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Design and development of learning mathematics game for primary school using handheld augmented reality

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Abstract. The traditional learning methods have some drawbacks and limitation such as restricted learning space, high cost, and lack of student engagement. In the era of digitalization, traditional education starts to transform into a more dynamic and modern education with the influence of the 21st-century learning method. Moreover, due to the pandemic, schools and universities are moving to digital learning to contain the spread of Coronavirus Disease 2019 (COVID-19). Therefore, the aim of this project is to develop a Mathematics game using handheld Augmented Reality (HAR) for primary school children as an alternative method in learning Mathematics. There are three main phases have been carried out, first is to study the requirements of an educational game. The second phase involves the design and development including the game element, storyline, game characters as well as user interface design. Finally, the third phase is integrating the learning Mathematics game using HAR, followed by evaluation. The evaluation of the learning Mathematics game was carried out for usability and user acceptance. The usability results show that the users are satisfied with the prototype and feedbacks show the game is fun. Overall, this project has successfully produced a learning Mathematics game using HAR for primary school children.

1. Introduction

In the era of digitalization, traditional education starts to transform into a more dynamic and modern education with the influence of 21st-century learning method. A modern education system focuses mainly on using technology in education. One of the common uses of technology in education is digital game-based learning also known as an educational game. Today kids grow in a world full of the advancement of technology, a lot of electronic games that targeting our youth. This causes kids today to spend leisure time playing electronic games is not an extraordinary thing [1]. Besides, there are many researchers argued that electronic game such as the educational game is potential to support learning and it shows a positive improvement in various domains such as science, statistics, math, and biology [2].

Recent year Augmented Reality [2] has evolved as a popular technology and rapidly been used in the fields of business, gaming, logistics and others [3]. There are various studies have shown AR technology offers many advantages in the education field. For example, a digital immersion provides by AR to build a student's confidence in solving problems in the real world [4]. This paper will discuss about a proposed game focusing on learning Mathematics that combines the use of handheld AR

technology and it is specifically designed for primary school children to strengthen the knowledge on the topic fractions. The outline of this paper will be as follows; Section 2 presents the related literature review, Section 3 outlines the methodology and Section 4 explains the implementation of this project. Sections 5 and 6 respectively discuss on the results and testing, while Section 7 summarizes the paper.

2. Literature Review

2.1. Background of Mathematics

Mathematics was defined as the abstract science of quantity, number, and space either as abstract concepts whereas applied Mathematics was defined as Mathematics that is applied to other disciplines, for example, physics and engineering [5]. Mathematics is not only one of the compulsory subjects in Malaysia's education system and it is also one of Science, Technology, Engineering and Mathematics (STEM) subject. According to the Education Blueprint 2013-2025 published by Ministry of Education Malaysia, the aims to implement STEM education is to prepare students with the skills to meet the science and technology challenges and to ensure that Malaysia has a sufficient number of qualified STEM graduates. In primary school, children learn about subtopics like the whole number, fractions, decimals, percentage and money in the topic of number and operation. This proposed project focused on the subtopic of fractions.

2.1.1. Fraction

Fractions define as a numerical quantity that is not a whole number [5]. A fraction is telling a "part" of a "whole" and the number is between zero to one. The number on top of the horizontal line call numerator and the lower part of the number call denominator. Figure 1 shows the fraction 2/3. 2/3 represented the shaded areas and it means that the whole is divided into 3 equal parts, 2 parts of the same is considered. Therefore, 2 is the numerator while 3 is the denominator. It can read as 2 over 3.

Figure 1. Fraction of 2/3.

2.1.2. Mistake and Error in Learning Fraction

There are a lot of researches and scholars from different education paradigms begun to identify the main problems encountered by the primary school students in learning the topic of fraction and provide an explanation about the problems. The common errors and possible common mistakes did by the student were identified by Aksoy and Yazlik [26].

One of the student errors is related to addition and subtraction with fractional especially if two fractions have a different number of the denominator. Based on the finding that integrated by [26], the common mistake that students make is writing the value of denominator of the fraction with the largest denominator value to the result statement and directly adding up the value of denominator of a fraction without equalizing the denominators. Figure 2 shows the mistake that student makes during the addition with the fraction. Next, students were asked to answer a question related equivalent fraction using model given by [26] and the success rate has increased compared to the previous question.

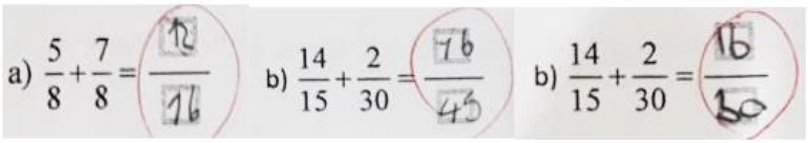

Figure 2. Majority students directly adding up the denominators [26].

2.1.3. Game

Game is an activity or a sport that one engages in for pleasure or amusement and the activity is in the form of competitive activity or sport that played according to the rules [5]. The game also can be defined as an activity that has rules, has a victory condition and it requires at least one player [6]. The digital game is a game that played using electronic devices such as computers, videogame console, and handheld device [7]. The game played on handheld devices such as smartphones, tablets or personal digital assistants (PDA) is known as handheld gaming or mobile game. A mobile game is defined as a game that embedded, downloaded or networked in handheld devices such as mobile phones, tablet and portable consoles [8]. In recent years, the number of games for mobile devices has exploded and can be easily downloaded and installed from the App Store for iOS devices and Play Store for Android devices.

2.1.4. Game Genre

There are various types of game genres that have been splintered off over the years. A game genre is used to classify the style of gameplay. Table 1 shows the game genre and its description [6], [9].

Table 1. Game genres and description.

Game Genres	Description
Action	A game that requires hand eye coordination to play. This genre has several subgenres including: • Action-adventure: this subgenre features an emphasis on item collection, puzzle solving and long-term story related goal. • Fighting: a game consists of two or more opponents battle in arena settings. Fighting games are distinguished from action games for the depth of the player controls. • Platformer: a game often features a mascot character jumping, shooting, fighting through challenging "platform" environment. • Stealth: a game with emphasis on avoiding enemies instead of fight against the enemies.
Adventure	A player is the protagonist of a story in the adventure game and the player needs to do the puzzle solving, item collection and inventory management. Adventure games often have a storyline with significant dialog. This genre has several subgenres including: • Role-playing game (RPG): this subgenre allows the player to choose a character class and increase the character's statistical abilities through treasure finding, combat and exploration. • Graphical adventure: a player uses a mouse or cursor to click to uncover clues and navigate around. • Massively multiplayer online role-playing game (MMORPG): an RPG game that can support hundreds of the players in one environment. • Survival/horror: a player often giving limited resources and attempt to survive a horror scenario.
Simulation	The game aims to simulate physical activities in real world. Some simulation game aim to provide simulations of forms of management such as city management and hotel management. Currently, the popular simulation game is The Sims series that allows the players to control the lives of the game characters. Sports game is one of the subgenres of simulation. • Sports games: a game stimulate the sporting experience such as football, snooker, fishing, tennis, golf etc.
Shooter	Shooter mainly focuses on firing projectiles at enemies. This genre has evolved to several subgenres that are distinguished by the camera view: • First person shooter: a shooter as seen from the player's perspective. • Shoot them up: arcade style shooters • Third person shooter: the camera is placed further behind the player
Racing	Racing games typically involving competing in a race against other players or time. Two subgenres can be identified: simulation and arcade.
Puzzle	A game requires the player to solve problems or puzzles, and can involve the exercise of logic, pattern matching, reaction time, memory, etc. The popular puzzle game is Tetris.
Education	A game designed for teaching purpose.
Traditional	A game represents computerized versions of board, card games, word, chess, mah-jongg, checkers etc.

2.2. Quality Requirements for Educational Game

According to [10] and [11], there are various quality requirements for the educational game that need to be considered, as follows:

- Learning Goal. The educational game should clearly define the learning goals of the game without skipping the fun elements. Besides, the game should give opportunities for the players to practice.
- Contains a full spectrum of learning principles. The game should provide direct feedback to the user. For instance, the audio of the gameplay important role to give feedback and provide instructional support. Besides, the game should create real-world problems that are relevant to the players.
- Evoke positive emotions. The game should have an attractive game design, interesting storyline or gameplay to guarantee that learners have fun. Furthermore, the game should provide positive feedback for learner's accomplishments so that the learners feel satisfaction.
- Evoke and keep motivate. Besides the learning goal, the game goals of each stage of the game also need to be clearly defined in order to create a sense of mission and motivate the user to play the game until achieving the mission. The difficulty game level should adapt to leaner' abilities and skills.

2.3. The Advantages of Handheld Augmented Reality

A handheld is defined as a piece of electronic device that designed to be held easily in one or two hands [5]. As the definition of handheld mentioned, handheld AR is describing as an AR system that can be held by the user's hand. In recent year, AR technology started implemented in handheld devices such as the smartphone and tablet. The obvious advantage of handheld AR is it allows people to carry it to any places. In addition, it can also be operated while people are walking [12].

Besides, one of the key advantages is the handheld AR inexpensive compared to the Head-Mounted Display (HMD) devices. Many people already own handheld devices such as smartphones and tablets. Moreover, to launch the AR application only requires the three necessary hardware components such as a computer processor, a display and a camera [13]. These hardware components can be found in the majority of mobile phones sold today.

2.4. The Benefits of Augmented Reality in Education

In recent years, many researchers found that AR applications are able to improve learning performance and motivate students [14]. One of the benefits is through AR technology, students can master the specific subject content easier and faster, because students can explore the objects from various perspectives [16]. With AR, there are possibilities for learners to control the objects by manipulating the size, position, shape, color and other properties of the virtual objects [17]. This allows learners to get more understanding of the properties and behavior of objects and at the same time can improve the learner's creativity.

Besides, many studies in literature found that AR learning can be effective in raising the learning achievement level [15], [17]-[19]. Furthermore, AR application able to trigger student's curiosity, interest, and motivation in learning as AR can help achieve a sense of reality [18]. Another study provided by Sirakaya and Cakmak [15] stated that students had fewer misconceptions in AR learning. There are a lot of similar studies in the literature support that AR has the ability to eliminate the misconception of the student [17], [18], [20], [21]. Another advantage obtained from AR learning is students are encouraged to study independently and follow students' own pace with AR [16]. Students are more self-responsible in academic progress and able to learn individually and explore or accept new knowledge [22].

Last but not least, AR in learning able to reduce costs compared to traditional learning. According to Chen and Tsai [23] the cost like execute manpower and the cost of signing or renewing the courses can be eliminated with the AR learning. In short, AR is eligible to be used in the educational area and a lot

of studied had proof the AR application able to improve the learning achievements, student's motivation and allow student-centered learning.

3. Methodology

This section explains the methodology used to guide the development of proposed game. Waterfall approach has been selected to construct the project. The flow of the project methodology is divided into four sequential phases.

3.1. Phase 1: Requirements Analysis for Educational Game

In the first phase, research has been conducted to analyse the requirements of educational game. Besides, some study also conducted to get the related data and information about the proposed project. For example, the issues of the traditional learning method and the issues of learning the topic of fractions, this information helped to define the current problem in society.

3.2. Phase 2: Designing the Mathematics Game Structure

The previous phase is used as a reference for this design phase. The game design of the proposed game including the gameplay, game storyline, game characters as well as game is described in this phase to ensure the proposed game is fun to play.

3.2.1. Game Design

- Game Name: Ali's Math Adventure
- Game Concept: Ali's Math Adventure is an adventure game with problem solving and education elements where the player needs to answer the mathematics questions involving fractions to unlock the collections and new levels.
- Game Genre: Ali's Math Adventure is under the adventure and education genre.
- Game Play and Mechanics: The player allows selecting the choice given by using the 2D touch screen interaction to click the choice on the handheld screen. Figure 3 shows the game Mechanics.
- Game Story: There are two chapters in this proposed game. Both chapters have its own story to describe Ali's adventure journey.
- Game Level: The game difficulty follows the syllabus listed in Kurikulum Standard Sekolah Rendah (KSSR) Mathematics [24]. KSSR is the education system introduced by the Ministry of Education in 2011.

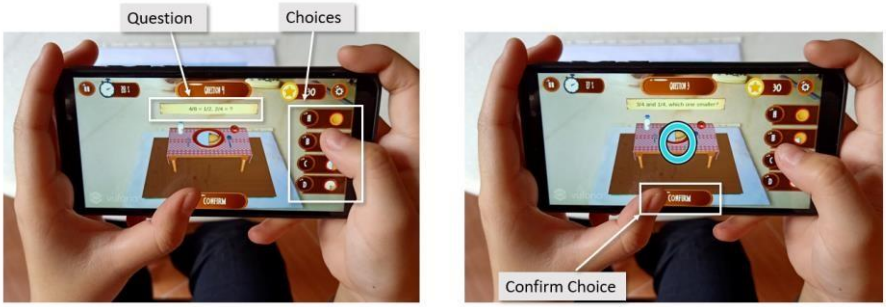

Figure 3. Game Mechanics.

3.3. Phase 3: Game Development and AR Implementation

In the third phase, Unity3D engine is used to develop the proposed game, and the target platform is Android handheld with the Android version 4.4 or above. After the game development, Vuforia Software Development Kit (SDK) integrated into the game to allow the interaction between the real-world environment with the three-dimensional virtual objects. Initially, the designed marker or image target uploaded to Vuforia Target Manager for processing and adding the image target to the database.

Figure 4 shows the image target used for this project. The implement process will be properly discussed in next section.

Figure 4. Image marker for the project.

3.4. Phase 4: Game Testing and Evaluation
In the game testing phase, functionality testing including the user acceptance testing method also known as the black box testing method was used to examine and determine the game developed to match the game requirements and specifications. The actions of the user were recorded for further evaluation and analysis. In order to evaluate the usability of the game, the suggestions or feedback given by the testers collected through pre-experiment and post-experiment questionnaire.

4. Implementation
The development of the mathematics game on handheld devices is carried out based on the game design stated. The AR tracking is then implemented to the game using the Vuforia AR Software Development Kit (SDK).

4.1. Develop AR Mathematics Game on Handheld Devices
Unity3D game engine is the main tool in the development of the proposed game and the targeting platform is the Android handheld devices. Initially, the Three - Dimensional (3D) objects are obtained from the online free open source model store such as Unity Asset Store. Those models are imported into the game scene and its position and scale been modified to a suitable position and scale.

A *GameController* class is scripted to handle the game logic. For instance, *GameController* randomly displays the question, receives the player's input, checks if the time limit reach, checks if the player's selection is correct, gives instant feedback to the player and calculates the score gained.

4.2. Implementation of Augmented Reality Tracking
The AR tracking method used in this project is a feature-based tracking technique, also known as an image-based tracking technique. This technique uses a camera to detect and track the features that are found in the two-dimensional (2D) image itself. To integrate the AR tracking in the project, Vuforia AR SDK is imported to the Unity3D game engine.

Figure 5 shows the workflow of the feature-based tracking using Android handheld camera with Vuforia SDK. The initial step is the Android handheld's camera capture the image marker and Vuforia SDK search for the input markers. Once the image marker identified, the Vuforia SDK match the tracked image or feature points with the Vuforia database. Once the matching is found, the Vuforia starts to calculate the viewpoint of the virtual object including the position and orientation of the virtual object on the real environment. Lastly, the three-dimensional virtual object displays on the Android handheld screen. The Vuforia SDK continues to track and display the virtual object on the screen until the feature marker is away from the camera's field of view.

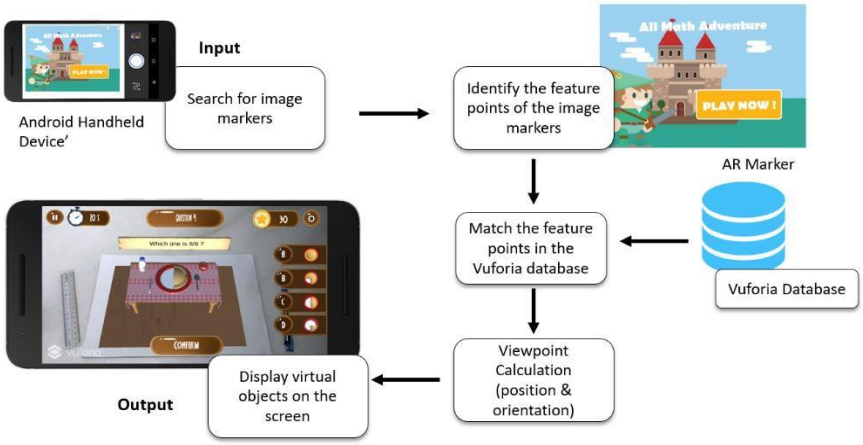

Figure 5. Feature-based tracking workflow using Android handheld camera with Vuforia SDK.

5. Results

The first objective of this project is related to the requirements analysis of related educational games. This was fulfilled in literature review as the requirements were studied based on past research papers. This serves as a guide to deliver a good quality educational game. Next, the second objective is related to development of the Mathematics game for primary school children using handheld device. Waterfall approach was used to manage the development progress by separating the task by phases and also maintained the development pace based on the proposed timeline. The third objective is related to implementation of Augmented Reality Technology into the Mathematics game. This objective has been fulfilled in the implementation stage of the project, including the implementation of AR tracking in the handheld device using Vuforia Software Development Kit (SDK).

The result of this project is a prototype of a learning mathematics game in an Android handheld device with the implementation of Vuforia AR Software Development Kit (SDK). The prototype is an educational game for primary school children and the subject Mathematics has been chosen for learning purpose. This prototype features Mathematics multiple choices questions with Two-Dimensional (2D) touch screen input to display the Three-Dimensional (3D) models on the AR marker in the Android handheld devices. Figure 6 shows the result of AR Mathematics game in handheld device.

Figure 6. AR Mathematics Game.

6. Testing and Evaluations

6.1. Experimental Setup

The experiment has been set up as shown in Figure 7. This experiment requires a single-player, an android handheld device installed with the prototype's Android Package (APK) and also a printed A4 feature-based marker. The marker is placed on a flat surface, while the player requested to be seated in front of the marker. The handheld device is held by the player and the player can interact with the game

prototype on a handheld device screen. The handheld device's camera used to track the image marker and render the game models.

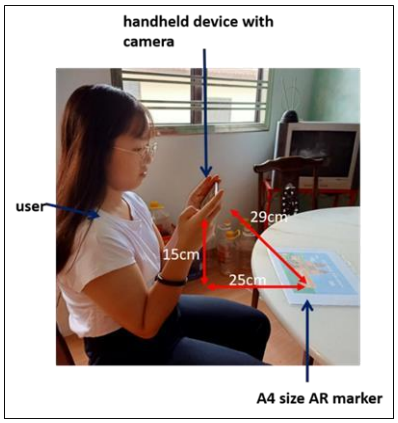

Figure 7. Experiment Setup.

6.2. Usability Testing

3 target users (3 female) and 10 non-target users (5 male and 5 female) were involved in this experiment and the selected number of participants is related to what was done in previous studies. The number of primary school children involved in the testing is limited due to the COVID- 19 outbreaks. Therefore, the testing is conducted by small sample of primary school children as the target users and several non-target users. The information and procedure of the testing has been provided to the parent or guardian of the target testers in order to get the permission for the testing. Testers could ask questions if they face any issues during the testing progress. For non-target users, any volunteers within the age from 18 to 24 years old as this aged is the largest group of handheld mobile users based on Nielsen [25]. Each participant is given around fifteen minutes to explore the prototype individually by following the experiment setup as discussed. The pre-experiment and post-experiment questionnaires were distributed to collect the participants' background, feedback and suggestions.

6.2.1. Evaluation Result for Non-Target Users

Based on the result shown in pre-experiment questionnaire for non-target users, 80% of respondents do experience with Augmented Reality (AR) and Handheld Augmented Reality (HAR). However, only 40% of the respondents had experience in learning Mathematics game on handheld devices. Based on the results shows in the post-experiment questionnaire for non-target users, most of the respondents gave positive feedback and also feel satisfied with the prototype. All respondents responded that the game user interface is attractive and the game is fun to play. Besides, one respondent gave a good reflection on the attractive game storyline and the game flow. Moreover, most of the respondents responded that AR tracking is effective and accurate and also the game can be play smoothly without facing any issue or evolved the feeling of frustrated. About the time given in each game level, only 10% of respondent feel it is not sufficient and suggested to increase the number of time while the rest 90% of respondents responded that the time given is sufficient for them.

6.2.2. Evaluation Result for Target Users

The result for target users in pre-experiment questionnaire shows that none of the respondent experience with AR and HAR. Only one respondent experience on learning Mathematics game using handheld device. Based on the results showed in the post-experiment questionnaire for target users, all respondents satisfied with the game prototype and gave positive feedback for the game user interface. Moreover, most of the respondents responded that AR tracking is effective and accurate and also the game can be play smoothly without facing any errors. About the time given in each game level, two out of three respondents suggested increasing the number of times. All respondents also agreed that the feedback of the game is clear after completed answered the question. In short, these results showed that the game

prototype able to engage the children to play the game and practice the Mathematics questions independently.

7. Conclusion

Overall, this project has successfully produced a learning Mathematics game using HAR for primary school children. The proposed game is specifically designed for primary school children to strengthen the knowledge on the topic fractions and as an alternative method in learning Mathematics. Based on the testing results shown in both usability testing and black box testing, the game prototype with AR features is able to engage the children to play the game and trigger their curiosity in learning process. Besides, children are also able to practice the Mathematics questions independently in their preferred pace. To further enhance this project in the future, this proposed Mathematics game can be enhanced by implementing the multiplayer features. Secondly, the number of questions for each game level can be increased and store the list of questions in the cloud database. Currently, the AR tracking in this Mathematics game relies on image marker, the virtual objects will only appear superimposed in the real environment if the image marker is identified. Instead of using feature-based tracking, AR tracking can be enhanced by using motion tracking in the future.

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