamental or routine skills (Goldstein & Levin, 1987). Gurat (2018) stated that these skills need to be mastered by students, as they can enhance students' problem-solving abilities in everyday life. There are various types of models that can serve as references and guidelines in the problem-solving process, for example, the Polya model as the main reference in solving mathematical problems (Yapatang & Polyiem, 2022). Based on the Polya model, the problem-solving process is facilitated by decomposing the information in the question. Information decomposition is carried out through four main steps, namely translating or understanding the problem, planning problem-solving strategies, implementing the plan, and reviewing the obtained answers. This model also requires students to contemplate what they are seeking, identify relevant information provided, determine the operations required to solve the problem, and ensure that the obtained answers are logical (Bruun, 2013).

Bransford and Stein (1993) introduced the IDEAL problem-solving model, which provides five key guidelines. First, *identifying* the problem involves recognizing the issue, collecting relevant information, asking questions, describing the context, and using creative thinking to identify the next steps. Second, *defining* the problem requires organizing information and questions, as well as searching for and selecting important data to answer these questions. Third, *exploring* solutions entails searching for or creating possible strategies, such as patterns, tables, or models, to address the problem. Fourth, *acting* according to the strategies calls for utilizing numeracy, algebra, or geometry skills to solve the issue at hand. Finally, *looking* back and evaluating involves reviewing the solution, identifying alternative approaches, discussing findings, and refining responses for future scenarios. The IDEAL model serves as a comprehensive learning strategy to describe students' thinking skills during the problem-solving process (Permata et al., 2018).

Another problem-solving strategy is computational thinking, which uses systematic steps. Wing (2006) described computational thinking as the cognitive process involved in formulating a problem so that its solution can be effectively articulated using information processing agents. This concept has found broad application across multiple disciplines, extending beyond the initial realm of computer science. Pei et al. (2018) reported that numerous earlier studies have demonstrated beneficial outcomes in problem-solving for mathematics through the adoption of computational thinking. There are differences among scholars regarding the framework of elements in computational thinking. Angeli et al. 2016) suggested a framework consisting of abstraction, generalization, decomposition, algorithms divided into sequencing and flow of control, and debugging.

Harangus and Kátai (2020) emphasized that computational thinking is most beneficial when students' cognitive abilities are harnessed and cultivated across diverse learning contexts. Román-González et al. (2019) further reinforced this notion by providing new evidence that the elements of computational thinking are linked to cognitive skills such as visual-spatial abilities, reasoning, and problem-solving skills. This opinion is also supported by the study of Echeverría et al. (2019), which demonstrated that the computational thinking approach has been able to enhance learning in mathematics subjects. In addition, Zakaria et al. (2023) suggested further research to develop a teaching and learning model by integrating mobile learning as well as problem-based learning (PBL) approaches.

3. Methodology

We utilized the PRISMA (preferred reporting items for systematic reviews and meta-analyses) approach. This approach is suitable for studies employing the systematic review method with eligibility and exclusion criteria, involving steps such as the review process (identification, screening, eligibility) as well as data extraction and analysis. This method is guided by the PRISMA Statement (Moher et al., 2009). Offering three distinct benefits, the PRISMA approach: (1) establishes precise research questions that enable systematic investigation, (2) sets out specific inclusion and exclusion criteria, and (3) aims to analyze an extensive body of scientific literature within a defined timeframe.

As presented in Figure 1, the systematic review was carried out in four main steps, namely identification, screening, assessing eligibility, and inclusion. We adhered to the PRISMA criteria, as it promotes evidence-based analysis and encourages transparent and comprehensive reporting of systematic literature reviews. The transparency and completeness of reporting ensure research quality, as it allows readers to assess the research procedures and credibility of the conducted study (Sarkis-Onofre et al., 2021). The aim of this study was to identify the impacts achieved by employing AR technology in diverse learning strategies, particularly for problem-solving in education. We also aimed to extract common characteristics from the review to categorize them based on the types of AR technologies and the implementation of learning strategies in their execution.

The following keywords were employed for the database search: "augmented reality", "learning strategy", and "teaching strategies" (see Table 1). Searches were conducted in Web of Science, Scopus, and ScienceDirect databases, yielding 298 results. However, only 14 articles were deemed relevant according to these criteria: (1) the study explicitly mentioned that the learning strategy involves AR, (2) the study was published between 2018 and 2023, and (3) the study contained empirical data.

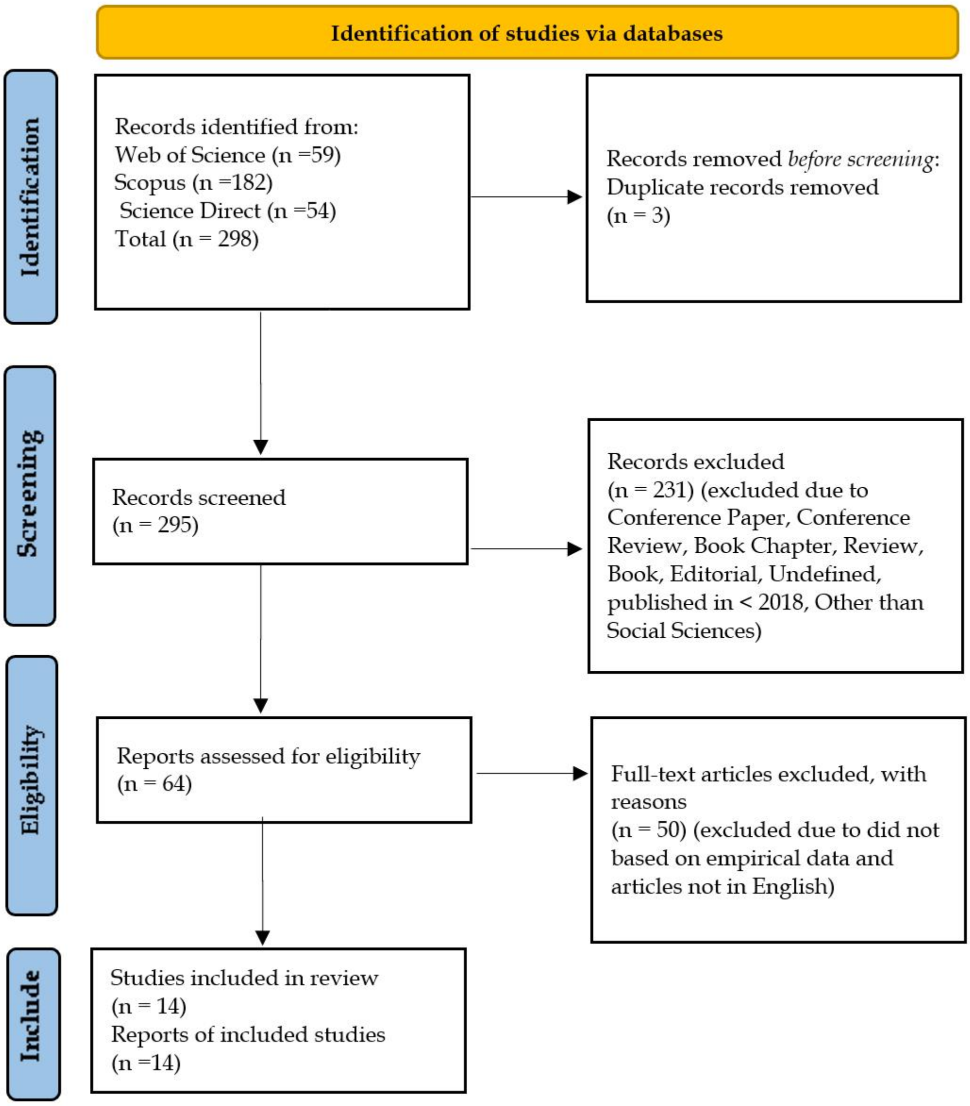

Figure 1: Flow diagram of the study (adapted from Moher et al., 2009)

Table 1: Search terms utilized in the systematic review process

Database	Boolean operator used
Web of Science	ALL=((Augmented Reality) AND TOPIC: (Learn* Strateg*))
Scopus	TITLE-ABS-KEY ("Augmented Reality" AND ("Learn* Strateg*" OR "Teach* Strateg*")) AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018))
ScienceDirect	("augmented reality") AND learning strategy

In the systematic review, as outlined in the flow diagram above, a total of 298 articles were initially gathered from various databases for consideration. These databases included Web of Science, which contributed 59 articles, Scopus, with 182 articles, and ScienceDirect, with 54 articles. To ensure that the studies reviewed were relevant and of a high standard, strict criteria were applied to filter these articles.

Upon the first screening, 3 duplicates were removed, leaving 295 articles. Subsequent to this, a further 231 articles were excluded for a number of reasons. These included the type of publication, such as conference papers, conference reviews, book chapters, and editorials, as well as those that were not clearly defined, published before the year 2018, or outside the scope of social sciences.

The process then moved to a more detailed assessment of eligibility, during which 64 articles were closely examined. Of these, 50 were excluded because they either lacked empirical data or were not written in English. This careful and systematic approach to selection led to the final inclusion of 14 studies in the review. The diligent application of these criteria ensured the review was founded on evidence that was both relevant and of high quality, providing clarity to readers on the methodology used in selecting the articles for the review.

3.1 Identification

The initial step in the systematic review involved the identification phase, where we utilized the PRISMA approach to conduct a comprehensive search across reputable online databases, including Web of Science, Scopus, and ScienceDirect. If the selected database is known for its stringent quality standards, researchers may trust it as a reliable source of credible publications. The search targeted publications from the years 2018 to 2023, employing specific keywords such as "augmented reality", "learning strategy", and "teaching strategies". This phase was crucial, as it set the groundwork for gathering a broad spectrum of studies relevant to the research questions concerning the integration of AR technologies with learning strategies and problem-solving methods in education.

3.2 Screening

Following the identification phase, the screening process involved a meticulous review of the 298 articles initially identified. This step was intended to eliminate duplicates and articles that did not align with the predetermined criteria for relevance and quality. The criteria for screening included the type of publication, the clarity of the definition, and the scope of the study in relation to the social sciences and education. This screening process ensured that only studies with a direct relevance to the research questions were considered for further analysis. After this phase, 295 articles remained, indicating that 3 duplicates were removed. This stage was essential for refining the pool of articles to ensure they are pertinent to the research objectives.

3.3 Eligibility

During the eligibility phase, we conducted a detailed assessment of the articles that passed the initial screening. This involved a closer examination of 64 articles to evaluate their empirical data and whether they were written in English. The focus was to determine the direct relevance of the studies to AR technologies, learning strategies, and problem-solving methods within the educational context. The exclusion of 50 articles at this stage was due to the lack of empirical data or because they were not in English, emphasizing the strict criteria used to guarantee the quality and relevance of the chosen studies.

3.4 Inclusion

The final phase, inclusion, resulted in 14 studies being selected for the review, based on the stringent criteria that the studies had to explicitly state the use of AR in learning strategies, be published between 2018 and 2023, and contain empirical data. This phase culminated in the completion of the systematic review. The selected studies offered insights into the type of AR technologies employed, the dominant learning strategies, such as PBL, and the use of specific problem-solving approaches, such as the computational thinking approach. The thoroughness of this four-step process ensured the credibility of the systematic review, providing a solid foundation for analyzing the integration of AR technologies with learning strategies and problem-solving methods in education.

The systematic literature review, following the methodology adapted from Moher et al. (2009), is summarized as shown in Table 2.

Table 2: Summary of the reviewed studies

No.	Study	AR technologies	Methodology	Sample	Learning strategies	Problem-solving methods
1	Pombo and Marques (2019)	Types of AR: marker-based & location-based. Output: 3D models.	Quantitative (questionnaires)	244 students	Game-based learning	Authentic learning experiences
2	Gu et al. (2022)	Type of AR: marker-based. Output: 3D models, animations, videos, sound effects.	Quantitative (questionnaires)	Survey 1: 120 students. Survey 2: 114 students. Survey 3: 514 students.	Peer learning	Not mentioned
3	Cai et al. (2021)	Type of AR: marker-based. Output: 3D models, sound effects.	Quantitative (quasi-experimental design)	168 students	Inquiry-based learning	Investigation based on the scenario/ problem
4	Buchner (2022)	Type of AR: marker-based. Output: 3D models, animations, videos, sound effects.	Quantitative (quasi-experimental design)	56 students	Generative learning	Not mentioned
5	Yang and Wang (2023)	Type of AR: marker-based. Output: 3D models.	Quantitative (quasi-experimental design)	32 students	Conceptual learning	Not mentioned
6	Balcita and	Type of AR: marker-based.	Quantitative (questionnaires)	30 students	Simulation	Not mentioned

	Palaoag (2020)	Output: 3D models.				
7	Hanid et al. (2022)	Type of AR: marker-based. Output: 3D models.	Quantitative (quasi-experimental design)	124 students	Problem-based learning	Computat-ional thinking
8	Ou Yang et al. (2023)	Type of AR: marker-based. Output: 3D models.	Quantitative (quasi-experimental design)	75 students	Problem-based learning	Computat-ional thinking
9	López-Faican and Jaen (2020)	Type of AR: markerless-based. Output: 3D models.	Quantitative (questionnaires); qualitative (observation)	38 students	Gamificat-ion	Not mentioned
10	Chen and Liu (2020)	Type of AR: marker-based. Output: 3D models.	Quantitative (quasi-experimental design)	112 students	Student-centered hands-on	Not mentioned
11	Fidan and Tuncel (2019)	Type of AR: marker-based. Output: 3D models.	Quantitative (quasi-experimental design)	91 students	Problem-based learning	Investigation to solve the real-life problem cases
12	Chang and Hwang (2018)	Type of AR: marker-based. Output: 3D models.	Quantitative (quasi-experimental design & questionnaires)	111 students	Blended learning (flipped learning)	Not mentioned
13	Ruiz-Ariza et al. (2018)	Type of AR: location-based. Output: 3D models, animations, sound effects.	Quantitative (quasi-experimental design)	190 students	Game-based learning	Not mentioned
14	Lim and Lim (2020)	Type of AR: markerless-based. Output: 3D line sketches.	Qualitative (interviews)	5 students	Six learnings framework	Learner-generated augmentat-ion approach

Figure 2 illustrates the frequency of the different types of AR technologies used in the reviewed studies, highlighting that marker-based AR was the most commonly used type, followed by location-based and markerless-based AR.

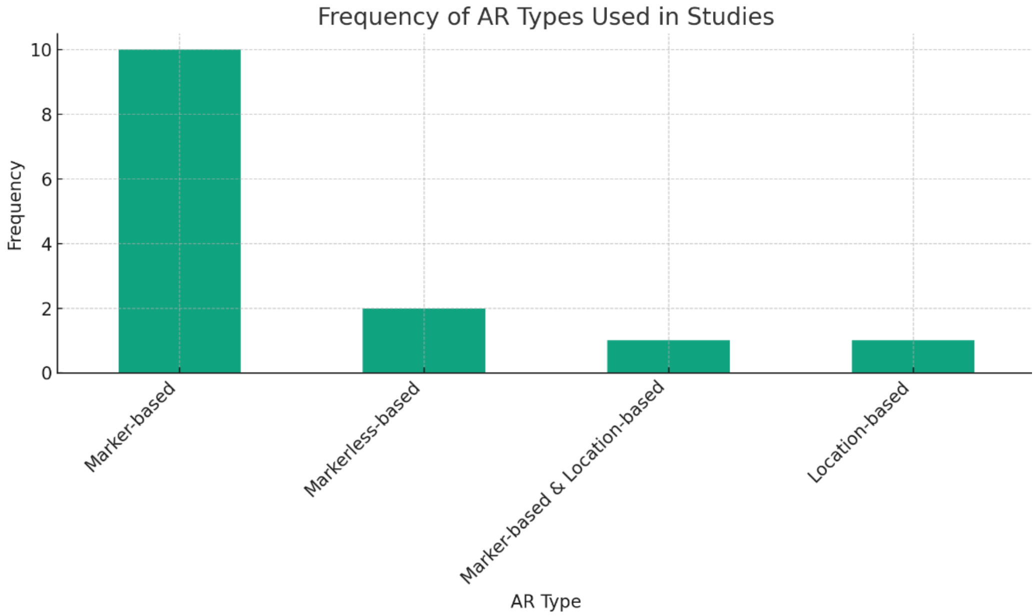

Figure 2: Frequency of augmented reality types used in the reviewed studies

The graph displaying the frequency of AR types used in the reviewed studies reveals a significant inclination toward the use of marker-based AR technology in educational settings. This preference for marker-based AR could be attributed to its relative simplicity and ease of implementation within existing educational frameworks. Marker-based AR allows for a straightforward augmentation of physical objects and printed materials with digital information, making it a versatile and accessible option for enhancing learning experiences. However, the graph also indicates an emerging interest in location-based and markerless-based AR technologies, although to a lesser extent. Location-based AR introduces opportunities for outdoor learning and exploration, engaging students in real-world contexts. Conversely, markerless-based AR offers a higher degree of flexibility and interactivity by recognizing objects and surfaces without the need for predefined markers. The varied use of AR technologies suggests a growing exploration of how different AR types can cater to diverse educational goals, highlighting the dynamic nature of AR integration in pedagogy.

Figure 3 illustrates the frequency of learning strategies employed in conjunction with AR technologies, with PBL and GBL being among the most frequently mentioned strategies.

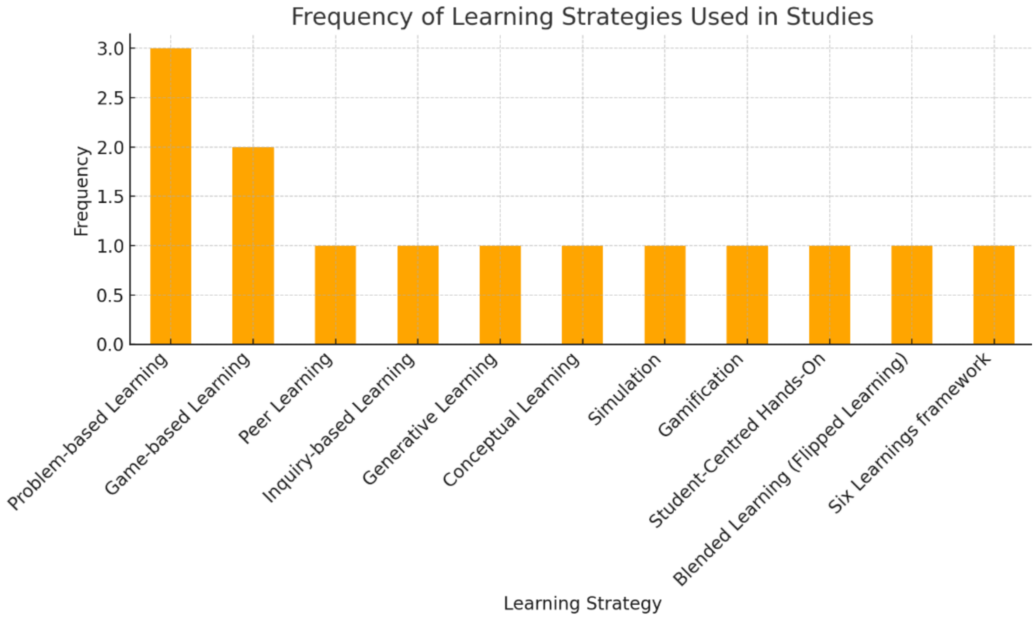

Figure 3: Frequency of learning strategies used in the reviewed studies

These graphs provide a clear visual overview of the trends in AR technology types and learning strategies as reported in the selected studies. The analysis of learning strategies employed in conjunction with AR technologies, as visualized in Figure 3, underscored the diversity of pedagogical approaches being explored in AR-enhanced education. PBL and GBL emerged as the most prevalent learning strategies, reflecting a pedagogical shift toward more engaging, interactive, and student-centered learning models. PBL, characterized by its focus on real-world problem-solving, is naturally complemented by the ability of AR to simulate complex scenarios and visualize abstract concepts, thereby deepening students' understanding and engagement. Similarly, GBL leverages the immersive and interactive nature of AR to create compelling educational games that enhance motivation and learning outcomes. The presence of various other strategies, including IBL, conceptual learning, and the innovative six learnings framework, indicates a broad experimentation with AR to support different learning objectives and styles. This diversity not only highlights the adaptability of AR technology to various pedagogical methods but also emphasizes the importance of aligning technological tools with appropriate learning strategies to maximize educational benefits.

4. Results and Discussions

An analysis of the literature review revealed that marker-based AR was the most used AR type in the reviewed studies. Gu et al. (2022) stated that incorporating AR picture books (marker-based AR) in learning German enhances the learning experience and promotes a more positive attitude toward learning by boosting satisfaction and psychological enjoyment. Cai et al. (2021) scanned images (marker-based AR) related to experiments during the IBL process. Meanwhile, Pombo and Marques (2019) utilized image recognition (marker-based AR) or user-based location (location-based AR) to promote authentic cross-subject learning during exploration in an urban park setting.

López-Faican and Jaen (2020), in their study, utilized markerless-based AR technology. Students scanned the physical environment to create scenarios that could influence their emotions by manipulating emoji characters that appeared. This subsequently evoked positive emotions such as enthusiasm, joy, and curiosity, which improve participants' mood and, in turn, raise their level of engagement in learning. Furthermore, Ruiz-Ariza et al. (2018) utilized location-based AR, namely the Pokémon GO application, to examine the impact of playing Pokémon GO on students' cognitive performance and emotional intelligence. The AR technology used in this study was also analyzed together with the integration of learning strategies because educational technologies need to have suitable methods or approaches to achieve learning objectives.

Among the learning strategies analyzed in this study was GBL. Pombo and Marques (2019) used GBL in exploration within the context of formal and informal education, where students could physically explore in an urban park setting and subsequently make connections with curriculum content in their learning. Gu et al. (2022), on the other hand, employed the peer learning strategy in multimedia to examine the effects of peer interaction when using AR technology to learn the German language. Research findings by Cai et al. (2021) indicate that IBL combined with AR technology was an effective educational approach. However, additional time was required for students to grasp the AR application handling through teacher instructions or demonstrations.

Furthermore, Buchner (2022) utilized generative learning. This method involved students engaging in self-explanation and self-testing, within an AR learning environment, to investigate its impact on students' attitudes toward AR as an educational technology tool. This study was particularly interesting because it compared two groups: the treatment group, which utilized AR technology integrated with learning strategies, and the control group, which solely relied on AR technology. The study findings demonstrate that incorporating the generative learning strategy did not diminish positive attitudes toward AR as an educational technology.

Yang and Wang (2023) conducted a study using the conceptual learning strategy. They explored how different 3D visualizations of AR technology can affect the learning of complex scientific concepts, as well as how individual differences in the learning process can influence learning outcomes. Chen and Liu (2020) compared two learning strategies, and the results show that student-centered hands-on learning with AR technology was more effective than teacher-centered demonstration-based learning in enhancing students' knowledge of chemical reactions.

Balcita and Palaoag (2020), on the other hand, explained the simulation learning strategy utilized in their study as not achieving a satisfactory level of student learning experience due to several limitations encountered during the implementation of the learning. They proposed that there were opportunities for further enhancement in students' learning experience by developing an AR technology framework or model to enhance the learning experience. Implementing visual technology, such as developing an AR framework or model, can help reduce the learning gap and serve as a tool for more intuitive learning.

Fidan and Tuncel (2019) concluded that the integration of AR into PBL activities in the classroom can significantly improve students' academic achievement and promote a positive attitude toward physics subjects. The immersive and realistic context provided by well-designed AR environments could foster the development of students' cognitive skills and support knowledge transfer to real-world applications.

Furthermore, in the study by Chang and Hwang (2018), they employed the blended learning approach, specifically flipped learning strategies, with the integration of AR technology. The study revealed that flipped learning strategies, coupled with AR-based guidance, improved students' project performance, while also boosting their learning motivation, critical thinking disposition, and group self-efficacy. The research conducted by Ruiz-Ariza et al., (2018) determined that using the GBL approach with Pokémon GO could positively affect students' cognitive performance and emotional intelligence. Lim and Lim (2020) concluded that student-centered and AR-based learning strategies using the learner-generated augmentation approach had the potential to assist students in memorizing historical facts, which is a common challenge in history learning at the secondary school level.

In addition, the aim of this study was also to identify how AR technology is used in problem-solving within the context of education. Based on the information in Table 2, the majority of the reviewed studies did not provide specific explanations of the problem-solving methods utilized in learning. However, they clearly mentioned the learning strategies that were employed. Among the studies, Pombo and Marques (2019) stood out, as the study touched on the method of problem-solving. The study provided empirical evidence of the effectiveness of the authentic learning experience approach with AR technology in fostering problem-solving skills during the learning process. AR technology, according to Cai et al. (2021), with the investigation based on the scenario/problem approach, was proven to provide benefits in developing critical thinking and problem-solving abilities.

In their study, Hanid et al. (2022) demonstrated that the integration of AR applications and the computational thinking approach for tackling problems in geometry topics led to improved computational thinking, visualization skills, and academic performance in geometry among students. This opinion is supported by research carried out by Ou Yang et al. (2023). These authors concluded that the implementation of computational thinking with AR technology showed an improvement in certain elements of computational thinking in programming courses, such as algorithmic efficiency skills. However, there were also elements that did not demonstrate a significant improvement, such as problem decomposition skills.

Furthermore, the problem-solving methods utilized in the study by Lim and Lim (2020) employed the learner-generated augmentation approach. This approach can be seen as a problem-solving method that involves students in creating AR content to enhance their own learning. This student-centered approach aims to address passive learning issues by involving students in creating their own learning materials.

5. Conclusion

The systematic review disclosed a prominent gap in literature regarding the incorporation of AR technologies with an assortment of learning strategies and their problem-solving methodologies within educational settings. While PBL frequently intersects with AR applications, there remains a dearth of comprehensive knowledge concerning the amalgamation of various AR technologies with distinct learning strategies to enhance problem-solving competencies. The predominant focus of extant studies is on marker-based AR; nevertheless, alternative modalities such as markerless-based AR, object recognition AR, and location-based AR require further scholarly attention. Although strategies such as GBL and IBL are integrated with AR, the potential for combining AR with an extended suite of learning strategies presents an opportunity to elevate educational outcomes. Furthermore, while certain research indicates that AR is instrumental in developing critical thinking and problem-solving skills, the specific methods of problem-solving incorporated remain underreported. This indicates a lacuna in the comprehensive understanding of the role of AR in facilitating problem-solving within learning processes. Additionally, there is an opportunity to investigate the application of AR in less commonly studied strategies, potentially unveiling new perspectives on student-centric, active learning modalities. In essence, future investigations are poised to probe into novel AR technologies alongside diverse learning strategies and problem-solving methods. Such scholarly endeavors could substantially augment educational practices by promoting a more dynamic and interactive learning environment, thereby nurturing essential skills pivotal for the 21st century learner.

6. Acknowledgment

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