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The Application and Effects of Augmented Reality in Geometry Learning

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Abstract: With the development of new technology, augmented reality (AR) technology is revolutionizing the educational landscape, particularly in geometry. This innovative approach deepens their comprehension of geometric principles and stimulates their motivation to learn. This paper aims to provide a comprehensive introduction to AR's application in the educational field, especially the topic of geometry, and evaluate its effectiveness in improving users in two aspects: motivation and academic results. The study applies the Attention, Relevance, Confidence, and Satisfaction (ARCS) Model to assess the impact of AR in education compared to traditional teaching. It finds that AR boosts student motivation, especially for those with lower academic performance. While AR enhances learning experiences, its effect on improving grades is not immediate. The method that is mainly utilized in this study is reviewing the literature, summarizing, and analyzing critical information from them. And it turns out that short-term grade improvements are not significantly observable, AR technology offers long-term benefits by enhancing engagement and conceptual comprehension through interactive and spatial visualizations.

Keywords: Augmented reality, geometry education, learning motivation, academic performance, ARCS model.

1. Introduction

With the scaffold of an increased number of talented human resources, people have witnessed the extraordinary development of technology over the past few decades, which benefits human lives in various aspects, including education quality [1]. Integrating innovative techniques and teaching has assisted the educational field by eliciting the possibility of a more interactive, motivating, and attractive learning process for students, and Augmented Reality (AR) is an exemplary model here [2].

Although AR, according to the study done by Wu's team, is offered different meanings by researchers in varied fields, these definitions were centered around its technical features and characteristics [3]. Hence, a general definition of AR would be "a real-time direct or indirect view of a physical and real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it" [4]. In addition, the virtual content produced by AR computers, usually referred to as assets, is complex and diverse, ranging from text labels to audio messages and from three-dimensional (3D) models to animation and videos [5]. These rich capabilities of AR reveal

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the unfathomable potential of its applications in educational areas, further implying how useful it can be in supporting teaching. Many recent studies have researched AR's application and implications in this domain, covering a wide range of topics. For example, AR has been explored and utilized in physical education, architecture, art, and so on [6-8]. This paper will emphasize the educational domain of Geometry – one branch of mathematics topics – because AR is especially suitable for transferring related knowledge by allowing users to visualize abstract information or flat patterns in the 3D form and interact with multiple media. The primary objective of geometric education is to enhance people's spatial intelligence, a crucial component of human intelligence, which consists of five ramifications: spatial perception, spatial visualization, mental rotations, spatial relations, and spatial orientation [9].

Even though loads of studies have scrutinized AR's application in geometry, most of them focused on one specific AR software, such as Construct3D, Geogebra, and Geo+ where this paper sees a gap for incorporating AR's functions and its applications in geometry in a more general way [2,9,10]. In addition, students in different stages may have disparate ways of operating AR, and variations like this are scarcely considered or compared in existing studies. Moreover, only a few empirical literatures examine the effects of AR on students comprehensively, evaluating the changes in students' academic performance or motivation solely.

Therefore, this paper will be constructed as follows: the first section aims to introduce the functions and applications of AR in the educational area, demonstrating AR's more general features with examples from previous literature; section two will present a comparative analysis of AR's application in geometry education from three dimensions – leaners' profiles, teaching objectives and application procedures; section three aims to summarize and analyze AR's impacts on learners' using experience, learning motivation, and their academic performance; the last part will be a conclusion of this paper, involving limitations of this paper and suggestions for future researches. The main research method used in this study would be literature review.

2. Analysis of AR Applications Used in Geometry Education

2.1. Functions and Applications of AR in Education

Along with the development of AR's application in a wide range of fields like medicine, architecture, and entertainment, much of the research attention has been drawn to educational areas in recent years as well, which drives the emerging educational uses of AR. One supportive evidence of this phenomenon is an increasing number of AR-based apps, such as Zooburst which enables students to create 3D stories by uploading multimedia (texts, photos, audio, etc.), Wordlens which assists learners in language progression by generating translations on the top of documents or signs, and Fetch lunch rush which practices students' mathematical abilities by asking questions and seeking the right answers in a form of AR marker [11]. These examples demonstrate how AR can be applied to the teaching and learning processes, meanwhile draw forth questions about the functions or affordances of AR and how they support the achievement of innovative learning programs, which will be answered in the following section.

Firstly, one of the most obvious features of AR that differentiates it from traditional teaching strategies is the construction of 3D objects, enabling students to interact simultaneously. Students' visual perception of the targeted learning environments can be augmented and improved via AR's synthetic 3D information and by engaging with these tridimensional objects, learners are also enabled to observe and brain-process from different perspectives, which further consolidates their understanding of aimed contents. The second affordance of AR – promoting portable, contextual, and collaborative working opportunities – is related to its demand for operating equipment. Since AR programs are largely designed in an online form like applications, games, and simulations, mobile devices could be the most suitable platforms for AR to play which are accompanied by technologies of wireless connection and location registration [3]. Therefore, students who wish to study almost everywhere and at any time can be satisfied with AR's function. Moreover, by using the same program, "AR helps bring together different people to enrich their learning with different student perspectives or experiences". AR can enable users to work on the same project or experiment in a real-world context, so collaboration ability, social interactivity, and social construction of knowledge are trained while they communicate, divide tasks, and exchange opinions with teammates. The last function of AR mentioned in this paper is producing not only images but also sounds and animation leading to the result of a greater presence and impressiveness for students' learning process. Thus, AR is effective in fostering learners' progress as many of their senses – like seeing, hearing, and gesture movement – cooperate to understand a term. This function, on the other hand, makes visualizing abstract learning content, such as science theories, movement of chemical substances, and physical phenomena, possible, which deepens students' memorization and understanding of such concepts [3].

2.2. Applications of AR in Geometry

After explaining the applications and functions of AR in the general educational field, this section will specifically underscore AR's use in one branch of the mathematics subject – geometry, which is also the targeted topic of this paper. The technology of AR can play an important role here.

While learning geometry, many students have a problem building a bridge connecting 2D objects and the 3D real world, which further leads to difficulty in differentiating flat shapes from tridimensional solids. This further results in a vague understanding of spatial relations. AR can solve these issues by overlapping synthetic 3D outputs in an actual environment, which enables students to see and compare multiple solid figures in textbooks and meanwhile inspect them from any point, any direction [1]. Considering this application, students' recognition of spatial relations can be improved. Besides, students can understand geometrical objects or models more deeply, knowing their features more comprehensively.

Furthermore, challenges occur when students have to construct a 3D model by simply viewing the pictures that record the image of an object from varied sides and directions. Since the AR technique provides an interactive learning environment for users, this problem can be mitigated by students engaging in visualizing geometrical models by themselves after carefully observing the AR-generated information. For instance, the AR app, Construct3D, has several essential functions that enable users to practically draw points, lines, curves, and hook faces on top of their real-world environment [9]. Hence, AR assists learners by cutting their cognitive load like processing numerical data and transferring numbers into graphs/solids in the brain. Students' ability of spatial visualization could be enhanced as well.

Apart from the two main applications of AR in the geometrical study described above, there are a bunch of other uses but from a relatively micro and detailed perspective. Firstly, as AR can create a multi-user learning environment, students can work on the same solids together. For example, an AR software named Geo+ enables learners to team up and explore the geometrical solid figure collaboratively, students can acquire and discuss their investigations, questions, and ideas with each other based on the multimedia information [2]. Secondly, AR can be used to display geometrical information like functions, equations, and concepts above synthetic objects, helping students connect theoretical knowledge and geometrical models which foster their deep memorization and understanding to do some calculations. The final application of AR has an impact on students' intrinsic quality. A combination of greater interactivity and a wider range of information displays can inspire students' interest and motivation for learning geometry [12]. This is because, on the one hand, it creates a more suitable form of teaching dynamic geometry since videos can demonstrate the

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changing process of figures and solids; on the other hand, makes students' learning experiences more vivid and immersive compared to traditional teaching methods.

2.3. Learning Objectives When Using AR

Overall, according to the functions and applications illustrated above, AR is a useful tool to assist geometry teaching and learning and helps achieve several teaching objectives which can be broadly classified into two categories. igniting students' motivation and passion for learning geometry and improving students' spatial intelligence. While the former aim is more attitude-related rather than dependent on students' ability and knowledge, the latter refers to their academic performance and results, meaning this is linked closely to the geometrical curriculums that students receive. By using AR, educators expect students to experience greater curiosity and fantasy during the learning process, attracting more students' attention to the learning content. Compared to the passive learning attitude in a traditional educational form, AR-based teaching aims to transfer students' learning attitude toward a more active state. By doing so, learners are expected to spontaneously learn with AR even outside the classes and so devote more time to studying. More importantly, teaching designed with AR use hopes students to enjoy learning rather than suffering and the interest and passion in learning raised from AR's features may persist in the long run.

Additionally, enhancing students' motivation in learning can assist in achieving the learning goal of improving students' academic performance as motivation determines the energy and effort that students are willing to devote to study [13]. For subjects like geometry in mathematics, examination and scores would be a relatively effective way to reflect students' academic achievement. From other perspectives, students' memorization and understanding of learning contents are aimed to be improved considering AR's functions that enable students with deep interaction, and comprehensive and consistent observation. Besides the grades on paperwork and better knowledge acquired, students' ability to apply them is also targeted to boost since AR allows students to learn in their real-life environment. By doing practice and exercise on AR, students are expected to have proficiency in hands-on learning content such as doing surgery in medical areas and conducting experiments in chemical and physical fields.

Overall, AR assists in reaching learning objectives from many different perspectives which are relatively difficult to achieve with traditional teaching methods. In addition to that, students' use and learning experience are crucial for evaluating the AR technique as well which will be elaborated by a literature review then.

3. Comparative analysis of AR applications in geometry education

To demonstrate and compare how is AR applied in geometry education, 11 case studies are selected and examined in this paper. It should be noted that these case studies use different AR applications. Although all these applications provide the affordances and functions mentioned in the previous chapter, there are significant differences in the learners' profiles, the teaching objectives they focus on, and the application contexts. These differences will be compared and analyzed in this chapter so that further evaluation of the effectiveness of AR on students' performance can be done. An overview of the criteria compared in this chapter is demonstrated in Table 1.

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Table 1: Case Studies Examined in this Paper.

Case Study	Learner's Age	Region	Teaching Objectives	Application Procedure
Ibáñez et al, 2019 [1]	13-15	Mexico	Recognize, measurement and calculation of 3D bodies, filling prism with smaller prisms	1 lesson
Rossano et al, 2020 [2]	10	Italy	3D objects and their flat figure, rotating solids	1 lesson
Kaufmann, 2004 [9]	18	Austria	Boolean operations, surfaces of revolution, conic section, vector algebra and center of gravity	6 lessons
del Cerro Velázquez et al, 2021 [10]	16	Spain	Spatial Visualization of 3D shapes	12 lessons in 3 weeks
Lin et al, 2015 [12]	14	Taiwan, China	Spatial ability of 3D shapes	1 lesson
İbili et al, 2020 [14]	14	Turkey	Nets, manipulation, structuring, properties, calculation, comparison of 3D shapes	4 weeks of lessons
Hwang et al, 2023 [15]	10-11	Taiwan, China	Visualization, measurement, estimation, analysis of triangles	6 weeks, 1 lesson each week
Gargrish et al, 2021 [16]	17-18	India	Vector addition, cross and dot product, position vector, direction ratios	1 lesson, retention tests 2 and 4 weeks after lesson
Sarkar et al, 2020 [17]	13-14	India	Types and pairs of angles, interior and exterior angles of triangle	1 lesson
de Ravé al, 2016 [18]	18-20	Spain	Rotation of 3D objects, visualize a 3D object from a 2D pattern	(not specified)
Liu et al, 2019 [19]	13	Mainland China	three-view projection and drawing of 3D objects	1 lesson

*Pilot studies, pre-test and post-test adjacent with the learning process for evaluation purposes are not listed

3.1. Students' Profile

It can be found that the age of learners in the case studies varies from higher grades of primary school to the freshman year of college, and 8 out of 11 studies are conducted on students of secondary education. There are concerns about the possible impact on eye health for young digital device learners [20]. In some regions where the case study was conducted, there are limitations on younger students' daily usage of electronic devices. Thus, studies on younger students were not conducted. Using AR in education requires learners to have at least a basic level of digital literacy [21]. This brings difficulties for younger students and students from lower-income families, for they may be less familiar with interacting with the AR application used It should also be noted that the case studies are conducted in different regions, and different curriculums and teaching strategies are used in class before using AR. Therefore, students' acceptances for the learning procedures in the case studies vary.

3.2. Teaching Objectives

Geometry covers a lot of fields in primary and secondary education. In the case studies, 9 of 11 have their teaching objectives set on 3D geometry. This is because AR provides different affordances

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compared to traditional teaching methods, including paper/blackboard, multimedia, and simulations. The most outstanding affordance AR provides is 3D visualization, making it an ideal tool to teach 3D geometry. In Gargrish and Kaufmann's case studies, AR is used to give lessons on knowledge about vectors, which originates from abstract conceptions rather than tangible objects [9,16]. AR has proved to be useful in teaching 3D geometric knowledge, as it visualizes abstract conceptions and gives users a way to interact with them. Apart from geometry knowledge, skills are also considered teaching objectives in some case studies. General geometry skills, such as visualization, measurement, estimation, manipulation, comparison, calculation, and analysis are tested and analyzed apart from the specified geometry knowledge [14][15]. Also, students are split into pairs in the experiment group of Sarkar's study, and teamwork skills are emphasized in the teaching objective [17].

3.3. Application Procedure

All case studies were conducted in schools and learning sessions were given as formal classes. In 6 out of 11 case studies, AR was only used in one lesson (the time varies from 30 minutes to 1 hour) in the application process. In other case studies, AR was used in short periods and for limited knowledge points rather than covering the full span of the learning process. Although pilot tests and instruction courses are given before the learning process in the case studies, there are no further evaluations of students' ability to use the AR application.

Using AR requires dedicated devices for each (group) of learners, such as smartphones, tablets, or head-mounted displays. This means extra expenditure for schools that want to integrate AR as a regular teaching method in the curriculum. As some schools ban the use of electronic devices in classrooms, dedicated classrooms will be needed, which adds difficulties to the mass application of AR in schools. As for individual learners, the device and dedicated materials designed for the application also require extra expenditure, which limits the use of AR, especially for students from families of lower income.

4. Evaluation of AR Effectiveness on Students' Performance

With the emerging technologies of augmented reality (AR), the learning process in today's classroom is much more effective and motivational. Overlaying virtual content into the real world makes learning methods attractive and entertaining for students while performing activities [20].

4.1. Engagement and Motivation

The two case studies were used to assess the impact of the application of augmented reality (AR) technology in education on learning motivation. In both cases, the ARCS model was used as an assessment tool, and data were collected by a five-point Likert scale and IMMS scoring system. The purpose of the case study was to understand how AR technology affects students' four motivational dimensions attention, relevance, confidence, and satisfaction.

In the first research by Muhammad, the subjects were pupils from the primary section of two different schools in the Pakistani city of Peshawar [20]. The total number of students participating in the experiment was 150, with an average age of about 7 years old. The students were divided into three different groups of 50 based on their previous academic performance at their respective schools.

Participants from three different groups were surveyed using the ARCS questionnaire, adapted to a five-point Likert scale. Group A engaged with AR learning activities, Group B followed a video and presentation-based approach, and Group C experienced a teacher-led lecture format. The questionnaires were administered post-activity to capture immediate motivational responses.

It turns out that Group A demonstrated significantly higher motivation across all ARCS dimensions. The AR learning environment successfully captured and maintained attention, provided

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relevant and engaging content, boosted students' confidence in learning, and resulted in high satisfaction levels. In contrast, Groups B and C showed lower motivational outcomes, with traditional methods failing to engage students as effectively.

The subjects in the second research by Ahmed were 62 first-grade pupils aged between six and seven, from a public school in Cairo, Egypt. The students were divided into two groups of 31 [21]. In the experimental group, pupils used a mobile app to access augmented reality (AR) virtual manipulation of the material. The difference in IMMS scores in attention was statistically significant. It turned out that students were highly satisfied with using the Smart-flashcard mobile AR application, which significantly improved their learning outcomes. This suggests that AR applications can foster a positive learning mindset. Moreover, a key finding was that well-designed AR tools, grounded in multimedia learning theory, can boost motivation for typically less popular subjects like geometry. The application's interactive activities were particularly effective in engaging students and enhancing their creative thinking, going beyond traditional academic achievements.

The results of both research show consistency in the four dimensions of the ARCS model, that is, AR technology can effectively improve students' attention, relevance, confidence, and satisfaction. The application areas and research focus of the two papers differ but they highlighted a strong link between AR-assisted learning and the stimulation of creative thinking, often viewed as a product of supra-personal intelligence. Overall, the studies suggest that mobile AR applications can ignite a desire to learn, re-engage students, especially lower-performing primary school pupils, and encourage them to persist with educational tasks.AR technology may play different roles in different educational scenarios and goals, and educators can choose and design appropriate AR learning activities based on specific teaching objectives and student needs.

4.2. Academic Achievement

AR learning has various advantages, but whether it can be of substantial help to students' learning. The results are also obtained through the analysis of two practical cases.

There is in Taiwan that looked for 76 girls and boys in eighth graders from a middle school in Tainan, and sampled their scores, including gifted students, regular students, and students in an after-school alternative program, and they all operated a computer and webcam independently [12]. The students were divided into three groups of high, medium, and low-performance levels through their pretest to study the experience and effectiveness of students at different performance levels in learning mathematical functions using augmented reality (AR) technology.

In addition, it reveals that the effective values for groups distinguished by high, average, and low academic achievements stand at 0.04, 0.36, and 0.69, respectively. These figures correspond to null, minor, and moderate effects. The data underscores the beneficial impact of AR-assisted instruction, particularly among students who are struggling with lower academic achievements.

To compare with, another study involved 75 seventh-grade students, ranging in age from 12 to 14, from a junior high school in Beijing [19]. These students already have some knowledge of two-dimensional Euclidean geometry and space, but only a basic understanding of three-dimensional geometric concepts and projections. It is divided into the top 33 percent of high-achieving and the bottom 33 percent of low-achieving groups based on its pretest performance [19].

After learning the test, it shows that there is no statistically significant difference in the variances between the two groups of students. In essence, the learning gains of the students in both groups are not significantly different from each other.

In summary, the help brought by the application of AR technology in geometry cannot be significantly reflected in the difference in grades in the short term. However, from the perspective of different research and students' reactions after class, the help of AR technology in geometry is to help students better understand geometry through composition, spatial display, and other aspects. Students need to continuously understand and use AR technology for a long time to bring about significant improvement.

5. Conclusion

This study demonstrates the following findings. The features of AR that differentiate it from traditional teaching strategies are analyzed. The distinct features and affordances include the construction of 3D objects, the enabling of students to interact with the object simultaneously, the multimediality it provides in the learning process, and accessibility. Based on these features and affordances, this study pointed out that AR has solid applications in geometry education, especially in fostering students' connection between 2D and 3D objects and enhancing students' spatial visualization ability. AR also brings forth the possibility of improving students' motivation and providing a better learning experience.

Given the above, this study conducted a review of case studies on AR applications in geometry education. The learners' profile, teaching objectives, and AR application procedure are first examined. It is shown that AR is primarily used in teaching students of secondary education in the form of lessons taken in classrooms in the case studies. The most common teaching objective is visualization, interaction, measurement, and interpretation of 3D objects, as it is considered the way to utilize AR's unique affordances. AR is also used in teaching abstract concepts, such as the projection of 3D objects and vector calculations, as it demonstrates abstract concepts in an interactive and visualized way. The results of the case studies showed that students are more motivated to learn with AR applications compared to traditional methods. Students also perform better in tests of academic achievements after learning with AR, but some case studies investigated that AR could have a greater influence on low-performing students.

The study is limited in the following ways. Firstly, the case studies examined in this study are mostly limited to short-term teaching of a single knowledge point, failing to provide solid evidence on the general field of geometry education. Secondly, all the case studies conducted their education process in teacher-guided classes, limiting the scope to formal learning activity and omitting the self-learning and self-motivation of students. Future studies may consider conducting more complicated case studies covering a larger part of the learning process.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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