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An Enrichment Program Based on Using of Augmented Reality Technology for Developing 3D Geometric Shapes Skills for Second Grade Intermediate Students

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Abstract: Students usually encounter several barriers when entering STEM classrooms, including the novelty of the concepts, the necessity to develop mathematical thinking, spatial reasoning, critical thinking, and abstract understanding. Teachers usually face a major challenge with engaging students in STEM subjects due to their low interest and fear. Multiple studies confirm that the integration of AR into the classroom experiments carried out by students in STEM subjects could benefit them profoundly in terms of engagement, attitude, and productivity. This study used a quantitative experimental design to determine if AR affects student engagement in a 3D geography class and if it affects the attitudes of learners to the subject. To test the hypotheses, the study recruited 75 second-grade intermediate learners from Al-Masoudi Intermediate School, Jeddah City, Saudi Arabia. The results showed that AR has a positive effect on student engagement by improving it. AR also improved the students' attitude toward 3D geography. It is recommended to continue exploring AR technology in the context of STEM subjects, including math and geography.

Keywords: Augmented Reality (AR), STEM, 3D Geometric Shapes.

1. Introduction

Every object making up our surroundings has three dimensions (3D), meaning that children are introduced to the idea before starting schooling. However, 3D geometry is one of the most challenging concepts for students to grasp. At the same time, educators agree that geometry knowledge is essential as it enhances spatial thinking development, allowing individuals to consider different perspectives when dealing with everyday objects. For this reason, geometry is introduced quite early in the curriculum, and the concept is developed throughout the education levels as an approach often referred to as spiral teaching. Despite these efforts, most learners and teachers experience some level of difficulty in mastering 3D geometry. According to Rohendi et al. [1], the learning difficulties of 3D geometry stem from visualization problems as learners find it challenging to construct 3D spaces.

At the elementary level, learners are introduced to geometry but in 2D mode, and only after several years, they learn about 3D geometry. In other words, the conventional learning environment confines learners and teachers to 2D representations that are then used to teach and learn 3D geometry. Ozcakir & Cakiroglu [2] explain that using whiteboards and textbooks to teach 3D geometry creates a cognitive filter for realizing that figures are used to represent 3D objects. Technological advancements in augmented reality provide a possible solution to 3D visualization by blurring the boundary between the real and virtual worlds, thus enhancing the learners' experience with 3D objects when learning 3D geometry.

Existing literature indicates that augmented reality can help learners master complex spatial relationships and abstract concepts by allowing real and virtual objects to co-exist. In essence, studies demonstrate that AR has a significant learning effect on learners. However, existing literature does not consider aspects like learners' experience and engagement in relation to their age when developing 3D geometry knowledge. In this regard, the paper aims to determine the effectiveness of an enrichment program based on using AR in teaching 3D geometry to second-grade intermediate students. This aim will be broken down into three objectives to cover areas of learners' visualization of an object, learning experience, and overall engagement. The three areas determine the effectiveness of learning and teaching the concept of 3D geometry to second-grade learners.

1.1 Study Problem

When entering STEM classrooms, students typically face a number of obstacles, such as the ideas' novelty and the need to cultivate mathematical thinking, spatial reasoning, critical thinking, and abstract understanding. Due to their lack of interest and fear, teachers typically face difficulties in getting students interest in STEM topics. Modern research suggests

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that augmented reality can aid students in mastering abstract concepts and complicated spatial relationships by enabling the coexistence of real and virtual objects. In summary, research shows that AR has a significant learning impact on students. Existing research, however, does not take into account how learners' engagement and familiarity with 3D geometry relate to their age. The purpose of this paper is to evaluate the efficacy of a program for second-grade intermediate pupils that uses augmented reality to teach 3D geometry.

1.2 Objectives

1. To determine the effect of AR on learners' engagement when teaching 3D geometry;
2. To examine how AR affect young learners' visualization of objects when teaching 3D geometry;
3. To analyze how AR affect young learners' experience and attitude toward the concept of 3D geometry.

1.3 Study Questions

1. What is the effect of AR on learners' engagement when teaching 3D geometry?
2. How does AR affect young learners' visualization of objects when teaching 3D geometry?
3. How does AR affect young learners' experience and attitude toward the concept of 3D geometry?

1.4 Study Hypotheses

H1: AR has a significant impact on learners' engagement when teaching 3D geometry.

H1a: Learner engagement scores are higher in the experimental group compared to the control group.

H2: The use of AR technology has a significant positive impact on young learners' experience and attitude toward the concept of 3D geometry.

1.5 Study Limitations

1. The research was conducted in Saudi Arabia and the results are therefore representative of Saudi Arabia students.
2. The sample size is small; the results may be more accurate if the sample is larger.
3. The study available to study a research problem was in the first semester of 2022.

2. Literature Review

2.1 Impact of AR on Young Learners' Engagement

Radu & Schneider [3] analyzed the benefits and pitfalls of AR in the classroom and determined that educational AR have certain advantages for learning specific skills and knowledge and enhancing student. At the same time, the same study recognized that some learners acquire certain concepts better than others in a non-AR environment by increasing their curiosity [3]. The researchers pointed to the distinctions in learners, their personal interests in AR, and their ability to learn new concepts with or without it based on their individual skills, which has to be considered when applying AR in the classrooms [3].

The idea that geometry is a complex subject usually leads to decreased student engagement in it, which negatively effects students' ability to understand and acquire its core concepts [4]. Several inquiries confirmed that the concept of abstractness linked to geometry and 3D geometry, in particular, is not relevant, as the human environment is built in 3D [5]. Therefore, this means that learners are not taught geometry correctly, increasing their unnecessary anxiety from mathematics [4]. In general, the concept of 3D is a comprehensible, which could be difficult to develop for students due to the visualization problems related to inappropriate teaching strategies (e.g., using 2D visual aids instead of 3D), which confuses learners in the early stage of learning geometry.

Noting that students are not as involved in geometry as they should be, teachers are associated with simplifying the curriculum and reducing geometric concepts to work with 2D and 3D geometric and measure their properties [6]. This was a counterproductive approach. Educators ignored the significance of students' spatial reasoning and content visualization in an attempt to make learning easier [2]. For instance, it has been recognized that the current approach to teaching geometric concepts does not comply with international standards, because it requires the subject to develop three cognitive processes in students, including construction, reasoning, and visualization [7]. While these skills can be difficult to master for the youngest learners, in virtual reality, educators can bypass the complexities of visualizing objects by engaging students rather than confining them in a passive situation where they have to struggle to use a 2D image to obtain a 3D mental image [2].

The outcome creates a learning barrier that Ozcakir & Cakiroglu [2] call a cognitive filter. Su et al. [8] explain that VR enhances learners' sensory experiences, impression and understanding of the subject. The authors note that the first step towards changing the negative attitude of young learners towards a particular topic is to introduce the element of fun, which increases overall engagement and attention, thus increasing the likelihood of mastering the concept being brought up.

Aydogdu & Kelpsiene [9] agreed with Su et al. [8] that AR offers young students an engaging and fun experience by creating a sense of magic and an exciting learning experience. The main benefit of AR in learning geography is its ability to transform 2D objects into 3D objects allowing learners to interact with them in the virtual world [11]. This can improve the students' sensory stimulation, as well as increase their attention, and possibly their engagement [10]. Flores-Bascunana et al. [11] explain that despite the complexity attributed to geometry, the concept can be exciting and interesting for students who are engaged in mathematics but challenging for those who are less interested.

However, the study by Yen et al.[12], which tested AR versus 2D animation and 3D simulation, reported that all three techniques improve learner performance and academic achievement; however, no statistically significant differences were observed among them. In addition, students enrolled in 3D and AR classrooms were more engaged in their activities by manifesting increased motivation and focus [12]. Martín-Gutiérrez et al. [13] revealed that AR could enhance collaborative and independent learning among students when its implementation protocol is group-based. The researchers recognized that AR enhanced the learners' engagement and their positive interaction with their peers [13]. It is possible to notice that AR produces primary positive and secondary results that appear as a byproduct.

2.2 Importance of Visualization in Learning 3D Geometry

Other than learner engagement, visualization is crucial in mastering geometric concepts. Presmeg [14] explains that visual thinking is essential for learning abstract concepts in mathematics. This approach could be supported by the fact that mathematics uses multiple types of symbols and includes some abstract reasoning approaches that are crucial for acquiring mathematics concepts [6]. For example, mathematical thinking is characterized by abstraction; as a result, an individual's perception of math assists in developing this skill [15]. Consequently, educators have to use visual aids and stimulate students' perceptive skills to develop their math reasoning, as the majority of students tend to be visual learners [16]. When learners develop conscious abstraction skills by resolving math cases, they develop advanced mathematical thinking.

Rosken & Rolka [17] describe abstraction as a mental construction process that involves defining the relationship between mathematical objects and transforming the relationship into a specific expression independent of mathematical objects. Visualization stimulates the acquisition of mathematical concepts, especially in geometry, and provides meaning for students who struggle with learning theory [6]. Visual aids are essential in maintaining student's understanding of geometry and its main concepts; thus, visualization might assist in overcoming challenges linked to problems with understanding abstract concepts among learners [16].

Young students usually have problems with geometry due to its novelty for them. For example, geometry in the early years may be problematic for many learners due to the traditional teaching approach to the subject, which requires using textbooks [9]. In most cases, younger learners are unable to master abstract concepts as a result of their developmental milestones and confusing teaching strategies (2D objects in textbooks) [9]. Thus, many students develop a negative attitude towards this subject, which impaires their further development of geometric knowledge [9]. For example, objects such as cylinders, prisms, cubes, and pyramids are difficult to visualize in 2D, and learners usually fail to comprehend their properties [18]. At the same time, these objects can be shown in 3D, which successfully leads to a better understanding of them in younger students [18].

Traditional classroom tends to teach 3D geometry by using 2D images as depicted in textbooks and whiteboards. VR allows students to manipulate 3D objects through visualization and mental image formation making the technology crucial in developing spatial thinking skills [19]. According to the investigators, 3D geometry inculcates basic skills in learners, such as the ability to make comparisons and make estimations [19]. Fernandes et al. [20] findings align with those of Ibili & Sahin [19] and Rosken & Rolka [17] on the view that VR allows learners to visualize and interact with the object being studied, which enhances understanding and interpretation.

2.3 Learners' Attitude and Experience in Learning 3D Geometry

Bascunana et al. [21] explain that multiple factors contribute to the difficulties experienced by young learners in mastering 3D geometry. Some of these challenges arise from the teaching approaches where 2D images are used to teach 3D ideas and learner-specific factors like cognitive capacity and attitude. According to the authors, geometry is an abstract idea introduced at a time when children's thinking capacity is at the concrete level. Thus, failure to adapt the teaching approaches accordingly makes mastery difficult for youngsters. Walkington et al. [22] explained that the difficulties experienced by learners when they are first introduced to 3D geometry led to the formation of a negative attitude that negatively affected learning experiences.

Gecu-Parmaksiz & Delialioglu [23] state that AR provides learners with an opportunity to learn through experimentation, increasing overall mastery of the idea. For example, the authors explain that young learners struggle to classify geometric shapes whenever certain attributes have been changed. For this reason, using an approach that provides different forms of geometric shapes can significantly improve the youngsters' understanding. This point is consistent with Rosken & Rolka's [17] argument that having rich representations consisting of a large number of related concepts and pictures increases one's success in Mathematics. Therefore, AR offers opportunities for learners to manipulate different 3D objects instead of imagining them, making the objects familiar and easier to understand.

Analyzing student's attitudes toward AR requires providing educators' opinion on this approach. A study by Mundy et al. [24] reported that teachers preferred using downloadable AR applications, marking them as highly engaging and satisfying to learners. According to several educators, some of them were involved in creating AR through using different platforms, which has increased their positive approach to AR in the classroom [24]. Sarkar et al. [25] recognized that AR stimulated students to discuss geometry concepts with their peers, improved their overall experiences, and promoted positive attitudes toward geography. In addition, Sarkar et al. [25] emphasized the importance of proper lesson design (the lesson involves students in AR as they were moving inside the house and measuring the angles) for AR-based classrooms to ensure that students participate in the experience as actively as possible.

Auliya & Munsiah [26] conducted a survey among middle-school students, which showed that learners develop better conceptual understanding in 3D geography when applying the AR approach. Students develop a better attitude toward geography and math as subjects due to the implementation of AR activities [26]. Simultaneously, Auliya & Munsiah [26] recognized that educators when applying AR in classrooms, as it could affect student engagement and the learning process in general, should consider the learning environment. Several studies emphasized the significance of the learning environment in the context of AR, which could be associated with the different techniques and devices used by educators in the classroom [26; 27].

3. Method

3.1 Study Design

This study uses a quantitative experimental longitudinal design to determine the relationship between variables and to test the hypotheses. The issues raised in the literature, the specificities of the subject in question, and the significance of the issues that the recent studies lacked determined the choice of methodology. The experimental design allows testing specific educational AR approaches in relation to student engagement and their attitudes toward 3D geometry subjects.

3.2 Materials

To investigate the effect of AR technology on student engagement and attitudes in second-grade intermediate students, this study used the AR approach by modeling the following:

i) 3D geometric shapes- through Shapes 3D Geometry Drawing App (Shapes, 2020)

ii) Prism perimeter

iii) Cylinder perimeter

iv) Pyramid perimeter

v) The surface area of the Prism

vi) The surface area of a cylinder

vii) The surface area of a pyramid

3.3 Study Population

The population of this study included 75 learners in the second intermediate grade. They were divided into experimental (n = 39) and control (n = 36) groups. The students were recruited to the study voluntarily and confidentially. The place of the study is Al-Masoudi Intermediate School, located in Jeddah City, Saudi Arabia. The study was prepared during the first semester of 2022.

3.4 Data and Variables

Data in this study was collected using primary methods. The variables of this study include AR (IV), learners' engagement (DV), and learners' experience and attitude (DV). A longitudinal study is carried out where various outcomes are investigated. Learner engagement was measured by course completion, course satisfaction, and monthly learning minutes. Learners' experience and attitudes are measured by the Attitude towards Learning Scale, which is an instrument measured by a 5-point learning scale.

3.5 Data Analysis

Data analysis was conducted by using SPSS statistical instrument. Tests such as descriptive statistics and paired sample t-tests were used to analyze the data. Since the study aimed to determine the relationship between variables, the use of statistical tools was justified.

3.6 Ethics

This study involved minors, which required adhering to the research ethics. Permission was obtained from school, parents, and learners before the recruiting young learners. The University Review Board provided permission to recruit human subjects. Participation in this research was voluntary and confidential, as no personal information was collected during the study. Students from the control group participated in their traditional routine of learning 3D geography, while the experimental group received AR-aided lessons. The data was collected before and after the experiment in addition to information on student involvement in the lesson, course satisfaction, and monthly learning minutes. Only the researcher of this study had access to the raw data. The raw data will be stored for five years and then deleted in accordance with the requirements of the Code of Research Ethics. All secondary sources were cited respectively.

4. Results and Analysis

Table 1: Paired Samples Descriptive

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Course completion rate (%)-E	83.7800	15	4.68511	1.20969
	Course completion rate-C	82.7435	15	4.29829	1.10981
Pair 2	Student satisfaction (%)-E	74.0867	15	7.46017	1.92621
	Student satisfaction -C	72.6220	15	6.98211	1.80277
Pair 3	Learning mins per months-E	47.60	15	10.105	2.609
	Learning mins per months-C	45.80	15	10.213	2.637
Pair 4	Attitude towards learning (5-point Likert)-E	3.607	15	.8128	.2099
	Attitude towards learning (Likert)-C	3.3900	15	.94344	.24359

Note: the letters E and C are used to separate experimental and control group variables

Table 1 shows that the mean course completion rate for the experimental group was 83.78% compared to 82.74% for the control group, student satisfaction for the experimental group at 74.09% compared to72.62% for the control group, learning minutes per week at 47.6 for the experimental group compared to 45.8 for the control group, and attitude towards learning rated at 3.6 on a 5-point Likert scale (with 1-negative and 5-positive), compared to 3.39 for the control group. The results showed that the experimental group had better outcomes.

Table 2: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Course completion rate (%)-E-Course completion rate-C	1.03653	.77878	.20108	.60526	1.46781	5.155	14	.000
Pair 2	Student satisfaction (%)-E - Student satisfaction -C	1.46467	.96998	.25045	.92751	2.00183	5.848	14	.000
Pair 3	Learning mins per months-E - Learning mins per months-C	1.800	1.474	.380	.984	2.616	4.731	14	.000
Pair 4	Attitude towards learning (5-point Likert)-E - Attitude towards learning (Likert)-C	.21667	.24029	.06204	.08360	.34973	3.492	14	.004

Note: the letters E and C are used to separate experimental and control group variables

Table 2 shows that the average difference between the experimental and control group course completion rate is 1.04%, 1.46% for student satisfaction, 1.8 for learning minutes per month, and 0.217 for attitude towards learning. Therefore it can be concluded that the learning outcomes in the experimental group and the control group are statistically significantly different. For course completion ($t14 = 5.155$, $p < 0.000$), student satisfaction ($t14 = 5.848$, $p < 0.000$), learning minutes per month ($t14 = 4.731$, $p < 0.000$), and attitude towards learning ($t14 = 3.492$, $p < 0.000$). Thus, all hypotheses are supported.

5. Conclusion and Recommendations

5.1 Conclusion

The current paper sought to investigate the effectiveness of an enrichment program based on using AR in teaching 3D geometry to second-grade intermediate students. It was proved that AR significantly affected learners' engagement when teaching 3D geometry and that learners' engagement scores were higher in the experiment group compared to the control group. The study also demonstrated that the use of AR technology has a significant positive impact on young learners' experience and attitude toward the concept of 3D geometry.

The results of this study supported findings of previous research with several exceptions. For example, Radu & Schneider [3] assessed the benefits and challenges of AR in the classroom and determined that educational AR have specific advantages for discovering specific skills and expertise and enhancing student. At the same time, the same study acknowledged that some learners acquire certain ideas much better than others in a non-AR atmosphere, by enhancing their curiosity [3]. The researchers pointed to the differences in learners, their individual interest rate in AR, and their ability to discover new concepts with or without them based upon their own abilities, which should be considered when using AR in the classrooms [3].

Mystakidis et al. [28] conducted a review of different AR approaches for training STEM topics and revealed that the augmentation laboratory tools, physical objects, as well as software sheets is one of the most popular and appropriate AR strategies. Widada et al. [4] also explored AR's capabilities to educate trainees on geometry, which according to authors, is not typically liked by students. The results revealed the ability to recognize the geometry ideas of trainees in AR was greater compared to those who were discovered in traditional classrooms [4]. Shufan et al. [29] acknowledged that the benefits of AR are its adaptability as well as applicability in the physics classroom if the problem of the teacher readiness for this method is significant. In general, Mystakidis et al. [28], Shufan et al. [29], as well as Widada et al. [4] had the ability to attract similar verdicts showing the efficacy of AR in mentoring students' STEM principles. However, factors such as the efficient application of this innovation as well as the preparatory work of instructors for this procedure might have a considerable function on the outcomes.

Rohendi & Wihardi [30] revealed that mobile-based AR raised student spatial understanding activities, as it enabled students to discover geographical content with even more aesthetically obtainable methods. Mastering geometry requires the individual to take into consideration multiple perspectives in relation to objects within their environments [31]. However, the learning procedure of 3D geometry is not constantly smooth; bringing about the mistaken belief that geometry is just one of the most challenging concepts in mathematics, which is supported by a limited interest rate of students in it [32].

The idea that geometry is a difficult subject usually leads to reduced student's engagement in it, which negatively affects students' ability to recognize and acquire its major [4]. A number of questions verified that the principle of abstractness connected to geometry and 3D geometry in particular is not relevant, as the human atmosphere is created in [33]. Therefore, this means that learners have not been educated geometry appropriately, which raises unnecessary worry and anxiety in mathematics [4]. Generally, 3D is a comprehensible concept, which could be difficult to create by trainees due to the visualization problems connected to inappropriate mentor strategies (e.g., using 2D visual aids instead of 3D), which confuses students at the very early stage of their geometry knowledge.

Discovering that pupils are not as participating in geometry as they needed to, made educators tied to simplifying the educational program and reducing geometric ideas to create collaboration with 2D as well as 3D geometric forms as well as gauging their buildings [6]. This was a counterproductive technique. Educators neglected the value of spatial reasoning and the visualization of web content in pupils in an effort to make the discovery less complicated [2]. For example, it was identified that the current method of teaching geometric ideas does not follow global standards, as they need to be based on developing three cognitive processes in pupils, consisting of construction, reasoning, and visualization [7].

A research study conducted by Sirakaya & Kilic [34] among three discovery astronomy courses showed that AR innovation was able to enhance student achievement and eliminate misunderstanding. However, AR did not affect their participation in training course. At the same time, as Sirakaya & Kilic [34] highlighted, the lack of influence on participation by AR could be linked to the types of communication used throughout the lesson (one-on-one with modern technology) and initially boosted the pupils' interest in the topic (astronomy). Gun & Atasoy [35] have actually attracted the exact same verdict by showing that AR application does not create a substantial effect on participation as well as on scholastic achievement. At the same time, when speaking with, trainees suggested the improvement of AR technology class in terms of illumination and the range of topics engaged [35]. Yet, it is important to consider the recommendation of Auliya & Munsiah [26] study that recommended teachers maintain correct discovering settings when implementing AR, as it affects student engagement in learning actions.

Nonetheless, the research by Yen et al. [12] that evaluated AR versus 2D animation and 3D simulation reported that all three techniques enhance learner competence and scholastic achievement. However, no statistically segnificant differences were observed amongst them. Additionally, pupils enrolled in 3D as well as in AR classes were more participated in their activities by manifesting raised motivation and focus [12]. Martín-Gutiérrez et al. [13] revealed that AR could cultivate collaborative as well as independent understanding among trainees when the method of its application is group-based. Researchers acknowledged that AR enhanced the students' involvement as well as their positive communication with their peers [13]. It is possible to see that AR produces positive primary results and the second ones that emerge as a byproduct.

This approach could be sustained by the fact that mathematics enables using of many types of signs and involves some abstract reasoning techniques that are necessary to obtain mathematics ideas [6]. As an example, mathematical reasoning is identified by abstraction; as a result, an individual's perception of math helps in creating this skill [15]. Subsequently, teachers need to use visual aids and enhance pupils' perceptive skills to develop their mathematics reasoning, as most trainees have a tendency to be aesthetic students [16]. When students create conscious abstract skills by solving math cases, they create sophisticated mathematical thinking.

Visualization enhances the acquisition of mathematical principles, particularly in geometry, and provides meaning for students who are struggling to discover concept [6]. Visual help is crucial in maintaining pupils' understanding of geometry and its primary ideas; therefore, visualization may assist in overcome challenges linked to problems with comprehending abstract concepts among students [16].

Young trainees usually face problems in geometry because of its uniqueness for them. For example, geometry in the early years could be bothersome for lots of learners mainly due to the standard mentor strategy to the topic, which needs to make use of textbooks [9]. For the most part, younger learners are unable to understand abstract principles as a result of their developmental turning points as well as confusing training strategies (2D objects in books) [9]. Hence, a number of pupils establish a negative attitude toward this subject, which impaires their further progress in geometric expertise [9]. For example, items such as cylindrical tubes, prisms, cubes, as well as pyramids are difficult to envision in 2D and students usually fail to understand their homes [18]. At the same time, these objects can be displayed in 3D, which efficiently creates a better understanding of them in younger students [18].

AR could potentially improve pupil development as well as the acquisition of new details in location. For example, Flores-Bascuñana et al. [11] examined the AR capabilities in mentor 3D location in sixth grade and discovered that pupil proficiency in this subject was significantly raised, in addition to their satisfaction with this program. However, Flores-Bascuñana et al. [11] additionally confessed that they did not examine the primary capabilities of pupils (in terms of geographic expertise and skills as well) and randomly divided the sample, which could be a potential limitation. Rashevska et al. [36] identified that the use of AR visualization created an environment of favorable psychological communication between students and educators, which reduced anxiety and stress, anxiety usually associated with mathematics and geography. According to Rashevska et al. [36], when teaching location or mathematics through AR, teachers should take into account the psychological part of discovering, because it influences the memorization of new concepts and web content, raises interest in mathematics, as well as allows realizing imagination to resolve geometric problems in different means. Research studies rarely discover the link between creativity and augmented reality in understanding geometry.

Gargrish et al. [37] reported that AR-based 3D location tasks enhanced the memory retention and discovery experience of students, as this strategy allowed for enhanced visualization of key concepts. This research study established AR-based tasks by producing a geometry-discovering assistant, which gave interactive and immersive experiences to trainees [37]. Overall, several research studies have recognized the positive outcomes of immersive experience in student skills and capacities, indicating the value of immersion for site-class students [37, 8]. Hanid et al. [38] also highlighted the value of visualization in learning geometry topics. As it was reported, AR-based tasks in site-class enhance computational abilities, visualization abilities, as well as the obtaining of geometry concepts [38].

5.2 Recommendations

Considering the findings of this study, it is recommended to pursue the investigation of the effect of AR on students' engagement in and attitudes toward STEM subjects. This study focused on the 3D Geography course, while future research has to explore other subjects as well to generate a full picture of the capabilities of AR in the classroom. It is recommended to analyze if and how AR influences other indicators of student success, including academic performance in STEM subjects (previous research has produced inconclusive results), student interest in STEM subjects, and course satisfaction.

AR should be investigated in relation to spatial reasoning, mathematical thinking, critical thinking, and problem-solving skills. Also, multiple research projects were conducted to address the phenomenon of math and science anxiety, which was partially addressed in this study when analyzing the difficulties which students encounter when they learn geometry. For example, it is possible to explore if AR can alleviate students from math or science anxiety by providing a more accessible and interesting approach to these subjects. Since previous studies reported inconclusive findings on the relationship between AR and student engagement, which was not supported by this study, future research should continue investigating this gap.

It is also recommended to conduct qualitative and mixed-design studies to explore students' attitudes and interest in STEM subjects in relation to AR. Collecting students' opinions and attitudes towards the AR approach in STEM may be valuable for educators who are planning to implement it in their classrooms. It is possible to determine specific techniques used in AR for teaching the content to students. Educators could be interviewed regarding their practice of using AR and their personal opinion of this approach. This area of research is particularly valuable for educators who could use AR in the classroom and policy-makers who could integrate AR into the curriculum if it proves to be effective. In addition, studies with a larger population have to be conducted to attain better generalizability of results.

Several recommendations have to be provided to educators who are planning to implement AR into geography, mathematics, or any other STEM subjects. According to the results of the study, students interact positively with AR-based activities in the classroom. However, as mentioned by previous studies, teachers need to consider the environment and application methodology of AR to ensure a positive experience for students. Educators have to take into account student's proficiency in the respective subject, as they will have to access the same materials in AR as their peers. AR-based activities are difficult to adapt to individual learners, which requires providing content that is relatively similar in terms of difficulty to all students. AR has a learning curve, which must be considered during the first implementation in the classroom. Students will appreciate AR-based lessons if they comply with their developmental milestones.

Conflict of interest

The authors declare that there is no conflict regarding the publication of this paper.

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Article in a Journal

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