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The integration of scaffolding and augmented reality in physics learning

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ABSTRACT

Physics learning often involves problem-solving in mathematical calculation that has become one of the many challenges among high school students. The integration of scaffolding and augmented reality (AR) has the potential to improve students' understanding in problem-solving involving mathematical calculation in physics learning. Therefore, this study aims to increase gravitational knowledge among high school students using AR learning kit with the integration of scaffolding. This study employed mixed method case study research design and involved 15 high school students in urban areas. Data was collected using semi structured interview and pre and post gravitation test then analyzed using qualitative thematic analytic and descriptive statistics. The findings showed that an AR learning kit integrating scaffolding named FizaAR has increased gravitational knowledge among high school students in physics learning. The findings further indicated that scaffolding element employed in FizaAR have the feature of simplified small subtopics help to increase confidence among students in physics learning. Consequently, the AR learning kit might enhance high school students' understanding of physics. This study found that integrating scaffolding and AR would help physics education.

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1. INTRODUCTION

Technology and innovation constantly evolve over time. The paradigm of today's world has changed conventional learning to technology-based learning [1], [2]. Technology-based learning is able to give a new dimension in learning among students in primary, secondary and higher levels. In line with the fourth sustainable development goal (SDG) which emphasizes the aspect of quality education, the use of technology is expected to provide quality education among students [3]. There is an increase in the use of augmented reality (AR) in learning with technologies [4]. There are various technologies that can help teaching and learning; one of which is AR. AR can be described where users can see a mixture of objects in the virtual and real world in real time [5]. AR is a widely used technology in many facets of our lives [6] which combines the real world and the virtual world created through computers [7]–[9]. AR has the ability to facilitate multimedia learning because it creates an interactive learning environment capable of providing a learning experience similar to the real world [10], [11] and offering better understanding [12].

Physics is a branch of science that studies all natural phenomena [13]. Physics is often labelled as a difficult subject [14], [15] and students often face conceptual misunderstandings [16]. Furthermore, students also experience problems in applying physics concepts that involve the use of knowledge related to physics in solving problems [17] involving mathematical calculations. Gravitation is one of the topics in the physics subject in the curricula in Malaysian secondary schools known as *Kurikulum Standard Sekolah Menengah* (KSSM) [18]. This topic emphasizes escape velocity that requires problem solving skills involving mathematical calculations and abstract concepts in physics. Our study focuses on the integration of scaffolding and AR to help students in solving problems involving mathematical calculations. A study has been conducted to determine the effectiveness of GraviSTEM Module involving Newton's universal law of gravitation [14], while another study has been done to develop GraviGame Keplers' law [19]. However, these studies focused on Newton's universal law of gravitation but did not examine the topic of escape velocity to high school students and did not use technology applications such as AR. A quasi-experimental study conducted among high school students has shown marked improvement with the use of AR in biology [20]. Another study focused on developing AR learning media in science subject [21].

AR-based learning can make learning more effective. Various studies involve numerous subjects that include teaching and learning using AR such as mathematics [22], [23], chemistry [24]–[26], physical education [27], biology [28], [29], science [30], early childhood education [31], and physics [32], [33]. AR is capable to facilitate and guide students because it creates an interactive learning environment where students can better understand the real world with the presence of multimedia assistance that integrates scaffolding [10], [11]. Researchers are still left with this question on how AR helps in teaching and learning: what methods should teachers use in using AR materials to ensure that the AR materials achieve the objectives of the lessons? Therefore, an appropriate approach and selection should be implemented. One of the methods being suggested is scaffolding.

Scaffolding plays a critical role in promoting learning in a better environment by offering students organized support to help them become more independent in their learning. Scaffolding techniques in the learning process highlight learning information needed to help students proceed to the next level of knowledge [34]. Scaffolding is also known as the process by which a more knowledgeable peer or teacher offers assistance that enables students to complete tasks that may be difficult for them to complete independently [35]. Vygotsky stated that the right guidance will help students improve their learning. It gradually increases difficulty and helps build on existing knowledge [35]. Scaffolding is further characterized as just-in-time support. It provides immediate assistance when needed and supports contextual hints and explanations [36]. The types of support that are included in scaffolding are chunking and modelling. Chunking is as a process of breaking down challenging learning activities into small and manageable chunks of components [37], while modelling is giving concrete examples by demonstrating concepts and tasks [38]. The principles of scaffolding are stressed in continuity and contingency. It ensures that help is consistent and adjusts to the learner's changing requirements [39].

It has been demonstrated that effective scaffolding formats, including interactive seating arrangements and mnemonic strategies, improve students' ability to solve problems in particular physics disciplines, such as temperature conversion [40]. Physics learning outcomes are also improved by the use of scaffolding-based worksheets in discovery learning models, which increase student comprehension and engagement [41]. Additionally, scaffolding techniques that promote debate and group learning improve scientific explanation abilities, highlighting the need of organized assistance in fostering critical thinking [42]. Another study shows that scaffolding improves language acquisition by simplifying difficult concepts and increase competence in learners [43]. The use of scaffolding in the game-based learning aspect in the development of Crayon Physics Deluxe has increased understanding and even amplified student creativity [44]. It shows many studies that have integrated scaffolding in the teaching and learning have positive impacts and create meaningful learning environment.

When the design highlights the scaffolding aspect and is integrated with AR, learning in an active environment will be able to increase students' knowledge. Scaffolding is used to bridge the gap between student understanding and mathematical problem-solving skills. Research on the integration of AR in physics learning has a positive effect on learning in the context of physics education [45]–[48], helps develop new knowledge, and improves students' ability in physics [49]. Therefore, this study aims to improve the knowledge in gravitational topics especially in the topics of escape velocity by developing and implementing teaching material with the integration of scaffolding and AR known as FizaAR. The study aims to propose an approach to integrating scaffolding and AR in solving mathematical problems in physics. FizaAR wishes to diversify student resources in physics education. Students are also in line with today's technology, especially AR, and are no longer tied to traditional learning because FizaAR can be used as an interactive learning resource that can stimulate students' interest.

2. METHOD

This study uses the case study approach. The case study approach combines both qualitative and quantitative data to present a comprehensive understanding of the topic [50]. Study shows by using qualitative and quantitative analyses, in case studies, will enhance the research process [51]. Another findings also show the increasing marks in students' data representations using a case study research that emphasizes the importance of structured inquiry for statistical literacy [52]. Trends of quantitative and qualitative approaches are more useful when used together than when either is used alone, but when combined, may produce richer and deeper research findings [53].

Sampling is the process of taking a subset of the population, observing them, and then extrapolating the results to the larger population [54]. The study used purposive sampling techniques. Purposive sampling is also known as judgment sampling, in which sample elements from the population that are thought to be typical, or representative are selected [54]. To guarantee that the sample is pertinent to the goals of the study, participants are selected based on their capacity to shed light on the research subject [55]. The technique of selecting the number of sets of components in such a way that the object depending on makes approximately the same estimation as the population for those personal characteristics that are currently the subject of data gathering [56].

The study involved 15 students in a public secondary school. They are at the age of 16 years old who were selected among students who enrolled in physics. The participants of the study are among students with low level of knowledge in a pre-liminary school test and among students who can use technology and have had exposure to modern technology learning such as online learning and learning using mobile applications. Case study research typically involves the detailed and intensive analysis of a single case or a small number of cases. The aim is not to generalize statistically, but to understand the dynamics within particular settings [57]. Pre-test and post-test design with a single group is suitable for preliminary investigation of an intervention's effect [58] and demonstrate the experimental effect [59].

The pre-test and post-test have been used in this research and has been evaluated and validated by expert teacher in physics. The questions in the pre-test and post-test has been validated by the aspects of formatting and suitability; the aspect of the questions are in line with the latest curriculum of physics secondary school in Malaysia. The questions have also been validated by the appropriateness and match the learning outcomes of the physics lessons. The questions that being selected are questions from previous year questions of the examination of high school education certificate Malaysia also known as "Sijil Pelajaran Malaysia" (SPM) and interstate level trial questions SPM. SPM is a well-known national level of examination at the end of high school education system. The technical aspects of validations also involve suitable instructions, appropriate diagram and simple language used in the test.

The research instruments used in this study are pre-test, post-test and semi-structured interview. The pre-test questions are the questions based on the selected topic in achieving the learning outcome in the topic of gravitation. The selected topic involved is finding the value of escape velocity. The design and development of FizaAR involved in three phases. The first phase involved the need analysis of the development a technology-based material and the topics by interviewing teachers in Peninsular Malaysia. The second phase involves the design and development of FizaAR that integrates the elements of scaffolding and AR. Finally, the third phase is the implementation and evaluation phase. After the implantation of FizaAR, students will undergo the post-test and selected students were also being interviewed to find their experience using FizaAR. The instruments used were semi-structured interviews where the theme is allocated with the support of each scaffolding aspects integrating AR in FizaAR.

The implementation of FizaAR was conducted for four periods of implementation. The implementation was using an approach of bring your own devices (BYOD) among students. The students brought their own Android mobile phone to the school during implementation. They will need to download the AR learning kit that is being prepared totally by Unity application. Each student will be given a printed-out AR marker for them to experience the learning environment in AR. Students need to solve all the questions involving the escape velocity in the exercises given. The questions include finding the value of escape velocity and finding the radius of certain planets accordingly. During the implementation, students need to scan the AR marker to get the relevant simulation. An audio element is also included for students so they can choose to listen for further explanations.

The analysis during the evaluation phase was carried out using NVivo version 14 which was used to identify several themes from the interviews conducted. The interviews were then analyzed by thematic analysis. The statistical package for the social sciences (SPSS) software version 29 was used to analyses the descriptive analysis which is the pre-test and post-test. Each student who was involved in the study and was interviewed had written consent from their parents and guardians. In addition, the study also had been obtained permission from the Education Research Application System (ERAS) of the Ministry of Education Malaysia, the State Education Department and the District Education Office.

3. RESULTS
3.1. Demographic profile

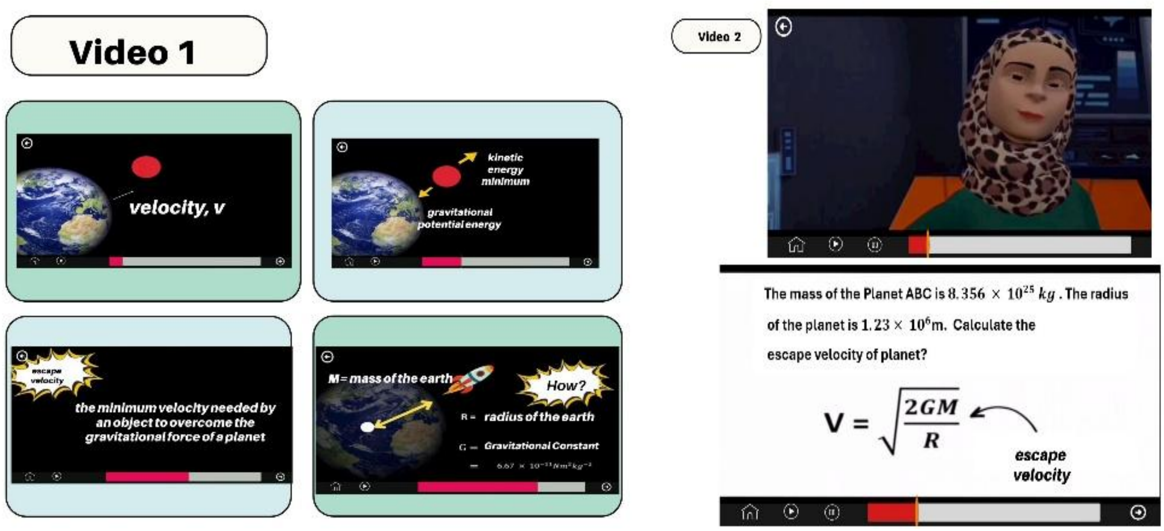
The demographic profile of the students involve are as shown. Table 1 shows the demographics of the participants. The analysis showed that the participants consist of 86.67% female while 13.33% are male. The study consists of a total of 15 students.

Table 1. The characteristics of the students involved in the study

Characteristic	Item	Frequency	Percentage (%)
Gender	Male	2	13.3
	Female	13	86.67

3.2. The integration of scaffolding element in FizaAR

The design and development of FizaAR is a mobile application with the integration of scaffolding. It is meant to be design with chunk of videos and animations provided to help assisting students understanding. The animation and video elements in FizaAR were desired to help in solving mathematical problems in physics especially in finding the value of escape velocity. Students have the experience of learning by watching small size chunk videos as guidance. Figure 1 shows the video and animation elements in the FizaAR to explain the theory of escape velocity and the calculations involved. Figure 1(a) shows the explanation on the theory of escape velocity. It also shows the formulae associated with the topic. Figure 1(b) shows the step-by-step video procedure on how to solve problems involving calculation.



(a) (b)

Figure 1. The video and animation elements in the FizaAR: (a) the explanation on the theory of escape velocity and (b) the step-by-step video on how to solve problems involving calculation

The integration of scaffolding elements in FizaAR has shown that it has been prepared in simplified, small subtopics. After the implementation, there were semi structured interviewed with the selected 8 students involved in the study. The learning experience based using FizaAR among students has shown that the animations and videos integrating the element of scaffolding. It has been provided in simplified, small subtopics. FizaAR in simplified small chunk of videos and animations had helped in increasing confidence among students. Students stated that previously, they lacked confidence and doubts, especially in solving problems involving mathematics in physics. FizaAR, according to their opinion, have helped them in increasing their confidence which has the feature of reducing the cognitive load of students.

> "*The apps FizaAR is in simplified. It's kind of fun. In the previous class, I don't really understand.*" (P1)
> "*Previously, I didn't really understand. I can't do it right away. After implementation, I think I can do it.*" (P2)

3.3. The integration of scaffolding element with AR

The integration of AR elements in FizaAR also being developed in small and manageable exercises task. Figure 2 shows the scaffolding element integrating AR in the exercises task provided by FizaAR. There are nine tasks in calculating and solving problems in the value of escape velocity. Students have to type in the desired value in the allocated space. Then, they will check the answer if it is correct or wrong.

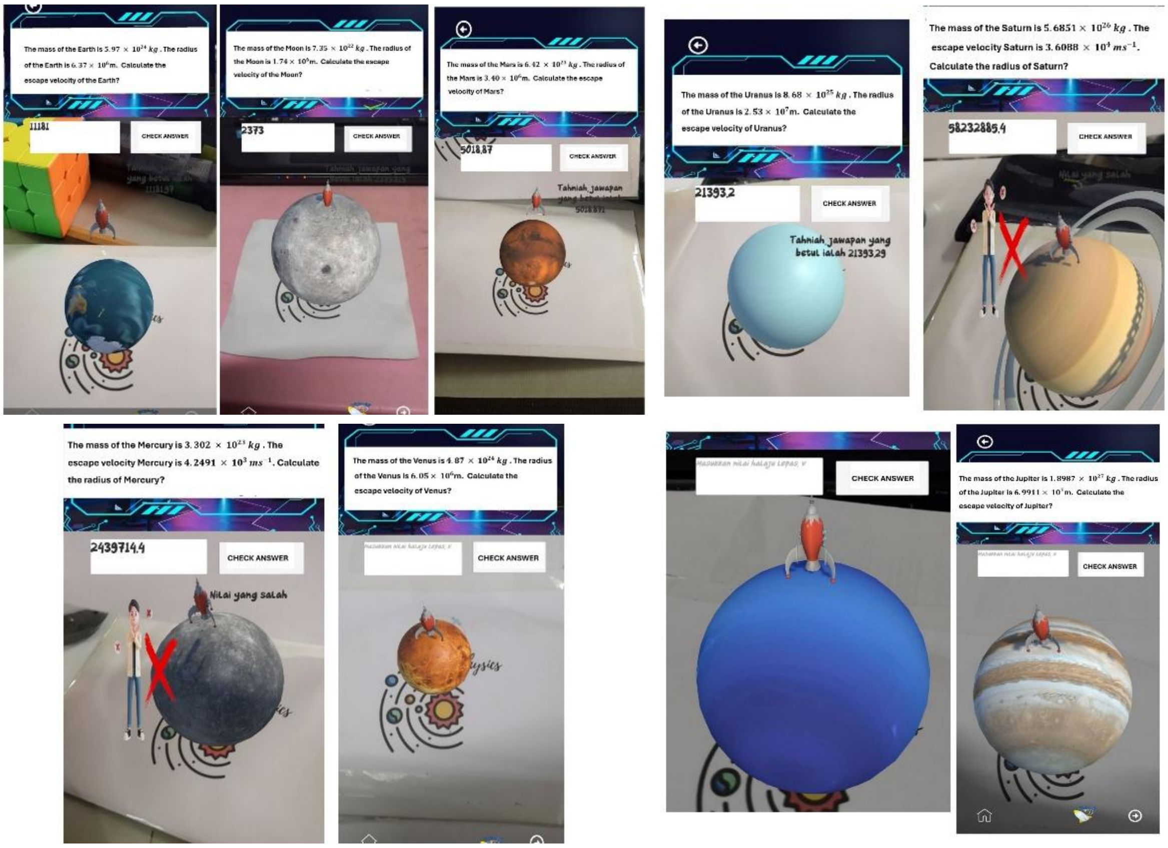


Figure 2. The scaffolding element integrating AR into nine exercises tasks provided by FizaAR

Three dimensional (3D) images of AR aspects were developed with the intention to make fun in physics learning. The AR simulation of rocket flown upward is being shown when the correct value is entered while the wrong answered will show the wronged sign. Students have to complete the nine cycles of calculation-based activity associated with the topic of escape velocity. The Unity game engine was used to develop the FizaAR with the integration with Microsoft Visual Basics on coding for calculation task involving mathematical function. Findings from the interview shows that FizaAR has helped students in visualizing and imagining the concepts involved. Students expressed their ability to imagine planets and simulations displayed in AR and further improve knowledge. For example:

> "*When I see the graphic. I can imagine it. Because there the FizaAR, I can imagine*." (P3)
> "*It pushed me further to study physics. For example, we can imagine. But after using the FizaAR, we can understand. It can be imagined and understood. So, there is no misconception*." (P4)

Secondly, FizaAR have been an organized, simple and compact material. Findings from students' interviews stating that FizaAR in their opinion is simplified compared to the textbook and is well organized. FizaAR have helped improve student knowledge because it is developed in a manageable navigation. It can help students to refer back if they forget any information related to the topic. For example:

> "*It is managed in a good flow. So that you can understand*." (P2)
> "*It can guide you back on the application. It helps in that we can refer back to any explanation when we need it.*" (P4)

Thirdly, FizaAR also has helped improved student knowledge because it applies the concept of playing while learning. The element of playing while learning can also create competition between peers during the implementation. It will then make the learning to be more fun and fill with excitement.

> "*Play while learning and do calculations. Because we have to calculate. It is an adrenaline rush. I was competing with my friend. Competing whether his answer is correct or if my answer is correct*." (P3)

The teaching and learning using FizaAR has the ability to make the learning environment to be exciting. The findings from the interviews showed that students expressed excitement and fun during learning sessions using FizaAR. It may be a slightly different learning experience than before. Students also think that it is more fun than learning using textbooks. Most of the students expressed their initial perception about this topic which was considered quite difficult, and then they started to be interested in this topic. In their opinion, it has the ability in increasing their interest and understanding. For example, the student stated as:

> "*It's excited. It seems that the FizaAR is more understandable. After that it looks cute. The planets look cute. Then after answering the question, a rocket was flown. After using the material, I understand better. For example, there is a step-by-step calculation shown. So, we better understand on how to use this formula*." (P2)
> "*In a way, it's portable. Because it is used on the mobile phone. One more thing if we want to use a book, it feels heavy to bring the book. But if it's a mobile phone, it's more fun, easier. FizaAR help. Because it is easy to understand. It's even more interesting than the book*." (P3)
> "*I'm interested because during my mid-term test, my physics score was bad. Because of this FizaAR, I became interested*." (P4)
> "*At first, when I study, I don't understand. After that, when I use FizaAR, then I seem to be able to understand. I can understand and can do the calculations. Usually, if I do physics, I can't get the correct answer. Now, I can. I am able to understand*." (P2)

3.4. The achievement among physics students before and after teaching and learning using FizaAR

The achievement of the students is measured from the pre-test and post-test. The questions were adapted from the questions of the examination high school education certificate Malaysia or SPM and from the compilation of state SPM trial questions and have obtained content validity from the physics expert teacher. Figure 3 shows the pre-test and post-test scores for each student involved in the study. The students have been labeled as students 1, 2, 3 until 15 as the total number involved were only 15 students. The results show a significant improvement for each individual student for their pre-test and post-test scores. Table 2 shows the minimum and maximum score for each pre-test and post-test. It also shows the value for the pre-test with mean=31.62 and standard deviation=10.83. For the post-test, the mean=84.7 with standard deviation=10.40. The minimum score in the pre-test is 16.7% and the maximum score are 58.3%. The study shows a score range of 41.6%. The minimum score obtained for the post-test are 62.5% and the maximum score are 95.8%. This has shown an increase in the mean value of score for post-test compared to the pre-test. The nine students out of a total of 15 students, which is 60%, have achieved a minimum score increase of at least 50% from the pre-test score. A total of four students have achieved a score increase of at least 40% from the pre-test score. Lastly, two students have achieved a score increase of at least 30% from the pre-test score.

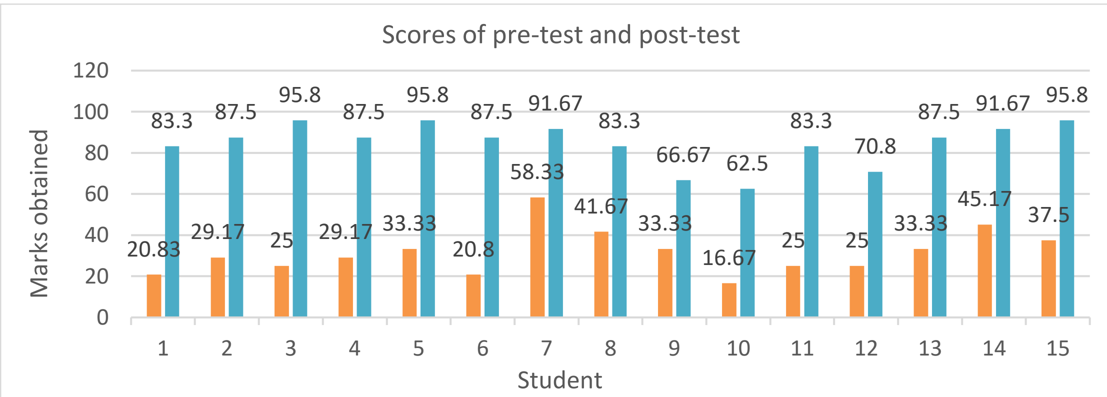


Figure 3. The scores of pre-test and post-test

Table 2. Show minimum and maximum score for the pre-test and post-test

Research instruments	Maximum	Minimum	Mean	Standard deviation
Pre-test	16.7	58.3	31.62	10.83
Post-test	62.5	95.8	84.7	10.40

4. DISCUSSION

The findings from the pre-test and post-test have shown an increase in scores for each individual student using FizaAR. The increase in test scores has shown that students' knowledge has increased. Learning activities using FizaAR have also increased students' confidence, especially in problem-solving skills involving mathematics. The findings of this study are in line with previous studies that stated positive impact [1] by improving students' cognitive abilities [60], increase student motivation and engagement [61] when learning involves the use of AR.

Study shows the scaffolding approach has shown an improvement in aspects of student self-learning [62]. A study inculcating zone of proximal development (ZPD) promotes students to build new understandings based on prior knowledge, often with the help of a teacher or peer [63]. Effective scaffolding gives opportunities for students to succeed, reducing fear and increasing engagement. Cooperative learning and interactive education are vital in this approach [63]. Scaffolding element entails incorporating pre-planned support structures into the learning process, ensuring that students may access relevant resources and advice throughout their assignments [64]. The concept of fading assistance is vital, which is also one of the aspect of effective scaffolding. It emphasizes in teachers gradually lessen their help as students become more proficient, encouraging autonomy and confidence in their teaching and learning. This plays as an element of gradual reduction of support in scaffolding [65].

A study in a school in Jambi City, Indonesia revealed that scaffolding and creative thinking skills impacted students in science process skills [66]. Understanding and solving physics problems requires good use of mathematical symbols, emphasizing the importance of students' proficiency in mathematical language [67]. A study show that using a transfer of mathematics knowledge model can greatly improve students' problem-solving abilities in physics, outperforming conventional teaching methods [68]. This study discovered that students who were taught utilizing the transfer of mathematical knowledge-model showed improved problem-solving abilities. Another research suggests that algebraic skills have a more significant impact on physics problem-solving than geometric skills, implying a specific concentration on algebra in educational contexts [69]. Our study shows that scaffolding with the integration of AR helps in increased students' confidence, especially in problem-solving skills involving mathematics in physics. It shows that the integration of scaffolding and technology, especially AR with algebraic and calculations helps in physics learning.

Another study integrating scaffolding in science education showed tiered e-scaffolding enhances scientific reasoning considerably by assisting students with less background knowledge in internalizing complicated ideas through inquiry-based learning (IBL) [70]. Scaffolding also shown a discovery in emotional assistance among the students. When scaffolding is effectively implemented, students report less anxiety and more involvement, indicating a positive emotional influence on learning based on a study done in Spain [71]. The study was conducted with students who took the Industrial Electronics and Robotics Associate Degree using a pre-post design. However, the study indicates that students value teacher scaffolding more than technological scaffolding.

Findings also suggests the development of learning materials with AR involves interactivity in the form of organized, simple and compact material. FizaAR through the aspect of interactivity helps in the aspect of combining limited working memory and further towards the strengthening of memory in the long term [72], [73]. The use of AR also shows that it increases achievement among students, and in fact, it can reduce the score gap between high achiever and low achiever class students [74]. The visualization aspect is one of the elements that help students understand abstract aspects. The importance of visualization in education is that it boosts cognitive processes by engaging visual thinking and boosting memory retention [75]. This is also in line with the findings of a study by Cai *et al.* [76] which states that the visualization aspect in language learning has given a new learning experience that has increased student achievement. This study also shows that the visualization aspect has helped in highlighting their self-confidence and ability in learning. Another study emphasizing the aspects of visualization involve in a field study experiment designed to assess the effectiveness of emphasizing the visualization aspect in two secondary school physics lessons, kinematics and Newton's laws of motion, by utilizing computer-aided learning materials such as appropriate diagrams displayed on a computer screen, video clips, animations, and simulations. The study employed a pre-test and post-test experimental design with the participation of 184 secondary school students from three government schools in Sri Lanka [77]. AR elements have helped in building concrete understanding because of abstract concepts through visualization aspects [78]–[80].

FizaAR also indicates the development of materials that integrated scaffolding and AR promotes playing while learning environments. This is in line with a study in GBL has been found to greatly improve student motivation and engagement. For example, upper secondary pupils demonstrated good player experiences and better problem-solving skills after playing a board game designed to teach force resolution in physics learning [81]. In a study of high school students, the element of play while learning in a GBL resulted effectiveness in learning outcomes, suggesting that students not only enjoyed the process but also acquired high levels of knowledge [82]. Elements of playing while learning also offer tangible learning. Physics toys are powerful instruments for making abstract subjects more approachable, improving critical thinking and understanding among students of different abilities [83].

5. CONCLUSION

The integration of scaffolding and AR are among the aspects emphasized during the development of FizaAR. This study shows the integration of scaffolding elements and AR have positive effect on the learning experience. Small, simplified subtopics applied in FizaAR help reduce the cognitive load among students. The study implies a recommendation for school teachers to diversify technology-based learning materials during teaching. In addition, the Ministry of Education and the District Education Office can propose a training courses for teachers in building effective technology-based materials, especially AR. Training are also proposed to the teachers on how to develop a teaching material with the element of scaffolding that will be benefit to the students. Furthermore, from the interview that has been conducted, the students view that the main element of scaffolding is FizaAR in small, simplified material has been a major role in their learning that helped them. The integration of scaffolding and AR will be helpful and make the teaching and learning to be interesting and fun. The research that has been carried out highlighted that the selection of the appropriate theory and approach can help students in improving their knowledge and achieving the desired learning objectives and further indicated that have increased students' interest, understanding and motivation.

This study aims to increase the knowledge among high school students in gravitational topics, especially the topics of escape velocity, by developing and deploying teaching materials that integrate scaffolding and AR. It is also suggested that the scaffolding element in FizaAR, which has the attribute of small, simplified subtopics, helps to increase students' confidence in physics learning especially making calculations. FizaAR wishes to diversify student resources to be applied with various learning activities. This study provides insightful information about how students view the use of AR learning material in 21st-century learning environments. Further research that is being suggested involves problem solving in Mathematics in another topic in physics. It is also suggested that the students involved include students from rural and urban areas.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Fariza Khalid	✓			✓		✓	✓		✓	✓	✓		✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

ETHICAL APPROVAL

The students involved in this study had obtained permission from the Education Research Application System (ERAS) of the Ministry of Education Malaysia, the State Education Department and the District Education Office.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author [FK]. The data, which contain information that could compromise the privacy of research participants, is not publicly available due to certain restrictions.

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