Augmented Reality Learning in Mathematics Education: A Systematic Literature Review

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The main purpose of this study was to review existing studies which are related to the characteristics of AR learning by using Systematic Literature Review (SLR). The following studies identified the implementation of AR in learning mathematics education and other studies that explored the effectiveness of AR learning towards mathematics education. The review was conducted with the processes of identification, screening, eligibility, inclusion and data analysis on five search engines which were Scopus, ProQuest, Springer Link, Science Direct and EBSCOhost. In reporting this study, the PRISMA guidelines were followed. The data were only selected from the included studies which had been sorted and this resulted in a total of 20 articles. Our findings identified that AR learning was implemented in several topics of mathematics which were geometry; algebra; statistics and probability; and others including mathematical modelling and mathematics technology. The effectiveness of AR learning towards mathematics education also included cognitive, affective, and psychomotor effect. This SLR also included research designs and distribution of studies in terms of trend and country.

Keywords: augmented reality, mathematics education, PRISMA, secondary school, systematic literature review

INTRODUCTION

Mathematics is an analytical science that serves as the foundation for all other academic disciplines. Mathematics improves brain function through enhancing problem-solving, critical reasoning and decision-making. A strong mathematical foundation not only leads to excellent academic accomplishment, but also to more efficient day-to-day tasks. Everyone is currently living in the fourth industrial revolution (4IR), in which digitization and automation have become dominant elements in practically all key areas of the global sector including education (Saundarajan et al., 2020). The most popular application of technology in 21st century education especially in mathematics education is Augmented Reality (AR), a technology which fuses virtual materials into a real-time situation or augments reality to facilitate teaching and learning (Saundarajan et al., 2020). It is a 3-Dimensional (3D) technology that creates a contextual layer of information for the user's sensory view of the real world. AR can transform how students study, learn, play and connect mathematics with the world around them. AR is an excellent way to see things that would otherwise be impossible or impractical to see.

The significant functions of AR lead to the implementation of that technology in mathematics education (Cai et al., 2018; del Cerro Velázquez & Morales Méndez, 2021; Elsayed & Al-Najrani, 2021; Suryanti et al., 2020; Zainudin & Ismail, 2020) and science education (Waidi et bal., 2021), language (Lai et al., 2021). The AR technology aims to incorporate the actual environment in the computer and promote it with virtual data, resulting in the student's incorporation between the real situation and the virtual situation generated by the computer (Elsayed & Al-Najrani, 2021). Ozcakir and Cakiroglu (2021) emphasize that AR interfaces provide a variety of virtual dynamic 3D structures to work with as it has potential to increase understanding about concepts to improve students' learning. One of the advantages of AR in mathematics education is its function making the learning interesting with interactive lessons. This reality is relevant as students grasp knowledge more by listening or seeing their visual representation more than by reading it. The visual appearance through the implementation of AR will provide excitement and spark enthusiasm to students to learn topics specifically related to mathematics (Suryanti et al., 2020).

Nowadays, AR has become a popular technology that plays an important role in research education as well as learning mathematics for secondary school students. Integrating technology such as AR can create an interaction between one object and other objects as well as between objects and students during the learning process in the classroom (Lainufar et al., 2021). Students can expand their minds and be exposed to the real world and acknowledge the application of mathematics in real life through AR. Thus, the importance of AR learning in mathematics education helps to build a virtual space which is helpful especially in providing 3D models for real life problems (Cahyono et al., 2020). Most studies on AR in mathematics education have utilised it as a visualisation tool to provide virtual content that is difficult to see in the actual world. Researchers believed that AR can be used to illustrate abstract mathematical concepts (Cai et al., 2018). There are also existing applications in mathematics learning which execute AR such as Autograph, PhotoMath (Saundarajan et al., 2020), Microsoft Math Solver and GeoGebra (Hamzah, & Hidayat, 2022); Lainufar et al., 2021).

In recent years, AR as a learning tool in mathematics education has received a lot of attention, and several studies on the subject have been published. For instance, Saundarajan et al. (2020) implemented PhotoMath in learning mathematics and investigated the effectiveness of the application in enhancing the learning of algebraic equations for secondary school students. The results showed that there was a significant increase in the post-test score of the students after the implementation of PhotoMath in their learning process. In addition, previous research by Cai et al. (2018) integrated tablet-based AR technology in learning the concept of probability and identifying the impact towards students' conception and approaches in learning mathematics. As a result, incorporating the tablet-based AR technology into the classroom may assist students with high self-efficacy in learning mathematics using profound procedures. Those mentioned findings and studies provide a critical summary for understanding the implementation, effectiveness, and prospect of AR in mathematics education for secondary school students.

The major areas of research of the application of AR technology in the context of education are science, geography, arts, engineering and in information and communication technology (ICT). Each research provides a broad understanding of the educational benefits that AR technology may offer in those fields of use. However, the study of AR technology in mathematics education is still on the surface (Alshafeey et al., 2019; Lainufar et al., 2021). There is little recent systematic review which provides detailed relevant work of literature in AR's effectiveness and implementations in mathematics education. For instance, Ahmad and Junaini (2020) performed a review of the literature on types of AR apps and AR development tools mechanisms together with its implementation on mathematics education for 19 sets of final articles. However, their findings only found one implementation of AR in mathematics education and a significant amount of the data point to the development of AR applications in mathematics education. Another review by Godoy (2020) includes studies on AR applications in the fields of education and one of the studies is mathematics education. Yet, the finding merely highlighted the use of AR technology in the geometry classroom and its value in mathematics learning.

Furthermore, Palancı and Turan (2021)'s research concerning the advantages and disadvantages of using AR in mathematics education also included AR effectiveness in the students' learning process. Nonetheless, the study only noted that AR method in learning mathematics was more effective than the traditional method to learn mathematics. In addition, Donnelly-Hermosillo, Gerard, and Linn (2020) conducted a meta-analysis study on the implementation of AR in mathematics through graph technology which resulted in a narrow scope of the study. AR has much potential in mathematics learning, especially when the concepts being taught are difficult to visualise. To bridge that gap, a systematic literature review was conducted to synthesize the related articles about AR learning in mathematics education for secondary school students. Accordingly, the aim of this study was to analyse the implementation and effectiveness of AR technology in learning mathematics. To provide helpful AR technologies in mathematics education, further suggestions would be provided in this study. Specifically, the current review contains the following five (5) research questions:

1. What are the mathematics topics used in implementation of AR?
2. What are the learning outcomes in implementation of AR?
3. What is the research design employed?
4. How are the AR learning studies distributed in terms of publication year?
5. How are the AR learning studies distributed in terms of country?

LITERATURE REVIEW

The rapid growth of technology is leading all the routine systems of human life in a sophisticated and modern way. The current technology allows individuals to access and interact with it through a simulated learning experience. In fact, there is a contemporary form of technology with the function to enhance the realism of such experiences by blurring the line between virtual experiences and reality. This futuristic element of technology is referred to Augmented Reality (AR) which superimposes computer-generated images on the user's real-world perspective. In other words, AR can complement the real-world with virtual objects that appear to coexist in the same space with the real-world. According to Elsayed and Al-Najrani (2021), AR allows the incorporation of digital content effortlessly to realize the user's insight of the physical world, as it is possible to add 2D and 3D forms and incorporate audio, video, and text files. AR uses an existing real-world environment and adds virtual information about it to improve the experience.

The significant functions of AR lead to the implementation of that technology in education. The ability of AR acts as a medium to realize the Education 4.0 concept that is aligned with the fourth industrial evolution to transform the future of education using advanced technology. The AR technology aims to incorporate the actual environment in the computer and promote it with virtual data, resulting in the student's incorporation between the real situation and virtual situation generated by the computer (Elsayed & Al-Najrani, 2021). Ozcakir and Cakiroglu (2021) emphasize that AR interfaces provide a variety of virtual dynamic three-dimensional structures to work with as it has potential to increase understanding about concepts to improve students' learning. One of the fields of Mathematics that requires the use of AR is geometry. For example, SketchUp software is used and able to draw geometrical objects as AR applications can be used to view the objects in 3D perspective. Moreover, AR could be used to teach a lesson related to solid geometry by utilising another software which is GeoGebra. Lainufar et al. (2021) emphasized that learning geometry with GeoGebra made geometry more visual. In addition, AR could be more useful in the algebra field. Saundarajan et al. (2020) highlighted that PhotoMath application has given rise to new dimensions in teaching algebra. PhotoMath can integrate visual math equations into image, understanding algorithms and subsequently solving it effectively. Suryanti et al. (2020) stated that many studies have explored the use of AR technology developed in improving teaching and learning. According to Ozcakir and Cakiroglu (2021), AR is still considered a relatively novel technology in educational fields as it needs research-based guides to design feasible AR tools for school-based learning.

The implementation of the concept AR in education can boost students' motivation to learn. Elsayed and Al-Najrani (2021) stated that AR helps to improve student learning and can stimulate motivation for learners. The approach used by AR which superimposes computer-generated images on the student's real-world perspective will lead the understanding of students towards complex concepts in their studies especially those involving mathematics topics. This situation indirectly will make students eager to learn and more focused as they already understand the contents. The wisdom of teachers to manipulate the function of AR in teaching can avoid students' boredom to continue learning more effectively. Wong and Wong (2021) highlighted that for students to be intrinsically motivated, a lesson's content and a task must be appealing and exciting.

METHODS

To identify the ideas and features of AR learning in mathematics education, we conducted a systematic literature review (SLR). The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Moher et al., 2009) and flow chart was utilized in this review as it was designed to help in synthesising relevant journal articles. Generally, a SLR consists of three phases: planning the review, conducting the review, and reporting. These steps influenced our methodology for performing this review and explained the data collection techniques.

Planning the Review

First and foremost, we discussed the title for this SLR. As the world evolves, modern inventions in the realm of education begin to emerge. Therefore, we made a conscious decision to explore more about AR learning, specifically in the context of mathematics education for secondary school. The appropriate keywords obtained from the title to conduct the review were secondary school, AR, and mathematics education. These keyword terms were then combined with Boolean operators of "OR" and "AND" to form a search string that is used in the identification process as a literature search strategy. The literature search strategy is shown in Table 1.

TABLE 1
LITERATURE SEARCH STRATEGY

Keyword	The strings and combinations of keywords
Augmented reality	("augmented reality learning" OR augmented reality") AND
Mathematics education	("Mathematics education" OR "mathematics") AND
Secondary school	("secondary school" OR "middle school" OR "high school" OR "senior high school")

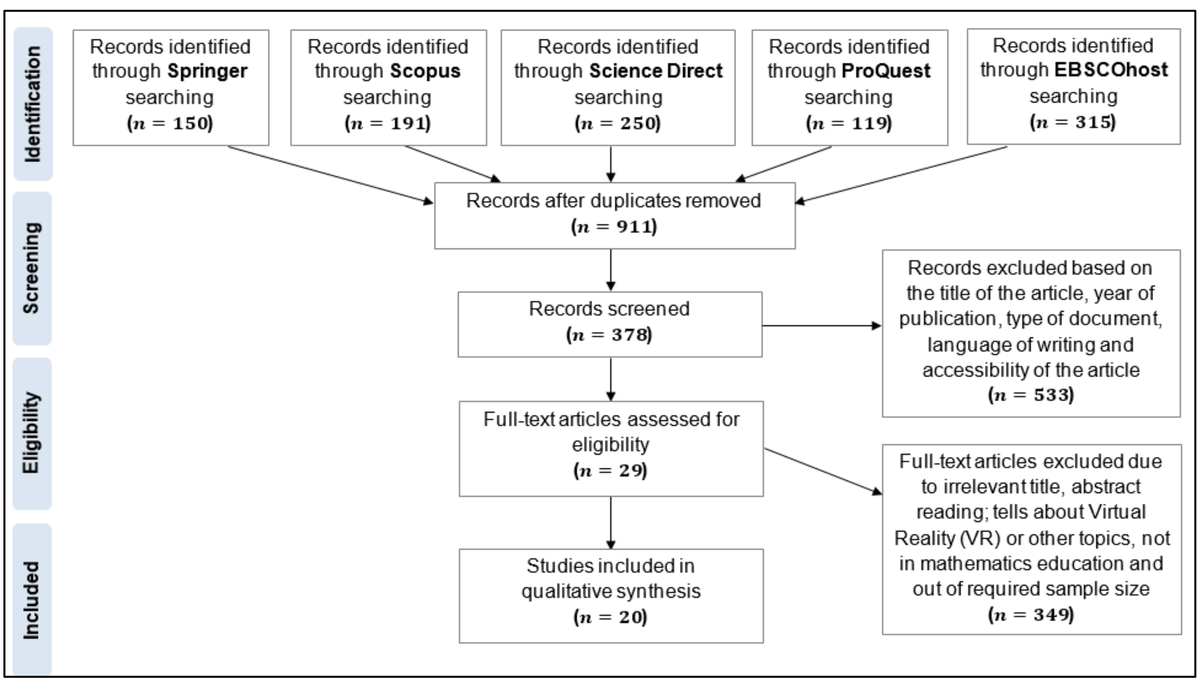
Conducting the Review

The next step in the phase was to continue to search the relevant articles by using PRISMA statements. This stage contributed to the data collection tools where the data from existing data were collected from a research journal. The PRISMA selection process consisted of four stages which were identification, screening, eligibility and included.

Identification

The identification phase was started by searching for relevant article to be reviewed. The search was conducted through Scopus, Springer Link, and Science Direct and this was done using the keywords in Table 1 which were (("augmented reality learning" OR augmented reality") AND ("mathematics education" OR "mathematics") AND ("secondary school" OR "middle school" OR "high school" OR "senior high school")). However, due to the small number of articles obtained, we expanded the search engine to include ProQuest and EBSCOhost databases. Furthermore, these databases offer a variety of features to refine search results related to the topic. For this stage, we only used the listed keywords to numerate the results from each search engine. The results identified through Springer Link was 150, 191 results through Scopus, 250 results from Science Direct, 119 results from ProQuest, and 315 results obtained from EBSCOhost database. The last search was done on 9 November 2021, and the total came up to 1025 results to be filtered. The flow of this PRISMA protocol is shown in Figure 1.

FIGURE 1
PRISMA PROTOCOL FLOW CHART



Screening

The screening stage was conducted by removing the duplicates between the results from identification. From the list of results, 114 results were found to be a duplication of other studies. Using the flow chart of PRISMA protocol, those results were removed. After that, we started to sort out the data based on the title of the article, year of publication, type of document, the language, and the accessibility of the articles. The title for the articles should be related to our topic which was AR learning in mathematics education for secondary schools such as Learning Algebra using AR: A preliminary investigation on the application of PhotoMath for lower secondary education (Saundarajan et al., 2020). The year of publication was set to the range of between 2017 and 2022 to gather relevant and up-to-date studies, as technological advancements or augmented realities are believed to develop rapidly. The type of document chosen was only for original studies which were published in scholarly journals. Trade journals, magazines, book, newspaper, conference paper and others were excluded. The language was set in English to standardize the studies and the accessibility was limited to the full-text articles with free access. This sorting process was done through each search engines and the details were declared in the criteria of inclusion and exclusion as in Table 2.

Eligibility

533 results from the previous stage were excluded because they failed to meet the requirements for our review. Therefore, the remaining 378 results were moved to this step, which involved determining the eligibility. This stage required all authors' cooperation to check the details manually guided by the abstract of the articles. We divided the articles evenly among the authors to minimize the time and ensure that everyone could identify the needs of our review. The criteria that we looked for were the relevant titles, related to topics, and suitability with our sample target. From this stage forward, we identified several criteria that did not meet the criteria for our review, including an irrelevant title, studies that did not focus on AR but rather virtual reality, studies not related to mathematics education but rather science, engineering, and other fields, and studies outside of the sample size we required, which was a secondary school. This stage resulted in a total of 29 articles which were eligible to be included in our review as shown in Figure 1.

Included

From the previous stage, a total of 20 studies were selected to be included in this review based on our inclusion criteria for this systematic literature review as in Table 2 below.

TABLE 2
CRITERIA OF INCLUSION AND EXCLUSION

Criteria	Inclusion	Exclusion
Article title and content	Appropriate title and met the requirements of the study	Irrelevant title and did not meet the requirements of the study
Year of publication	Publications from 2017 to 2022	Publications other than the specified range
Type of publication	Original studies and journal article type only	Reviews, editorials, and non-empirical studies
Language	English	Others
Field of article study	Mathematics education	Other than mathematics education
Sample size	Secondary school student	Out of the specified sample size
Accessibility	Full-text articles	Preview articles and required a payment

The validity and reliability of study were dependent on the quality of the included articles as well as the technique used to perform the review. A strict outline flow from the PRISMA protocol followed by the inclusion criteria is a method to improve the validity and reliability of data by decreasing the risk of bias.

These selected articles were reviewed to determine prior studies' grasp of AR, its advantages, and disadvantages in learning, and to support authors in analysing the research question for the findings in the reporting segment.

Reporting

The results of data acquisition from previous studies were analysed and reported in this systematic literature review. The reporting segments required us to prepare the matrix of included prior studies, abstract of literature review, introduction, research question, theoretical foundation, methodology, findings, discussion, and a conclusion, as well as a list of references. The matrices were used to identify the basic information from each article that are utilised in this review. The abstract was developed to provide an overview of the topic and the fundamentals of our review. We prepared the introduction to emphasize the importance of this topic and how it correlated to the previous studies that we decided to study. The SLR would be incomplete without research questions, so we compiled a list of six questions to be determined in our findings. The theoretical foundation was constructed to elaborate the review and applicable issues obtained.

The findings for this review were conducted with the aim of answering every research question. Those included articles were studied and the suitable results were listed down. From the results of study, some of them were presented as a table, graph, and by explanation. These steps were believed to enhance the flow of review where there would be no research question left behind. Continuing from the findings, we discussed the summary of main findings. As there were six partitions in the findings caused by six questions, we only highlighted the most significant findings related to the objectives. The strengths and weaknesses of this study were also listed since this review could be improvised over the years. To fix the error, comparisons between previous studies were stated to give a general overview to what degree this study achieved the objectives. To conclude, we listed the limitations which were observed while undergoing this review as to give a vivid idea to others for further improvement. Finally, we concluded this review by justifying the significance of the findings and sharing possible recommendations to be implemented in further study. These steps on reporting were designed to ensure that the prolonged learning was implemented and referred to by other researchers.

Data Analysis

This SLR applied the meta-analysis method to analyse the studies. The meta-analysis method enables results to be presented by combining and analysing data from different studies conducted on similar research topics (Ahn & Kang, 2018). The relevant results and data from previous studies are collected and used in completing the literature review. Most importantly, the data or results obtained would be used to answer the research question. This review focused on combining and relating the findings from multiple articles findings and seeking for ways to improve from previous research. Apart from that, we applied thematic analysis which is known as a method of identifying patterns or themes within qualitative data (Nowell et al., 2017). The data were selected from the included studies which were sorted previously resulting in a total of 20 articles. The process of analysing involved the country the paper was published in, since we wanted to have a diversified viewpoint. We include the associated theory as we wanted to relate how the theory fits the mathematical education area. We also included the research design as we wanted to identify the type of studies which could be performed related to AR learning. All these details or data were collected from the abstract, introduction, methodology, results, and discussion of the studies. These types of findings were classified as qualitative data where we sought the description and explanation from the studies to interpret and integrate them in our review topic.

RESULTS

The above-mentioned systematic review procedure yielded the findings in this section, which were organized based on different years, different nations and research design and topics that prompted our review and analysis. Based on the total number of AR learning in mathematics education analysed studies published between 2017 and 2022, the following subsections provided answers to the designated research question.

The Mathematics Topics Used in Implementation of AR

The first research question was concerned with the mathematics topics used in implementation of AR. The systematics analysis was undertaken on twenty (20) selected articles resulting in four common branches of mathematics which are: geometry; algebra; statistics and probability; and others including multivariable calculus, mathematical function, and mathematical modelling. These subfields reveal the implementation of AR in learning mathematics, according to this study.

TABLE 3
SUBFIELDS OF IMPLEMENTATIONS OF AR IN LEARNING MATHEMATICS

Author(s)	Geometry	Algebra	Statistics and Probability	Others
Ozcakir & Cakiroglu (2021)	/			
Batubara et al. (2022)	/			
del Cerro Velázquez & Morales Méndez (2021)				/
Suryanti et al. (2020)		/		
Smith (2018)	/			
Medina Herrera et al. (2019)				/
Fatimah et al. (2019)	/			
Aldalalah et al. (2019)	/			
Elsayed & Al-Najrani (2021)	/			
Wong & Wong (2021)	/			
Mailizar& Johar (2021)	/			
Lainufar et al. (2021)	/			
Saha et al. (2020)				/
Ibáñez et al. (2020)	/			
Saundarajan et al. (2020)		/		
Cahyono et al. (2020)				/
Sandoval-Henríquez & Badilla-Quintana (2021)				/
Cai et al. (2019)			/	
Cai et al. (2018)			/	
Mulbar et al. (2021)	/			
Total	11	2	2	5

According to Table 3, eleven (11) of the studies included in this review conducted AR in learning geometry for secondary school students. Based on analysed study, AR interface was designed as a learning toolkit using mobile devices to identify the characteristics and structures of three-dimensional (3D) objects among spatial students (Ozcakir & Cakiroglu, 2021), learning geometric shapes like circle, cylinder, ellipse, hyperbola, prism also area and volume (e.g., Aldalah et. al, 2019; Batubara et. al, 2022). In addition, most of the studies found that AR was utilised in dynamic geometry software (Wong & Wong, 2021) such as Geometer's Sketchpad and GeoGebra (Lainufar et al., 2021; Mailizar & Johar, 2021). Two (2) of the studies demonstrated the implementation of AR in learning algebra for secondary school students with different countries and different applications. Recent studies by Suryanti et al. (2020) have put into practice AR technology in integer learning as a form of students' activity in the classroom. AR technology also has been implemented through algebra learning by using PhotoMath application (Saundarajan et al., 2020).

A further review on the selected articles concerning the implementation of AR in mathematics learning revealed that two (2) studies were implemented in the learning of statistics and probability. In studies by Cai et al. (2018) and Cai et al. (2019), the researchers introduced an AR application on a tablet for the students to explore probability concepts in the classroom. There were three (3) AR applications used by students in their lesson to allow students to have conceptual understanding about empirical probability and theoretical probability. From the 20 articles included in this review, five (5) of the articles were out of the common subfields which were mentioned before. In detail, these articles discussed the implementations of AR in mathematics learning such as multivariable calculus, mathematical function, and mathematical modelling. Recent research done by Cahyono et al. (2020) integrated AR-MobileMathTrails programme that encouraged students to participate in mathematics education and to learn mathematical modelling through outdoor activities. Also, AR was implemented as learning tools by integrating it into 3D tools to learn calculus and functions which consist of cognitive transition of graph such as linear, quadratic, exponential, and logarithm (del Cerro Velázquez & Morales Méndez, 2021).

The Learning Outcomes in Implementation of AR

In addition to the extrapolated findings given in this study, a configurative examination was conducted on the 20 articles. This would offer a deeper layer of understanding beyond the data presented in the systematic review, indicating the effectiveness of AR learning which could add further insight into AR learning in mathematics education for secondary school students. The effectiveness of implementing AR learning in mathematics education can be classified based on Bloom's Taxonomy. Table 4 represents a list of selected studies classified into cognitive domain, affective domain, and psychomotor domain.

TABLE 4
DOMAIN CLASSIFICATION OF THE EFFECTIVENESS OF AR LEARNING IN MATHEMATICS EDUCATION

Author(s) (Year)	Effect		
	Cognitive	Affective	Psychomotor
Ozcakir & Cakiroglu (2021)	/		/
Batubara et al. (2022)			/
del Cerro Velázquez & Morales Méndez (2021)	/	/	
Suryanti et al. (2020)	/	/	
Smith (2018)	/		/
Medina Herrera et al. (2019)	/		
Fatimah et al. (2019)	/	/	
Aldalalah et al. (2019)	/		
Elsayed & Al-Najrani (2021)	/	/	
Wong & Wong (2021)		/	
Mailizar & Johar (2021)		/	
Lainufar et al. (2021)	/	/	
Saha et al. (2020)		/	
Ibáñez et al. (2020)	/	/	
Saundarajan et al. (2020)	/	/	
Cahyono et al. (2020)	/		/
Sandoval-Henríquez & Badilla-Quintana (2021)	/		
Cai et al. (2019)	/	/	/
Cai et al. (2018)	/	/	
Mulbar et al. (2021)	/		
Total	16	12	5

Based on Table 4, from a total of 20 articles analysed in this review, eight (8) of the articles only discussed the effectiveness of implementing AR learning which focused on one (1) domain only, specifically as the cognitive domain ($N = 4$), affective domain ($N = 3$) and psychomotor domain ($N = 1$). The number of articles which examined the effectiveness of AR learning in mathematics education for two (2) domains were eleven (11): ten (10) articles focused on cognitive domain, another ten (10) articles focused on affective domain and three (3) articles emphasised on psychomotor domain. Furthermore, only one (1) article focused on all the domains to study the effectiveness of AR learning.

Generally, the cognitive domain involves the development of intellectual skills. This involves recalling or recognising certain facts, procedural patterns, and concepts which assist in the development of cognitive abilities and skills (Clark, 2015). In the context of effectiveness of AR learning, cognitive effects can be categorised into three (3) components which are conceptual, procedural and achievement. Table 5 below shows the list of articles which have been classified according to the cognitive effect.

TABLE 5
THE EFFECT OF AR LEARNING ON COGNITIVE DEVELOPMENT

Author(s) (Year)	Cognitive Effect		
	Conceptual	Procedural	Achievement
Ozcakir & Cakiroglu (2021)		/	
del Cerro Velázquez & Morales Méndez (2021)	/	/	
Suryanti et al. (2020)	/		
Smith (2018)	/		
Medina Herrera et al. (2019)	/	/	
Fatimah et al. (2019)	/		
Aldalalah et al. (2019)	/		/
Elsayed & Al-Najrani (2021)		/	
Lainufar et al. (2021)		/	
Ibáñez et al. (2020)			/
Saundarajan et al. (2020)			/
Cahyono et al. (2020)	/		
Sandoval-Henríquez & Badilla-Quintana (2021)	/		
Cai et al. (2019)	/		/
Cai et al. (2018)	/		
Mulbar et al. (2021)	/		/
Total	11	5	5

Based on Table 5 above, most articles review the effectiveness of AR learning for the conceptual understanding in learning mathematics ($N = 11$), followed by reviewing the students' achievement ($N = 5$) and procedural understanding ($N = 5$). The results of the analysis based on conceptual knowledge found that AR-based learning media can help students understand integer material, solve integer problems in daily life, utilize mathematical concepts of algorithm and can contribute to increasing students' critical thinking skills (Medina Herrera et al., 2019; Suryanti et al., 2020). Fatimah et al. (2019) advocated that multimedia-based AR in mathematical materials can facilitate students' understanding in learning mathematics concepts. In addition, the application of AR technology aids students in the mathematical modelling process, generate mathematical function particularly at the stage of comprehending real-world situations (Cahyono et al., 2020; del Cerro Velázquez & Morales Méndez, 2021).

In the context of procedural knowledge, AR-based multimedia can improve spatial ability and intelligence by using AR application practically (del Cerro Velázquez & Morales Méndez, 2021; Ozcakir & Cakiroglu, 2021), facilitate student's imagination and visualisation (Elsayed & Al-Najrani, 2021) and improve students' visual-spatial ability (Lainufar et al., 2021). For other cognitive effect which involved achievement, AR-based technology was effective in increasing student's achievement and visual thinking (Aldalalah et al., 2019) and led to high academic performance between high-engagement learning students. Ibáñez et al. (2020) stated that students who used AR applications had performed significantly compared to the students who used web-based applications. Furthermore, AR-based technology also enhanced the learning of algebraic equation (Saundarajan et al., 2020), increased engagement of secondary school students in the probability learning process (Cai et al., 2019) and achieved the learning outcome in mathematics learning (Mulbar et al., 2021).

Subsequently, affective domain can be defined as the way individuals deal with things emotionally (Clark, 2015). There are two (2) main components of affective effect that can be classified from the selected studies which are attitude and motivation. The following table shows the effectiveness of AR learning in mathematics education based on affective effect.

TABLE 6
THE EFFECT OF AR LEARNING ON AFFECTIVE DEVELOPMENT

Author(s) (Year)	Affective Effect	
	Attitude	Motivation
del Cerro Velázquez & Morales Méndez (2021)		/
Suryanti et al. (2020)	/	
Fatimah et al. (2019)		/
Elsayed & Al-Najrani (2021)		/
Wong & Wong (2021)		/
Mailizar & Johar (2021)	/	
Lainufar et al. (2021)	/	/
Saha et al. (2020)		/
Ibáñez et al. (2020)		/
Saundarajan et al. (2020)	/	
Cai et al. (2019)	/	
Cai et al. (2018)		/
Total	5	8

According to the table, five (5) of the included articles demonstrated the effectiveness of AR learning on students' attitude whereas eight (8) of the included studies emphasised on the effectiveness of AR learning towards students' motivation. A systematic review on students' attitude after the intervention of AR learning revealed that AR-based technology learning had increased students' interest and enthusiasm for learning mathematics (Suryanti et al., 2020). Further review on the selected articles found that AR learning influenced students' motivation in learning mathematics. This can be discovered in a recent study by Fatimah et al. (2019) stating that mathematical material which executed AR-based technology could increase students' motivation and challenges. Similarly, AR-based technology promotes students' motivation which can enhance them to acquire mathematics knowledge (del Cerro Velázquez & Morales Méndez, 2021; Elsayed & Al-Najrani, 2021), increase learning motivation by using interactive technology (Lainufar et al., 2021), reduce students' level of mathematics anxiety (Saha et al., 2020) and aid students with high self-efficacy in learning mathematics by encouraging them to employ deep techniques (Cai et al., 2018).

In terms of the psychomotor perspective, the psychomotor domain is the competence to carry out something by involving the body parts as well as competencies related to physical movement and motor-skills. This includes reflex movements, perceptual abilities, complex, expressive, and interpretive skills (Clark, 2015). The psychomotor effect can be categorised into two (2) components which are verbal and physical and articles which study the significant effect of AR learning in mathematics education are listed in the table below.

TABLE 7
THE EFFECT OF AR LEARNING ON AFFECTIVE DEVELOPMENT

Author(s) (Year)	Psychomotor Effect	
	Verbal	Physical
Ozcakir & Cakiroglu (2021)	/	
Batubara (2022)	/	
Smith (2018)		/
Cahyono et al. (2020)		/
Cai et al. (2019)	/	/
Total	3	3

Based on the above-mentioned table, three (3) of the articles listed reviewing student development in terms of verbal and physical movements. Studies have found that AR technology which integrates with body-based activities is more effective during learning mathematics (Smith, 2018). Students also gained mathematical modelling experience practically when they used the AR-based technology outside the classroom and allowed students to bridge the real-world situation with mathematical concepts (Cahyono et al., 2020). Furthermore, research found that AR-based applications encouraged students to participate actively in exploring the relationship between mathematics concepts (Cai et al., 2019) which can result in development of mathematical communication skill (Batubara et al., 2022). Next, in the context of verbal development, studies show students diligently practisee a variety of social practices. Students who participated in AR learning can explain their findings about a particular topic in mathematics with their friend by using their own terminology (Ozcakir & Cakiroglu, 2021).

Research Design Employed

The third research question was concerned with the research design related to AR learning employed in mathematics education setting. As seen in Table 8, it was recorded that 15 studies focused on quantitative analyses (Aldalalah et al. 2019; Batubara et al. 2022; Cai et al. 2019; Cai et al. 2018; del Cerro Velázquez & Morales Méndez 2021; Elsayed & Al-Najrani 2021; Ibáñez et al. 2020; Lainufar et al. 2021; Mailizar & Johar 2021; Saha et al. 2020; Sandoval-Henríquez & Badilla-Quintana 2021; Saundarajan et al. 2020; Suryanti et al. 2020; Smith 2018; Wong & Wong 2021). Meanwhile, another two studies focused on mixed methods approach (Medina Herrera et al. 2019; Mulbar et al. 2021) and two studies included educational design research (EDR) (Fatimah et al. 2019; Ozcakir & Cakiroglu 2021). One study employed the qualitative analyses (Cahyono et al. 2020).

TABLE 8
THE RESEARCH DESIGN EMPLOYED

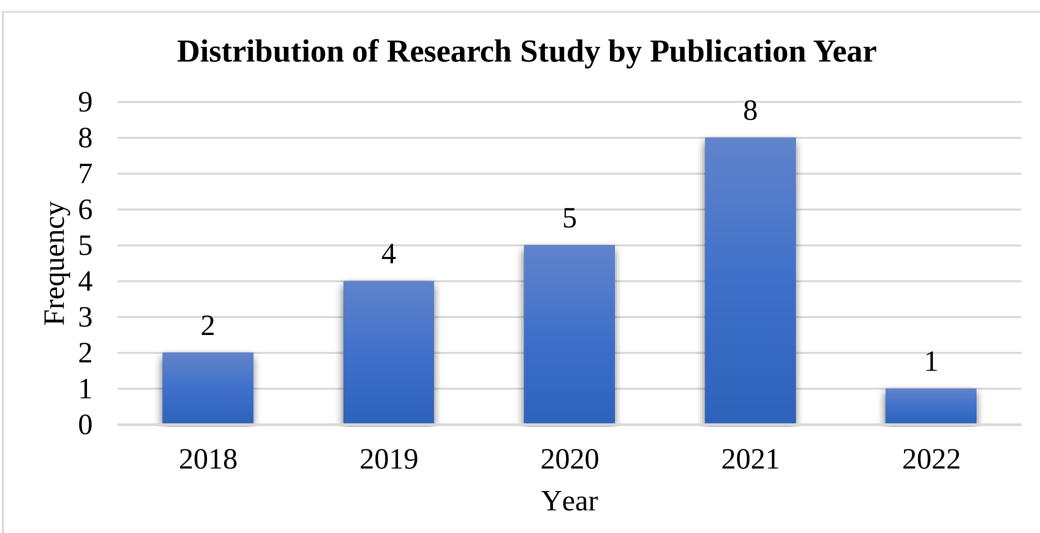
Author(s) (Year)	Research Designs
Ozcakir & Cakiroglu (2021)	Educational design research (EDR)
Batubara et al. (2022)	Quantitative
del Cerro Velázquez & Morales Méndez (2021)	Quantitative
Suryanti et al. (2020)	Quantitative
Smith (2018)	Quantitative
Medina Herrera et al. (2019)	Mixed methods
Fatimah et al. (2019)	Educational design research (EDR)
Aldalalah et al. (2019)	Quantitative
Elsayed & Al-Najrani (2021)	Quantitative
Wong & Wong (2021)	Quantitative

Mailizar & Johar (2021)	Quantitative
Lainufar et al. (2021)	Quantitative
Saha et al. (2020)	Quantitative
Ibáñez et al. (2020)	Quantitative
Saundarajan et al. (2020)	Quantitative
Cahyono et al. (2020)	Qualitative
Sandoval-Henríquez & Badilla-Quintana (2021)	Quantitative
Cai et al. (2019)	Quantitative
Cai et al. (2018)	Quantitative
Mulbar et al. (2021)	Mixed methods
Total	20

Distribution of Research Study by Publication Year

The fourth research question was concerned with the publication year. Altogether, there were a total of 20 articles published between 2017 and 2022 which concerned AR learning in mathematics education for secondary school students. Figure 2 demonstrates the analysed study of distribution according to their publication year. It is noteworthy that the interest in AR learning has increased through the years. Overall, existing studies related to AR learning in mathematics education for secondary school have increased starting from 2018, 2019 and 2020 with two (2) articles published in 2018, four (4) articles published in 2019 and five (5) articles published in 2020 resulting in a total of eleven (11) articles published. Research in the implementation of AR in the education field especially in mathematics is considered as a new approach from the previous number of studies which were determined. Additionally, there was a rapid increase in the number of articles published in 2021 with eight (8) articles. However, in early 2022, only one (1) article was published. From the increase, it could be indicated that the interest among researchers was growing towards the implementation of AR in learning mathematics (Cahyono et al., 2020). The increased number of studies in terms of publication year could be analysed after finding the effectiveness of AR approach towards learning especially in mathematics by allowing students to have a better exposure of learning outcomes in real life (Mulbar et al., 2021).

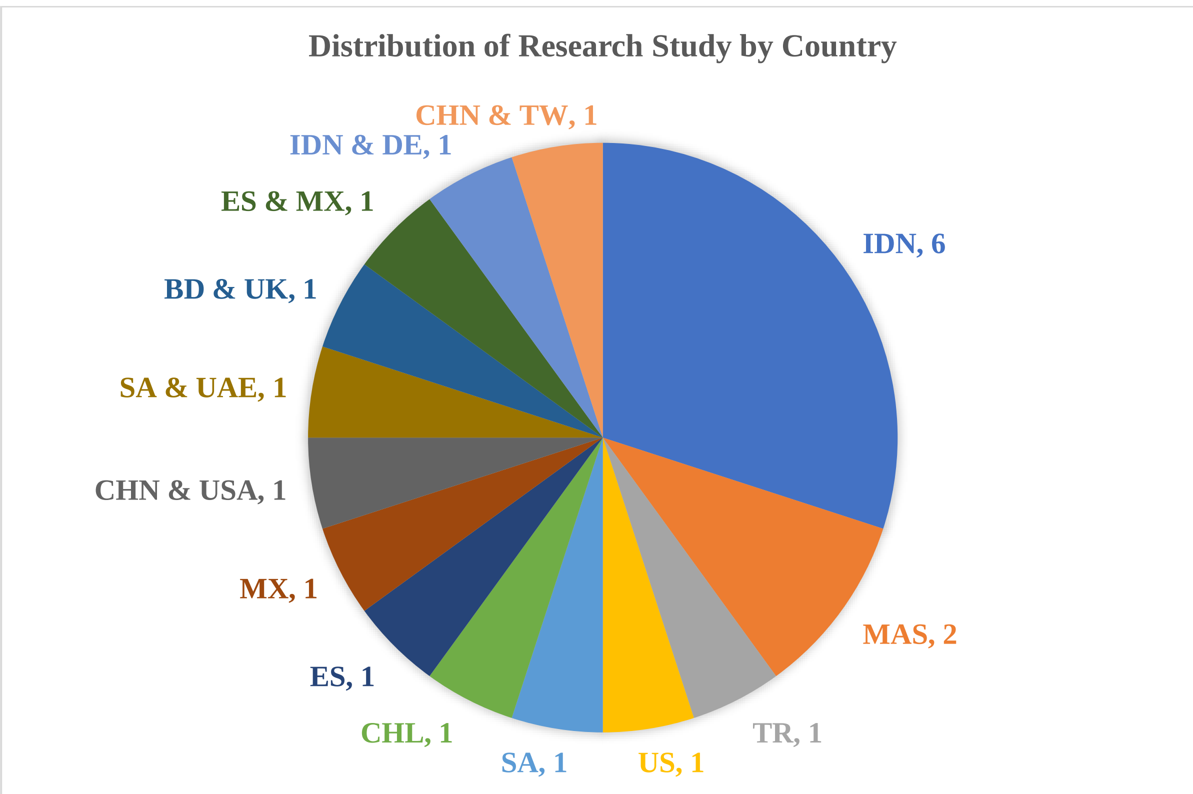
FIGURE 2
DISTRIBUTION OF RESEARCH STUDIES BY PUBLICATION YEAR



Distribution of Research Study by Country

The fifth research question was concerned with the AR learning studies distributed in terms of country. Figure 3 represents the publication of selected studies by identifying the rest of the countries where each study was conducted. It was found that Indonesia had the greatest number of studies followed by Malaysia with six (6) and two (2) articles respectively. However, the least numbers of research studies could be observed in other countries with only one article for each country, such as Turkey, United States, Saudi Arabia, Chile, Spain, Mexico, China & United States of America, Saudi Arabia & United Arab Emirates, Bangladesh & United Kingdom, Spain & Mexico, Indonesia & Germany, and China & Taiwan. Note that several articles consist of more than one country where the studies were conducted. By these outcomes, it can be concluded that there was a great enhancement of revealing the purpose of AR learning in mathematics among researchers in Indonesia and Malaysia focusing on secondary education. Thus, this interesting discovery of learning approaches demands further research in various countries all over the world (Cahyono et al., 2020).

FIGURE 3
DISTRIBUTION OF RESEARCH STUDY BY COUNTRY



IDN	:	Indonesia	UK	:	United Kingdom
MAS	:	Malaysia	BD	:	Bangladesh
CHN	:	China	TW	:	Taiwan
USA	:	United States of America	ES	:	Spain
TR	:	Turkey	MX	:	Mexico
US	:	United States	DE	:	Germany
SA	:	Saudi Arabia	CHL	:	Chile
UAE	:	United Arab Emirates			

DISCUSSION

In this systematic review, we screened 911 articles from five (5) search engines and selected 20 studies which were related to the field of AR learning in mathematics education involving secondary school students. Concerning the mathematics topics used in the implementation of AR, this review found that AR based media had been widely implemented in the field of mathematics such as geometry, algebra, statistics, and probability also in other subfields as reported in findings. This was supported by Cahyono et al. (2020) who stated that AR provided the opportunity to indulge in real objects which were manipulated into images or symbols. In line with previous research in Ibáñez et al. (2020), it was indicated that by implementing the application in learning geometry, students could choose among different options that were performed with image targets in ARGeo, and they were able to visualize 3D figures from any point of view in real time when using the application. Similarly, Saundarajan et al. (2020) demonstrated that the implementation of AR through algebra learning using the PhotoMath application could be used by students to learn algebraic equations through harnessing state-of-the-art text recognition and image understanding. This was considered an interesting approach for mastering algebra. Furthermore, in a study by Cai et al. (2018), AR was used in the field of statistics and probability to help students recognise probability in the real world by placing the designed AR card in front of the camera, as well as to teach students to recognise sample spaces of equally likely probability occurrences and to allow students to have a conceptual understanding of empirical probability and statistics.

Bloom's Taxonomy indicates that the classification of effectiveness is in the domain of cognitive, affective, and psychomotor. Concerning our second research question, this study found that mathematics relied upon cognitive domain as it consisted of several aspects: knowledge, comprehension, application, analysis, synthesis, and evaluation which were crucial in learning (Syahtriya Ningsih et al., 2019). Thus, this study discovered significant influence on students' interest through the implementation of AR learning by its ability to apply visualisation in mathematics, while allowing students to keep up with technology advancements. On the other hand, the affective domain plays a role in enhancing the effectiveness of AR in learning as previous studies found that AR-based technology promotes student's motivation which can enhance them to acquire mathematics knowledge (Elsayed & Al-Najrani, 2021), increase learning motivation by using interactive technology (Lainufar et al., 2021), reduce student's level of mathematics anxiety (Saha et al., 2020) and aid students with high self-efficacy in learning mathematics by encouraging them to employ deep techniques (Cai et al., 2018). Along with that, studies also found that AR technology integrated with body-based activities was more effective during learning mathematics (Smith, 2018). This psychomotor domain contributed to the strong improvement towards engagement between secondary school students in the mathematical learning process (Cai et al., 2019).

In discussing the issue of research quality, the effectiveness of learning was classified in three domains: cognitive, affective, psychomotor. Nevertheless, only one study included all domains in their research, which was by Cai et al. (2019), who explained that the impact of AR on concept understanding was investigated using a psychological framework of AR learning. This framework included three dimensions in the teaching and learning process: physical, cognitive, and contextual. The authors also stated that it was worthwhile to note that AR could aid students in understanding figurative language in the cognitive dimension. Whereas, in the study of Saha et al. (2020), they identified that students could develop a strong positive attitude toward mathematics because of AR, which assisted them in overcoming their mathematics fear by only involving affective domain in the research. Due to this, this review experienced a data imbalance in measuring the effectiveness of AR learning in mathematics education due to the lack of dominant emphasis contributing to the findings of the review.

In other cases, the usage of learning theories in each selected research paper contributed to the connection between AR learning and secondary school mathematics learning. Each article employed a different learning theory; for instance, Ibáñez et al. (2020) characterised constructivism as a learning theory in which learners could use AR technology to actively encounter digital content and incorporate new information into their existing knowledge base, allowing them to embark on a personalized path of discovery. As a result, AR can be a great tool for constructivist learning. Meanwhile, through the writings of Cahyono et al. (2020), Liu et al. (2019) stated that students could quickly make connections between real-life events and relevant mathematics issues. As a result, as explained by Kaiser (2007)'s theory, students could model real-world situations in more rigorous mathematics. These learning theories demonstrate a real link between the use of AR and the learning process of students. Due to this, even though there were discrepancies in learning theory throughout the paper, the findings of the study remained unaffected if the arguments for the incorporation of AR learning in mathematics learning were supported. Therefore, researchers utilised a learning theory as one of the study findings to determine the breadth and depth of it used in all research papers.

Based on the research design employed, most researchers employed quantitative research design as their primary method of doing research in more than half of the research publications. This strategy was considered in 15 articles as one of the efforts to ensure that researchers had a larger sample size to achieve an accurate generalised conclusion connected to AR in secondary school mathematics learning. Meanwhile, the authors of two selected publications employed the educational design study (EDR) technique to conduct research on the application of AR in mathematics learning to obtain a better knowledge of the problem before designing and testing a prototype solution. Following that, two of the three articles employed a mixed method approach to conduct their research, while the other used a qualitative research design approach. Medina Herrera et al. (2019) and Mulbar et al. (2021) utilised the mixed method research design to demonstrate that they combined elements of qualitative and quantitative research approaches for the broad purposes of understanding and corroborating the use of AR learning in mathematics education. Finally, the author Cahyono et al. (2020) used a qualitative research design technique to illustrate that they focused on acquiring data through open-ended and conversational communication to learn more about the implementation of AR in mathematics education.

The fourth research question is related to the AR learning studies distributed in terms of the publication year. By 2022, various research topics had been conducted around the world. Consequently, this study also identified AR learning studies distributed in terms of publication year. As applied in the screening process in organising the databases, the publication year of studies had been set in the interval of 2017-2022. The results identified that studies related to AR in learning mathematics among secondary school students, had shown a consistent increment in each year of publication. Based on the 20 articles reviewed, we acquired journals starting in 2018 to 2022 without gaps. Although 2022 had only recently started, one (1) article had been published which was an article by Batubara et al. (2022). As mentioned in the limitation of study, in the early stages of the production of this SLR, it was difficult to obtain related articles because the field of AR was still a new discovery among researchers. However, the uniform increase of the number of publications which started with two (2) articles in 2018, four (4) in 2019, five (5) in 2020, and then eight (8) in 2021, proved that this topic had gradually gained attention of researchers and this study could become one of the contributors for future studies in determining the effectiveness and the application of AR in mathematics learning.

Regarding the geographical distribution of writers, the findings revealed that the leading authors who developed the modeling task were in Indonesia, followed by Malaysia, and a few studies had been conducted in China, USA, Turkey, USA, Saudi Arabia, United Arab Emirates, United Kingdom, Bangladesh, Taiwan, Spain, Mexico, Germany, and Chile. From these findings, we could identify the various countries which contributed to AR-related research in mathematics learning. However, these countries were mostly found with only one study each. This suggested that a lack of awareness among the researchers to investigate the contribution of AR to mathematics learning especially in the current wave of world technological development. To support the statement, based on 20 articles which had gone through the screening process and so on, six (6) of them were from Indonesia. This explained that the context of AR had been brought to the center by researchers in the country. Meanwhile, two (2) journals from Malaysia showed that Malaysia had followed the development of knowledge related to AR to meet the Malaysian Mathematics Curriculum which emphasized on the development of problem-solving abilities as a crucial element of mathematics education (Leong, 2013). However, it was still not sufficient to confirm the relevance and advantages of AR adaptation in school learning.

CONCLUSION

As a recap, this review had examined all the research questions. The implementation of AR learning in mathematics education was identified in geometry, algebra, statistics and probability, mathematical l, and graphics. Following that, the most frequent domain indicated in this study was cognitive learning, which was found to have an influence on the effectiveness of AR learning in mathematics education. Next, the distributions of research study by the main theory consisted of eight theorems with no recurrence, and most of the studies did not include learning theorems in their study. On the contrary, no specific theory had been discovered as the best fit for this learning. The effectiveness of AR in improving students' skills, the contributions of AR in student achievements, and the future work plan in enhancing AR in mathematics learning were the three main themes concluded in the distribution of research articles. In the previous two years, the distribution of study research by publication years had grown. The topic's exposure was believed to be the cause of the growth. In accordance with the last research question, Indonesia seemed to be leading the way in terms of research studies on AR learning in mathematics education, followed by Malaysia. This provided Malaysia with a tremendous opportunity to broaden the field of study for this related issue. All the research questions had been thoroughly investigated, and the objectives of the review had indeed been achieved.

Obviously, it can be concluded that AR was an efficient and valuable tool which could be utilised in education specifically towards mathematics education comprehensively. Aldalalah et al. (2019) emphasized that AR was effective in promoting better learning of mathematics and visual thinking skills as it should be integrated into all courseware on the learning of mathematics. The findings of this SLR provided considerable benefit to the application of AR learning in mathematics education; for instance, it provided educators with ideas for implementing the AR concept in mathematics education for various subfields, gave teachers the opportunity to transform teaching aids by incorporating it in education to make it more appealing to students, and encouraged more researchers to conduct AR studies to gain a deeper understanding of the effectiveness of AR in mathematics education.

RESEARCH LIMITATION

In terms of the findings, it can be acknowledged that this study had various strengths which could improve the study's quality. For instance, the use of numerous databases by five (5) search engines, ensured that the article discovery included all studies while the desired inclusion and exclusion criteria were clearly established, ensuring that the article filtering fit the requirements of the title for the SLR. Furthermore, the data from the attached study was accurately extracted based on the study's objectives, which were established at the outset. The researcher thoroughly analysed 20 publications to ensure that the information obtained fit the SLR objectives and addressed each research question. Contrary to the strength values, the flaws of this review were the content in the articles included. Despite the fulfilment of the criteria for inclusion and exclusion, certain articles were deemed to be inapplicable for the findings due the restricted view in extracting data relevant to the research question. Besides, most of the primary studies included were from Indonesia. Hence, the findings may not be generalized to Malaysian mathematics education. This gap, on the other hand, might be considered as an opportunity to introduce a new learning method in Malaysia.

After all, the execution of this systematic literature review was limited to several contexts. The first limitation was the limited number of articles accessible to study. Additionally, the implementation of systematic literature review related to this topic in a similar context by other researchers was also limited and lacking. As AR learning is infrequently studied in the field of mathematics education, the results obtained were constrained, making it difficult to make broad inferences. On the other hand, there are a few studies that merely discuss the surface of the application and effectiveness of AR learning in mathematics education in their research without providing an in-depth explanation. Therefore, the findings for this review were limited to several other studies that had explicit elucidation. In addition to what has been stated, AR topics have limited studies, hence the exclusion of duplicate articles between search engines reduces the acquisition of interesting research studies. In fact, there are various studies which focus more on the usage of AR in mathematics education involving higher education students rather than secondary school students. This reality is important as it is realistic to implement the usage of AR in education as early during school time to ensure that individuals are more proactive and skilled in utilizing the sophistication of technology to facilitate their life routine significantly. Moreover, there are many studies that only focus on certain specific areas in mathematics education, such as geometry and algebra which implement AR concepts as opposed to a comprehensive application in all areas of mathematics studied by secondary school students. It is vital to implement AR in all areas of mathematics comprehensively to create a conducive and relevant learning atmosphere in line with the concept of 21st century learning. Finally, this review was limited by the significant range of sample size in articles reviewed which had between 20 to 7699 respondents. This resulted in biased observations as the research was conducted in substantial variations.

FUTURE DIRECTIONS

Realistically, there is a need for suggestions to be made in terms of improving this SLR and future studies more significant and reliable in the stated context. In considering the barriers and limitations mentioned in the previous section, more comprehensive studies with diverse context especially in geometry and algebra should be emphasized and studies related to AR learning in mathematics education such as calculus should also be conducted. This aims to tackle the issue of limited research resources and encourage future researchers to conduct research with a wider range of references. Moreover, future researchers should also perform studies with apparent discussions on the topic so that the findings can be relied on as solid evidence to address relevant research questions and overcome the studies' limited explanations. It was also claimed that in this SLR only looked at academic articles. For that reason, future researchers may want to investigate other sorts of publications, such as books, theses, and conference papers, because these studies are of high quality. Finally, the sample size or technique of sampling for each study should be considered for the final recommendation in future research so that the results are more accurate, uniform, and relevant to the research.

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