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Enhancing Mathematics Learners' Experience using Mobile Augmented Reality: Conceptual Framework for the Design and Evaluation

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***Abstract*—The application of augmented reality (AR) has been demonstrated, especially in education. However, to our knowledge, no conceptual framework exists to assist in designing effective augmented reality applications for a specific topic in the mathematics curriculum, such as square and square roots. This study proposes a conceptual framework for the design of augmented reality applications for mathematics. Multiple elements were included in the framework, including specification, design, and evaluation. A preliminary study elicited opinions and information from students and teachers. The proposed framework was used as the guideline to develop an augmented reality mobile application for square and square root topics. We later conducted application testing sessions to evaluate the app's usability. The sessions include app demonstration, pre-and post-test, usability testing, and an interview session to assess user satisfaction. Twenty lower secondary students (13 years old; seven males and thirteen females) took part. The findings of the pre-and post-tests and the application's usability and user interface satisfaction test show that the application has been proven effective in learning mathematics. There is a statistically significant difference between the pre-and post-test means. The application effectiveness level is 72.6 percent. Positive responses were also received during the interview. The findings indicate that the suggested framework may serve as a guide for designing future effective augmented reality applications for mathematics learning.**

***Keywords*— Augmented reality; mobile learning; learning experiences, students, design and implementations, game-based learning.**

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I. INTRODUCTION

Numerous studies have demonstrated that incorporating augmented reality into education has several beneficial effects, including an increase in students' motivation, comprehension, and performance on the subject [1]. For example, Hanafi et al. [2] emphasize several advantages of implementing augmented reality in education, such as providing engaging, entertaining, and motivating learning environments. This can result in improved learning, with students having a better understanding of the learning materials. Positive effects on students' perceptions of visualization and visual thinking are another benefit of implementing AR [3], [4]. Furthermore, a study by Kamal et al. [5] indicated that AR applications could increase participants' learning behaviour, engagement, and interest when using the application. These advancements result in enhanced educational outcomes and experiences. Meanwhile, Ahmad and Junaini [6] identify major benefits of AR: enhanced visualization and interactive learning, as well as increased confidence and comprehension.

Additionally, Petrov et al. [7] demonstrate that AR can help students in art education, with students' achievement and engagement in learning art increasing after using AR. In addition, Lai and Chang [8] indicated that augmented reality could significantly improve students' motivation to learn English. According to Mahayuddin and Mamat [9], AR can aid in learning the Malay language in autistic children. Implementation of AR also shows that it can help enhance English learning in early childhood education [10]. Students involved in the usage of AR technology show better results. It would be advisable to conduct a longitudinal study to assess the effects of AR over a longer period.

Besides, Erbas and Demirer [11] indicated that AR could improve achievement and motivation in learning Biology courses. Using AR, students can see a clearer view of cells in three-dimensional (3D) models. Thus, it enables students to understand the subject better and increases their knowledge to achieve better results on the test. Purwinarko et al. [12] also stated that AR visualization could help attract students' attention and improve their understanding. Another study by Ba et al. [13] discussed the usage of AR in biology subjects, specifically for cardiac circulation. It can enhance the learning of cardiac circulation. Besides, Awang et al. [14] indicated that AR could provide a fun learning experience, which enables students to enjoy the learning process and also improve their performance at the same time.

Even though many AR benefits have already been discussed, only a few AR implementations focus specifically on mathematics. Currently, a limited number of learning AR applications are developed focusing on a specific topic in mathematics [15]. Students need to understand and memorize formulas and ways to calculate numbers in mathematics. However, the conventional textbook only provides typed explanations and some static two-dimensional (2D) pictures. The typed explanation and static visual in 2D from the textbook make it difficult for students to imagine the situation of the question and how to calculate the answers [16]–[18]. There are many AR mobile applications for learning nowadays to provide a new learning environment for students. However, there are insufficient applications for secondary school students focusing on a specific mathematics topic. Due to that, there is limited usage of AR technology used for teaching and learning mathematics [19].

The following summarises the primary contribution of this paper:

- The proposed new framework aids in designing an augmented reality application for learning a specific mathematics topic. Unfortunately, no framework for developing a specific AR application for mathematics has been discovered to our knowledge.
- This paper demonstrates how the application developed using the proposed framework met the requirements and guidelines for developing an AR-based learning app.
- The developed math app is tested and proven through usability analysis, application testing, and demonstration sessions.

For this study, the following objective has been proposed: To design a framework for developing a mobile application for learning a topic in mathematics subject using the AR approach. The second objective is to design an effective AR learning interface for math students. Meanwhile, the third objective is to evaluate the apps' usability level among mathematics class students.

This paper is organized as follows: Section I discusses the literature review and related work. The methodology is explained in Section II. Section III presents the preliminary study framework design, shows the app prototype design and development, and deliberates the study results and discussion. Finally, Section IV concludes the proposed work.

A. Framework for AR in the Educational Field

First, the study by Saidin et al. [20] designed a framework for developing mobile augmented reality (MAR) applications for learning chemical bonds by applying two principles which are principles in the cognitive theory of multimedia learning and principles for designing visual tools on Chemistry. The study explains the details of the principles and how they can correspond to developing MAR. Second, MAR is developed and tested involving 16 Form 4 students. Third, a pre-test and post-test were done. Finally, a post-test is conducted after four weeks using the MAR. Results of the study show that the framework designed can systematically develop a MAR for learning Chemistry Bonds to reduce misconceptions through visualization. It can also improve students' achievement of the topic.

Meanwhile, a framework by Rahman et al. [21] focused on an interactive learning system for learning calculus by implementing augmented reality (AR) after providing a systematic literature review of studies that analyzed the effects of human-human and human-system interactivity in students' learning experiences and learning performances. The framework contains four components: human-system interaction, human-human interaction, learning experiences, and learning performance. Hence, three hypotheses were created based on human-human and human-system interaction. The first hypothesis is the increment in human-human interaction to enhance students' learning experiences, and this hypothesis is based on teachers' and students' interaction.

Next, the second hypothesis is that human-system interaction enhances students' learning experiences. This hypothesis is based on education using technology such as games as an interactive system. The third hypothesis is that improving the learning experience improves learning performance. Based on the study, the learning experience is different for each student, and the students have their ways of understanding a certain subject. The study concludes that factors of human-human and human-system interactions through the application developed using the framework should affect learning experiences and eventually affect learning performance.

Another study by Kureerung and Ramingwong [22] shows usability factor analysis to aid in designing and developing m-government applications. This study is not about education but rather about user interface design. Using the usability factor as UI design guidelines are categorized into four steps: requirement, discussion, design, and UI. In the requirement, inputs and goals are identified and then continued with the discussion, where questions are raised according to the inputs and goals stated in the previous step. Designing consists of a factor in use, factor requirement, and criteria. Finally, criteria of a sub-factor requirement are used to determine which user interface items or components are required to meet the criteria. Learnability, satisfaction, memorability, simplicity, privacy, and security were identified as critical factors in the design of an m-government application's user interface.

The study by Balcita and Palaoag [23] concentrates on identifying several factors influencing learning experiences that can be addressed by incorporating advanced technologies to improve student's learning experiences. The factors identified are based on literature, monitoring reports, previous surveys, and studies conducted at one of the maritime institutions in the Philippines. A survey on student satisfaction was conducted on 32 marine engineering students. The survey result shows that improvement needs to be done to the current learning method.

Meanwhile, Kapetanaki et al. [24] introduced a novel framework that incorporates AR and pedagogy to improve reading comprehension in special education. The study suggested using the schoolbook enhanced with AR content, providing real-time visual and audio feedback. Personalized content such as images, audio, video, and text also provides multiple entry points for each student. Marker-based AR and tablets were used in the application. AR content was created with a domain model, a pedagogical model based on learning and special education theories, a student model, AR, and Artificial Intelligence (AI) techniques. The study concludes that a framework is designed and suggests that future research should use it to compare its feasibility for various special needs groups. Details from each framework are summarised in Table I.

TABLE I
DETAILS FROM EACH FRAMEWORK

Framework	Topic	Platform	Components/ Focus
Saidin et al. [20]	Chemical Bonds	Mobile application	CTML and principles for designing visual tools on chemistry.
Rahman et al. [21]	Calculus	System	Human-human and human-system interaction
Kureerung and Ramingwong [22]	M-government applications	Mobile application	Aid in the design and development of m-government applications
Balcita and Palaoag [23]	Maritime Education	Not stated	Identify factors affecting learning experiences.
Kapetanaki et al. [24]	Reading Comprehension	Schoolbook enhanced with AR	AR technology is associated with pedagogical theories and AI techniques.

II. MATERIAL AND METHOD

This study utilized an explanatory mixed methods approach using qualitative data to supplement quantitative data. The data collection and analysis process was divided into two stages: preliminary study and further study. The preliminary study phase contains only quantitative data, whereas the subsequent study phase contains both quantitative and qualitative data. Data for both the preliminary and further studies were gathered using convenience and snowball sampling methods. Figure 1 shows the visualization of the research design.

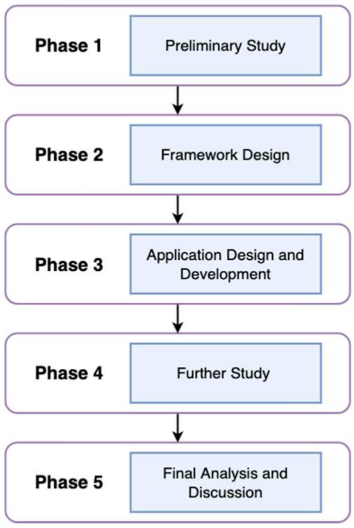

Fig. 1 Research design.

A. Setting

The preliminary study includes two types of respondents: students and teachers. The questionnaire for students includes a link to the pre-test. At the end of the pre-test, a link to the access multimedia notes (Google Drive) was attached, and a link to the post-test was included in the Google Drive. Teachers' information is gathered solely through a questionnaire, whereas students' information is gathered through a questionnaire as well as a pre-test and post-test. The questionnaire was distributed via social media platforms such as WhatsApp, Twitter, and Instagram. The flow of the preliminary study is depicted in Figure 2.

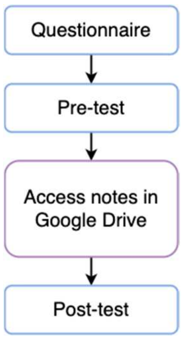

Fig. 2 Flow of the preliminary study.

A registration form (Google Form) was distributed to invite participants through social media platforms for further study. Participants who filled out the form were contacted and invited to join a group chat (WhatsApp). In the group chat, links were distributed to the pre-test, post-test, application demonstration session (Zoom meeting), questionnaire, and interview (Zoom meeting). Through the meeting, the application was explained to the participants, who then continued to watch the application demonstration video (screen recording of the actual application developed). The researcher also conducts a real-time shared screen session of the application to demonstrate application functionality. Figure 3 depicts the flow of further study.

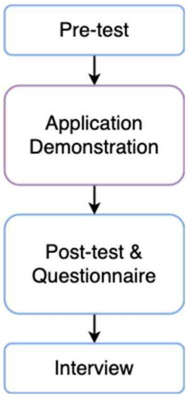

Fig. 3 Flow of the further study.

B. Participants

This study recruited secondary school students (13 years old) and secondary school teachers who teach mathematics subjects in Malaysia as respondents for the preliminary study. Only secondary school students from Malaysia were recruited as participants for further study. To be included in the further study, participants needed to (1) be 13 years old, (2) complete pre-test and post-test, (3) participate in Zoom video meeting (Application demonstration), (4) complete Application Usability Questionnaire (based on System Usability Scale (SUS)) to evaluate their perceptions on the usability of the application, (5) take part in the interview session.

C. Data Collection

The data collection procedure is divided into preliminary and further studies. The preliminary study consists of quantitative data gathered by using a questionnaire, pre-test, and post-test. Further study will include both quantitative and qualitative data. Pre-test, post-test, and a questionnaire were used to collect quantitative data, while interview sessions were used to collect qualitative data.

D. Quantitative Data

The augmented reality (AR) Application-based Learning Mathematics Questionnaire collected quantitative data for the preliminary study. The questionnaire is composed of several components that have been approved by four experts (senior lecturers). It is classified into three (5) sections: personal information, AR application, content, user interface, and problems and recommendations. Section A: Personal Information consists of four questions regarding respondent details. Section B: AR application includes seven questions about AR, games, and technology. Section C: Content consists of two questions asking respondents to choose which multimedia elements are suitable for a mathematics learning application and to explain why they chose those elements. Section D: User interface consists of eight questions about multimedia elements, each with one to nine sub-sections about its characteristics. Finally, section E consists of six open-ended questions and one close-ended question regarding problems and recommendations for AR in learning mathematics.

The Application Usability Test (AUT) was utilized in a further study. AUT is derived from SUS [25]. This questionnaire consists of 10 questions with a 5-point Likert scale to assess participants' opinions on the usability of the application developed using the proposed framework. In addition, the questionnaire consists of various system usability domains, including app complexity, ease of use, app functionality, and user confidence [26].

Pre-test and post-test were conducted using the same sets of questions adapted from the Form 1 mathematics textbook (Squares and Square Roots topic). The test consists of 10 multiple-choice questions (MCQ) for the preliminary study and 15 questions for further study. These two tests were used to assess students' performance in the topic before and after they used multimedia elements in the preliminary study and before and after they used the application for further study.

E. Qualitative Data

Interview sessions were used to collect qualitative data. The interview questions consist of 12 questions about the participants' perspectives on learning with the application and the application's user interface. Questions about user interfaces are derived from the Questionnaire of User Interfaces (QUIS) [27].

III. Results and Discussion

A. Preliminary Study

A pre-test and post-test, as well as a questionnaire, are part of the preliminary study. The pre-test and post-test questions are each made up of ten questions about the square and square root topics. There is a significant difference in the mean of the pre-test and post-test results. The post-test mean (8.58) is higher than the pre-test (6.21), indicating students' performance improved after using multimedia elements.

Augmented reality (AR) Application-based Learning Mathematics Questionnaire focuses on Form 1 students (13 years old) and secondary school teachers who teach mathematics. The data were analyzed in three sections: personal information, AR application, problems, and recommendations.

1) Personal Information: The questionnaire was distributed, and a total of 63 respondents' data were collected. However, 20 respondents' data were excluded due to uncertain data and duplication. A total of 43 respondents' data sets were chosen for analysis (33 students and 10 teachers). A total of 36 respondents are female, and 7 are male. Most respondents are 13 years old (77%). The teachers range in age from 22 to 38.

2) Augmented Reality Application: The first question is whether they are familiar with AR. Twenty respondents answered 'Yes' (47%), while 23 respondents answered 'No' (53%). More than half of the respondents are unfamiliar with AR (53%) (21 students, 2 teachers). This shows that the implementation of AR is not widely known among the respondents.

Respondents are mostly familiar with game-based learning as 36 respondents answered 'Yes' (84%) to the question (27 students, 9 teachers), and only 7 respondents answered 'No' (16%). Fourteen respondents (33%) said they had used an AR application before (10 students, four teachers). Another 29 (67%) said they have never used one.

A total of 14 respondents addressed the name of an AR Application that they have played. The most played AR game, according to 5 respondents, is *Pokemon Go, Choki-Choki,* *Boboiboy,* and *Harry Potter: Wizard Unite*, the next most popular games. Respondents listed *AR Geometry, Jurassic World Alive, Shapes 3D,* and *The Walking Dead.* Table II shows a list of the application listed by the respondents.

TABLE II
LIST OF GAMES

Name of AR application	Num. of respondents	Category	
		S	T
AR Geometry	1	0	1
Choki-Choki AR Boboiboy	3	3	0
Harry Potter: Wizard Unite	2	2	0
Jurassic World Alive	1	1	0
Pokemon Go	5	3	2
Shapes 3D	1	0	1
SNOW	1	0	1
The Walking Dead	1	1	0

* Respondents are allowed to list multiple applications.

This question is not mandatory because some respondents may not have a desktop or laptop. Most respondents use Windows as their operating system for their desktop/laptop (25 students, ten teachers). Only five students used Mac OS. Three (3) respondents do not respond to this question. The majority of respondents, 36 (84%), use Android as their operating system (29 students, and seven teachers). Only seven (16%) use iOS.

This question allows respondents to select more than one answer. According to the chart below, most respondents (27= 38%) prefer smartphones as a platform for learning with AR. A laptop is preferred by 20 respondents (29%), while a tablet is preferred by 14 respondents (20%). With nine respondents (13%), the desktop is the least preferred platform.

TABLE III
PLATFORM PREFERRED FOR AR LEARNING

Platform preferred for AR learning	Category	
	S	T
Desktop	9	0
Laptop	18	2
Smartphone	19	8
Tablet	7	7

3) Content: This section includes one Likert scale and one open-ended question. Respondents were asked to select which multimedia elements would work best for a mathematics learning application and to explain their selections. Multimedia elements listed are text, image, animation, video, and audio. All elements received a score above 4.70. Table IV displays a list of multimedia elements as well as their scores.

TABLE IV
LIST OF MULTIMEDIA ELEMENTS

Elements	Category		%
	S	T	
Text	4.88	5.00	98.0
Image	4.90	5.00	98.6
Animation	5.00	5.00	100
Video	4.94	5.00	99.0
Audio	4.79	4.90	96.2

Almost half of the participants stated that multimedia elements could aid in mathematics understanding (41.9%). The remaining respondents stated that using multimedia to learn mathematics is enjoyable, interesting, and beneficial.

4) User Interface: This section contains 34 user interface characteristics statements organized into eight (8) user interface elements appropriate for mobile learning applications [28]. Multimedia elements include navigation, text, image, content, color, audio, input/output support, and feedback.

Respondents mostly agreed with all of the listed user interface characteristics. Almost all characteristics received scores above 90%. Only the text element received a score of less than 90% for its characteristic, which is the use of serif and san serif fonts (71.16%). Two respondents (teachers) stated that any font is acceptable as long as it is readable. Another feature that received a score of less than 90% is the audio element, and the audio characteristic of providing sound effects and background music scored 86.98%.

5) Problems and Recommendation: This section includes six open-ended questions and one closed-ended question about respondent problems and recommendations for AR implementation.

93% of respondents are positive about using augmented reality in education, while the remaining 7% are neutral. Most respondents stated that using AR is beneficial and can help attract students' attention and create a fun learning environment.

"For me, this implementation needs to be done because it can attract the attention of students or students like me to learn the subject in more depth if this 'Augmented Reality' is found in textbooks or school exercise books." (Form 1, secondary school student, female)

A respondent also mentioned that AR could provide a 3D visual and in-depth explanation, which can improve students' understanding.

"It's a good thing to show the images in 3D, it shows how it works, and that helps students understand more, even I myself use this method sometimes, but when teaching it's better using a tablet (since my students, around 10 kids) instead of a smartphone, so the views bigger." (26, secondary school teacher, female).

Forty-two (98%) of the 43 respondents provide positive responses to the question of whether AR can aid in the learning process, while 1 respondent provides a neutral response. Most of the responses indicate that AR can aid in providing clear visualization, which results in a greater understanding of the subject.

"Could be helpful to students who need to visualize the topics to understand and those who get bored easily during class. It would captivate them and hopefully make the lessons easier to understand and to memorize." (24, secondary school teacher, female).

Respondents also mentioned that AR could provide an interesting and enjoyable learning experience.

"*Yes, because students will be more interested in the learning process using AR, which can avoid boredom during learning sessions and AR can also give a clear visualisation compared to pictures only*." (Form 1, secondary school student, female)

AR can help the mathematics learning process, receives a positive response from 79% of respondents, a negative response from 7%, and a neutral response from the remaining 14%. Most respondents' responses are related to visualising the mathematics learning process. They claimed that visualization and AR could help provide a clear solution and make it easier for students to imagine the solution.

"I think AR would be much more suitable to help with the math learning process because it can visualize how the solutions process with detailed explanation on how to answer the math question." (Form 1, secondary school student, female).

Some of the responses also mentioned that AR could provide students with a fun and interesting way of learning that will keep their interest in learning mathematics.

"*I think AR is suitable to help to learn mathematics because it is fun*." (Form 1, secondary school student, female).

Several responses also mentioned that using AR to learn mathematics can keep students from becoming bored during the process.

"*Yes, because math is boring, and when you use augmented reality, it makes more fun*." (Form 1, secondary school student, female).

Because the respondents' negative response does not include an explanation, it is unclear why the respondents believe AR is unsuitable for the mathematics learning process. Respondents who gave neutral answers stated that they were unsure because they had never used the AR application and that AR may be appropriate for questions in a situation.

Game-based learning can help ease the learning process. Forty-one (95%) of the 43 respondents gave positive responses, while the other two (4%) gave neutral responses. Respondents stated that game-based learning could assist in providing a fun and interesting learning environment that can help attract students' attention.

"Yes, because I did this every day at school, I teach my students through the game, and they learn it by using all motor skills they have, fine motors, sensorial, focus, and solving problems, and by doing this, they have fun playing the game while studying." (26, secondary school teacher, female).

Respondents also mentioned that game-based learning could also help increase students' memorization skills.

"*Yes. Because game-based learning is more interesting and can help students to memorize formulas and so on."* (Form 1, secondary school student, female).

Neutral responses stated that they were unsure and those line interruptions may occur while using the application.

Respondents chose nine topics from a list of 13 in the Form 1 mathematics textbook syllabus as the most difficult topic for students to learn. Among eight respondents, the most popular topic is Squares and Square Roots. Seven respondents chose Linear Inequalities, and two respondents chose basic Polygons. Table 11 shows the list of topics that are considered difficult by the respondents.

The most difficult topic is Squares and Square Roots, as chosen by the greatest number of respondents. According to the respondents' explanations, most of them have difficulty understanding the topic and cannot properly apply the formulae because they have forgotten how the calculation works.

AR can help ease the learning of the topic chosen; Square and Square Roots received seven positive responses and one neutral response. Respondents stated that AR could help attract students' attention, ease students' understanding, and provide a clear explanation of the topic.

"*Yes. AR may be helpful in explaining to attract students so that students easily understand*." (Form 1, secondary school student, female).

One of the respondents emphasizes that AR can help, but only if teachers provide clear explanations.

"*Yes, but it must be with the explanation from the teacher clearly and easily understood*." (Form 1, secondary school student, female).

The neutral response stated that the respondent was unsure whether AR could aid in the learning process.

B. Framework Development

To complete this framework, several components are combined. The framework is divided into three major phases that support the concept of user-centered design in order to focus on users' requirements. The first phase is the design, during which important data is gathered. This study focuses on the AR application's contents (multimedia elements) and user interface. Marker-based AR was chosen for this study because it is the most commonly used type of AR in education [29]. Next, a table is created based on the topic chosen to list the most crucial information about the topic. The table is required to determine which multimedia contents are appropriate to be used in enhancing the topic's learning process. Each mathematics topic has unique information required to improve students' understanding. These data were gathered via a preliminary study and a mathematics textbook for Form 1 students. For example, by focusing on the Squares and Square Roots topic, important information needed to be focused on is shown in Table V.

TABLE V
IMPORTANT MULTIMEDIA ELEMENTS FOR SQUARES AND SQUARE ROOTS TOPIC

Topic	Implementation in application
Text	Explanation of the topic and formulas.
Image	Displays the shapes and situational questions.
Animation	Show step-by-step calculations.
Video	Explain the calculation for situational questions.
Audio	Provide a fun learning environment.
2D and 3D model	Visualise formulas that include shapes.

The application user interface (UI) was designed using guidelines by [28] and incorporated the Cognitive Theory of Multimedia Learning (CTML) [30]. The UI designed by [28] is used because it focuses on mobile learning for children and has been approved by experts. According to the study, the following eight elements are critical for application UI for children's mobile application design: navigation, text, image and icon, audio, content, color, input/output support, and feedback. In addition, elements with appropriate characteristics for the proposed application are used.

After all relevant content for the topic has been identified and the UI characteristics have met the requirements, CTML will be integrated to apply learning mathematics effectively. As shown in Table VI, each screen in the application will be guided by the CTML principles.

In this research, an effective application is determined using the ability to increase learning performance, usability, and user interface satisfaction. Three evaluation tools are included: pre-and post-tests, a System Usability Scale (SUS) [25], and a Questionnaire on User Interface Satisfaction (QUIS) [27]. Pre-tests and post-tests are used to evaluate the users' knowledge gained from the application. Questions for pre-and post-tests can be obtained from the learning topic of the application. The result from pre-and post-tests can conclude whether the application developed can help students learn the topic and increase their performance. SUS is used to evaluate the usability of the application. Lastly, QUIS is used to assess users' satisfaction with the applications' interfaces. Figure 4 shows the full view of the proposed framework

TABLE VI
CTML IMPLEMENTATION ON AR APPLICATION

Principles of Cognitive Theory of Multimedia Learning [30]	**Explanation**	**Implementation in the novel AR application**
Coherence	Reducing the process of unnecessary material by removing unnecessary material.	Only include relevant statements/graphics.
Signaling	Reducing the process of unnecessary material by implementing cues for how to process the lesson.	Provide a guide for the user on what to do next (Info button).
Redundancy	Refrain from using identical streams of printed and spoken words all at once with the corresponding animation.	Use words as narration.
Spatial Continuity	Cut down the need for visual scanning by setting printed words near the corresponding parts of graphics.	Set the corresponding text near the picture.
Temporal Contiguity	Minimize the need to hold the representations in memory by simultaneously providing corresponding narration and animation.	Display the narration and animation synchronously.

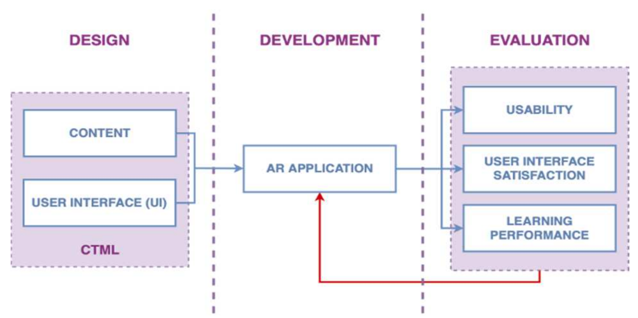

Fig. 4 Proposed framework.

C. App Prototype Development

1) Navigation: The next and previous page buttons are designed with a simple arrow shape, and both are located in the same location on every screen. The screen's title is displayed at the top of the screen.

2) Text and image: The topic's information is presented in the form of a simple text explanation and a cartoon-style image. The font used is Arial, which is simple to read, and the font size is appropriate for the screen size.

3) Content: For the calculation, only essential information is displayed. The information is displayed using a step-by-step process through animation transition. First, the 3D model is animated to capture the attention of users. Then, on the lower-right corner of the screen, a question mark (?) button is accessible. When the button is pressed, information about the 3D model is displayed. Figure 5 shows the 3D model content.

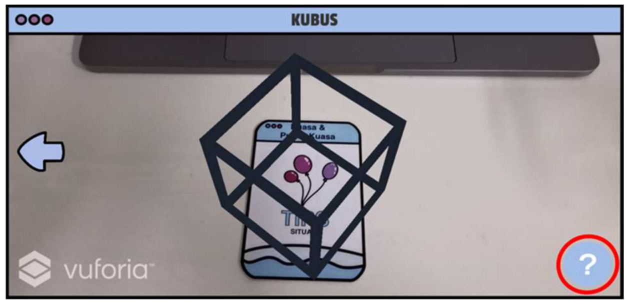

Fig. 5 3D model content.

When the question mark (?) button is clicked, the information about the 3D model is displayed. To avoid confusion, the information provided is kept simple. Figure 6 shows a 3D model content with information.

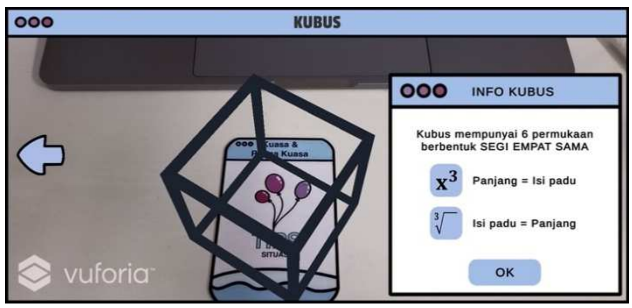

Fig. 6 3D model content with the information.

A quiz-style game is added to the application to assess the user's understanding of the topic quickly. In addition, each sub-topic question's score will be displayed.

4) Color: The application background and contents are in pastel colors. The application's overall colors are blue, white, and black. The majority of the components in the application are in various shades of pastel blue.

5) Audio: The application includes background music to provide a fun learning environment. The music was obtained from bensound.com. In addition, all buttons in the application have a click sound.

6) Input/output support: The application implements simple user input. The application's input consists of button clicks and drags and drops.

7) Feedback: Immediate feedback is given when the user completes a task in the application.

D. Results

Analysis of data for further analysis phase was conducted after application testing (demonstration) sessions were completed. Data is collected using convenience and snowball sampling methods. Data collected were analyzed using the Statistical Package for the Social Sciences (SPSS). The registration form to join the application testing session was distributed through multiple social media platforms such as WhatsApp, Instagram, and Twitter. As a result, 25 participants' registration was received. However, only 20 participants completed the demonstration session.

1) Demographic Data: This section includes the participant's age, gender, and experience using augmented reality (AR) applications. All participants are 13 years old. Based on 20 participants, 13 are female, and 7 are male. Therefore, 85% (n=17) of the participants do not have experience using AR applications, while another 15% (n=3) have experience using AR applications.

2) Pre-test and post-test: Pre-test and post-tests consist of 15 *Kuasa Dua, Punca Kuasa Dua, Kuasa Tiga, and Punca Kuasa Dua* topic questions retrieved from the Form 1 mathematics textbook. The pre-test was done before the application demonstration, while the post-test was done after the demonstration session.

The scores for the pre-test and post-test were computed to analyze the participant's performance before and after the application demonstration. The minimum score for the pre-test is 5, and the minimum score for the post-test is 6. The maximum score for both the pre-test and the post-test is 14. Meanwhile, the difference between the minimum and maximum scores is 9 (5-14) for the pre-test and 8 (6-14) for the post-test. The mean score for the pre-test is 9.70, with a standard deviation of 2.975. The mean score for the post-test is 11.20, with a standard deviation of 2.504. The mean for the post-test is higher than the pre-test, which shows that the average score in the post-test is higher than the pre-test. Table VII shows details of the descriptive analysis.

TABLE VII
DESCRIPTIVE ANALYSIS FOR PRE-TEST AND POST-TEST

Test	N	Mean	Std. Deviation	Min	Max
Pre-test	20	9.70	2.975	5.00	14.00
Pos-test	20	11.20	2.504	6.00	14.00

Inferential analysis through a non-parametric test (The Wilcoxon Signed-Ranks Test) is used to analyze the mean of the pre-and post-tests due to the limited number of samples (20 participants). The hypotheses for the analysis are:

- $\mathbf{H_0}$: There is no significant difference between the mean of the pre-test and post-test scores.
- $\mathbf{H_1}$: There is a significant difference between the mean of the pre-test and post-test scores.

Results from the test show that four participants got lower scores on the post-test than the pre-test (Negative Ranks), 11 participants received higher scores on post-test than pre-test (Positive Ranks), and five participants got the same scores on both the pre-test and post-test (Ties). Table VIII shows the ranks for pre-and post-tests. ('N' is the number of participants, 'a' refers to post-test < pre-test, 'b' refers to post-test > pre-test, 'c' refers to post-test = pre-test)

TABLE VIII
RANKS FOR PRE-TEST AND POST-TEST

Ranks				
		N	Mean Rank	Sum of Ranks
Post-test – Pre-test	Negative Ranks	4^a	4.00	16.00
Pre-test	Positive Ranks	11^b	9.45	104.00
Post-test	Ties	5^c		
	Total	20		

The significant value from the test is 0.011, which is lower than the alpha value of 0.05. Thus, the $\mathbf{H_0}$ is rejected. This means a significant difference exists between the mean of the pre-test and pre-test scores. The result verifies that using AR applications guided by the proposed framework can improve participants' performance in mathematics topics. Table IX shows the Wilcoxon Test statistics of the pre-test and post-test ('b' means based on negative ranks).

TABLE IX
THE WILCOXON TEST STATISTICS OF THE PRE-TEST AND POST-TEST

$\boldsymbol{Test\ Statistics^a}$	
	Post-test − Pre-test
Z	-2.529^b
Asymp. Sig. (2-tailed)	0.011

3) Application Usability Test: The application Usability Test (AUT) is derived from System Usability Scale (SUS) [27]. The questionnaire scores were calculated using the SUS equation, and the three equations below were used. Adjective ratings, as in [31], are used to analyze participants' scores.

$$Score_{Q1,Q3,Q5,Q7,Q9} = Scale\ score - 1. \quad (1)$$

$$Score_{Q2,Q4,Q6,Q8,Q10} = 5 - Scale\ score. \quad (2)$$

$$SUS\ scores = Sum\ of\ scores \times 2.5. \quad (3)$$

All participants' scores are above the 'OK' level based on the adjective ratings, 65% of the participants achieved an 'OK' rating, and 15% achieved 'GOOD. Another 15% of the participants are at an 'EXCELLENT' rate, and the remaining 5% rated 'BEST IMAGINABLE'. As for the mean from all 20 participants, the score is 72.625, which is the 'OK-GOOD' rate. According to a study by [27], any product or system's usability is acceptable if the overall usability percentage is greater than 55%.

4) Interview: Interview sessions were done using Bahasa to ease the participants' understanding of the questions. All answers were transcribed and translated into English for data analysis purposes. The interview consists of two main sections, learning and user interface. The learning section includes five questions, while the user interface section consists of seven questions. Some questions have sub-questions, and participants can provide multiple answers to each question.

Question 1 inquired about users' satisfaction with the AR application's learning method. The learning method was deemed satisfactory by all 20 participants. When asked why they were satisfied, most participants stated that the application assisted their understanding of the topic and provided clear explanations of the topic. Table X shows a list of participant responses classified by themes.

TABLE X
USERS' SATISFACTION WITH LEARNING USING AR APPLICATION

Theme	No	%
Ease understanding	9	45
Easy to use	1	5
Easy to study	1	5
Organizing method makes it easier to use	2	10
Interesting	2	10
Provide detailed explanation	1	5
Simple	2	10
Clear explanation	1	5
Fun	1	5
There are many benefits of using this app	1	5

Question 2 surveyed the impact of using this method as a learning process on understanding the subject and whether the explanation provided made it easier for them to understand it. Table XI classified the responses of the participants based on themes.

TABLE XI
IMPACT OF LEARNING USING AR APPLICATION

Theme	No	%
Ease understanding	9	45
Simple notes that lead to easy understanding	1	5
More eager to learn because it is easy to understand	1	5
Easy	3	15
Easy to study because the notes are complete	1	5
Notes easy to memorize	1	5
Make study easier for a student who has problems understanding the topic	1	5
A detailed explanation	1	5
Give a positive effect	1	5
Learning becomes fun	1	5
This application does not make you bored while studying	1	5

Question 3 asked participants if they thought this method effectively taught mathematics. All participants answered yes. Some of them provide explanations as themes shown in Table XII.

TABLE XII
EXPLANATION FOR QUESTION 3

Theme	No	%
Notes provided are simple. Easy to understand	1	5
Notes provided easy to understand	1	5
Easy to understand	1	5
Because this method can increase understanding for students who find it difficult to learn face-to-face with the teacher. Because this app is easy	1	5

Question 4 asked whether the application displayed the 2D and 3D models clearly displayed, and all participants answered 'Yes'. Finally, Question 5 focuses on whether multimedia content in the application helps them understand the topic better. Again, all participants answered 'Yes'. Table XIII summarizes the main themes based on five questions in the learning section.

TABLE XIII
SUMMARY FOR LEARNING SECTION

Theme	No	%
Satisfied with the learning method (using AR)	20	100
Easier to understand the subject	20	100
Effective method for learning mathematics	20	100
Can clearly view 2D and 3D model	20	100
Usage of multimedia content (images, videos, 2D & 3D model) helps to understand the topic better	20	100

Questions 6 to 12 are about the application's user interface. Some of the questions are from the User Interface Satisfaction Questionnaire (QUIS) [27]. Question 6 implied feedback from participants on the font type and font size used in the application. Focusing on whether the font used can clearly be seen by participants. All participants agreed that the font used was easily readable. One participant (P10) stated that the font needed to be enlarged slightly. Question 7 asks participants' opinions about the information on the screen. Considering whether the arrangement of information on the screen is appropriate and whether the arrangement of information is consistent. All the participants agreed that the information displayed was appropriate and consistent.

Question 8 focused on the application's screen sequence and navigation. Is the screen presented in a logical order, and is it simple for them to return to the previous and main screens? The screen is in sequence, according to all participants. 95% (19) of participants said returning to the previous and main screens is simple. In comparison, 5% (1) said he is confused when returning to the previous screen after watching the video on the '*Situasi*' page. Next, does the screen's navigation take place smoothly, and does the button provided navigate them to the right screen? Again, 95% (19) participants said that the screen's navigation is smooth, while 5% (1) participants said that some parts do not navigate smoothly. All participants agree that the button provided navigates them to the right screen.

Question 9 is regarding the design of the screen. Are the screens aesthetically pleasing, and do the participants find the screen design and layout appealing? All participants agree that the displayed screens are aesthetically pleasing and appealing. The researcher then questioned participants on their thoughts on the colors and color combinations used in the application.

Question 10 focuses on the application's control method. Is it easier for participants to use the application with a touch screen and virtual buttons? All participants answered 'Yes'. In question 11, participants were asked their thoughts on the application's display orientation. A total of 85% (17) of participants found that the landscape orientation used in the application is suitable. Several participants also stated that using a landscape orientation allows them to see the information displayed on the screen more clearly because it provides more space on the screen. Meanwhile, 10% (2) of the participants prefer the portrait mode as they find it easier for them since people normally use a smartphone in the portrait mode. Another 5% (1) of the participant stated that she does not prefer orientation and that either is fine.

Question 12 is about the application's sound effects. The researcher inquired whether participants thought the use of sound effects in the application was helpful and whether it created a fun learning environment. A total of 90% (18) of participants agree that the sound effect is helpful, while 10% (2) think it is distracting and causes them to lose focus. Also, 95% (19) of the participants agree that it creates a fun learning environment. A participant explained that the usage of sound effects could prevent students from being bored while using the application, and two (2) participants emphasized that they prefer the background sound to be different and not repeat the same song. Likewise, 5% (1) prefer to learn without background sound to focus on learning using the application. Table XIV summarizes themes for seven questions in the user interface section.

TABLE XIV
SUMMARY FOR USER INTERFACE SECTION

Theme	No	%
The application used a clear font type and size	20	100
The arrangement of the information on the screen is suitable (logical) and consistent	20	100
The next screen in the sequence	20	100
It is simple to return to the previous and main screens	19	95
The navigation of each scene takes place smoothly	19	95
The buttons provided in the application navigate you to the right scenes	20	100
The screens are aesthetically pleasing	20	100
The layout and design of the screen are appealing	20	100
The application's control methods (touchscreen and virtual button) make it easier to use	20	100
The orientation used in the application is suitable	17	85
The use of sound effects in the application is helpful	18	90
The sound effects create a fun learning environment	19	95

E. Discussion

1) Ability to Improve Student's Performance: One of the main focuses for developing the application is to improve the students' performance. As in the preliminary study, respondents believe that implementing augmented reality (AR) in mathematics could help improve their understanding of the topic. Improving their understanding would lead to increasing their performance on the topic itself. Multiple studies have already indicated that using AR can help enhance students' performance in various subjects. According to the result, this study also proved to improve student's performance in the topic of mathematics. It is proven that 55% of the participants involved in the study received higher scores in the post-test than in the pre-test. The findings agreed with a previous study by Ahmad and Junaini [16] and Moreno et al. [32], in which AR application demonstrated that it could improve mathematical understanding and learning.

Participants said they were satisfied with the AR application's learning process in the interview session. Most of the participants indicated that it eased their understanding of the topic. Several participants also mentioned that the application provides a simple explanation that helps them understand the topic easily. They also agreed that the usage of AR is effective for learning mathematics. The application is equipped with multiple multimedia contents, such as a 2D model, a 3D model, images, and videos, to ease student understanding of the topic. All participants agree that the multimedia content used is helpful and able to help them understand the topic better.

Participants were also asked about the usage of sound effects used in the application. Most of the participants agreed that the sound effect could create a fun learning environment. However, 10% of the participants prefer to use the application without sound effects to concentrate on the learning process. The pre-test, post-test, and interview results suggest that the proposed framework can potentially develop effective AR applications that can help students improve their mathematics performance.

2) Application Usability: One of the most important aspects of developing an effective educational application is its usability. This study, like the one by Alahmadi et al. [33] and Ramadhani et al. [34], used SUS to test the usability of the AR application. However, this study focuses on mathematics, whereas Alahmadi et al. [33] and Ramadhani et al. [34]'s study focus on medical education and the design of computational digital game interaction and user interfaces. All participant results show that the application developed is acceptably based on the calculated usability percentage. Statements about usability include both positive and negative aspects. High scores for statements 1, 3, 5, and 7 indicate positive aspects of the application, while high scores for statements 2, 4, 6, 8, and 10 indicate negative aspects. This study discovered that the mean scores for all positive statements are greater than 4.

Even though the mean for positive aspects is high, we discovered that some negative aspects also received high scores. The highest score is 3.5, indicating the application is unnecessarily complicated, and another score above 3 is 3.05. This is where the statement about needing to learn a lot of things before being able to use the application is made. It was unclear why the participants felt the application was unnecessarily complicated and needed to learn a lot before using it. However, they also stated that the application was simple, and they felt confident using it.

According to Chin et al. [27], an application's usability is acceptable if its overall percentage exceeds 55%. Usability percentages in the previous study were 76.75% and 70.5%, respectively. The usability percentage in this study is 72.63%, which is higher than the usability percentage of Ramadhani et al. [34]'s study. SUS has been used to assess the usability of AR applications in a variety of subjects, so it is reasonable to assume that SUS is also appropriate for AR mathematics.

3) Application User Interface Satisfaction: CTML principles were used as guidelines for multimedia elements and the user interface of the AR application in this study, as well as in studies by Saidin [20] and Jalaluddin [35]. Both studies used pre-test and post-tests to assess the effectiveness of CTML implementation. On the other hand, the user interface satisfaction interview in this study was used to further explain user opinions on the user interface and multimedia elements used. This study also focuses on mathematics, whereas Saidin [20] and Jalaluddin [35]'s studies focus on chemical bonds and vocabulary, respectively.

Multiple user interfaces (UI) components were discussed to develop an effective application. Focusing on the user interface that can help in learning mathematics, seven components are included in this research: font, displayed information, navigation, screen design, control method, and orientation mode. From the result of the interview, most of the responses about the user interface are positive. In addition, all participants were satisfied with the font used in the application.

Like the font component, all participants were also satisfied with the information displayed on the screen. Participants found that the information displayed was suitable, and the information on each screen was consistent. In the navigation component, all participants agree that the screen displayed is in sequence, and it is easy for them to return to the previous and main screens. A total of 95% of participants were pleased with the navigation of each screen.

Meanwhile, with the screen design, all participants found that the screen design is aesthetically pleasing. They also agree that the screen design and layout are attractive. Regarding the color and color combinations used in the application, all participants were also satisfied with the color used. Several participants indicated that the color used is calming and suitable for educational applications. As the application developed is designed for the Android platform, the control method implemented is touchscreen. All participants were satisfied with the control method used. The orientation model used was well-liked by 85% of the participants.

The findings of this study support the idea that the user interface is crucial in helping students understand math concepts. The data also shows that using multimedia elements aids understanding. The most frequently repeated key response from the interview is understanding. This means that the proposed framework can be used to create an effective user interface and incorporate multimedia elements into an AR application.

F. Limitation

This study has some limitations. First, the number of participants was limited. Second, because the researcher could not conduct the application demonstration session face-to-face due to COVID-19, the application demonstration was conducted online using Zoom.

IV. CONCLUSION

Here, we proposed a framework for developing an effective application for learning a particular mathematics topic. According to our preliminary study, multimedia elements are required for learning mathematics, and the use of AR has the potential to aid in the learning process for difficult mathematics topics. The use of appropriate multimedia elements to aid mathematics understanding was also addressed, as each mathematics topic requires distinct multimedia features to aid the user's understanding. Then, significant findings from the preliminary study also show that an effective AR learning application must have acceptable usability, a user interface that is pleasing to users, and the capacity to boost users' learning performance. As a result, we added three evaluation criteria to the framework to ensure that the AR application developed using the proposed framework was effective. The three critical criteria for evaluating the developed application's effectiveness are the ability to improve students' performance in the mathematics topic, passing the usability test, and providing a user interface that aids in the learning process. The results obtained from 20 participants suggest that the AR application developed using the proposed framework was effective for mathematics learning. This shows that the proposed framework has the potential to serve as a guide for the development of effective augmented reality apps for mathematics learning.

Future work will determine the long-term effectiveness of this mobile app for mathematics education. Future mixed-methods studies involving participants from various cities and countries could be carried out to gain a broader perspective.

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