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Augmented Reality Maze Game with Google Cardboard for Child Edutainment

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Abstract: Students need to develop adequate problem-solving skill to keep up with studies. This project aims to improve primary school students' problem-solving skills as these need to be inculcated from young. Such training may also strongly impact interest in learning in the future. The application developed also targets hand-eye coordination skills. Higher Order Thinking Skills targeted are such as analysis, problem-solving, decision-making and memory skills. The results indicate that through multiple gameplays, better results are recorded. There are differences arising from students' power of observation, analysis, uninformed and informed hypothesis testing, serendipity and courage in thinking out of the box. However, due to the small sample size, more needs to be investigated to confirm observations, and the need to increase the difficulty of the problem for more sustainable outcomes.

Keywords: Augmented Reality, maze game, Google cardboard, child, edutainment

1. Introduction

The marketplace and consequently, educational institutions, have increased the need for problem-solving skills. In schools, such skills are referred to as Higher Order Thinking Skills (HOTS). HOTS correspond with the revised Bloom's taxonomy (Anderson & Krathwohl, 2001) illustrated in Figure 1. Since admission to higher levels of education depend on performance in HOTS, children with inadequate HOTs and problem-solving skills would face difficulties keeping up with their studies.

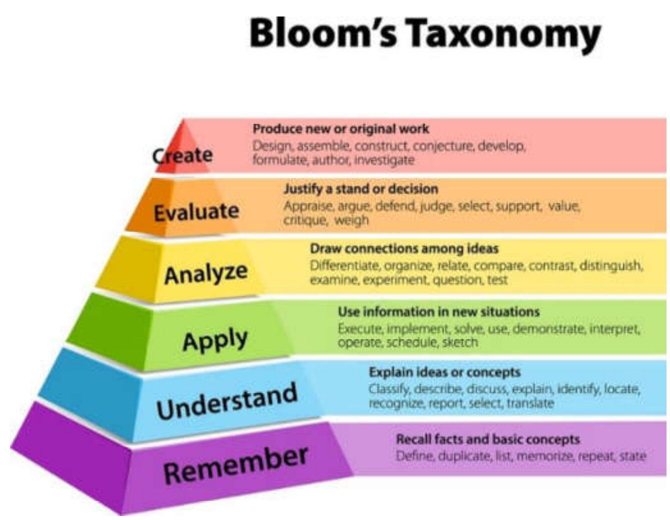


Figure 1. Bloom's revised taxonomy

Hence, we aim to improve the child's (ages between 6-12) problem-solving (analytical and evaluation) skills from young before they step into secondary school. Learning and experiences are additive. Hence, they should be able to perform better (Magsino, 2014; Brynes, 2016) and subsequently, to adapt and perform better in educational institutions and eventually, the workplace.

The scope for this project is an Augmented Reality (AR) Maze Edutainment game. AR and a 2D game enable tactile and immersive visual interactions. However, AR extends from a 2D game due to the superimposition of information on top of the actual object/image. Hence, they do make a difference that may not be possible in a 2D game, such as to enable students to solve problems in different ways.

A maze game is chosen because the game can trigger students' hand-eye coordination, memory and judgement. The project is developed using Unity 3D and Vuforia plugin. A single visible ball is superimposed in the virtual maze. The user can use his/her hands to coordinate and rotate the maze to guide the ball's path and rotation. A timer is superimposed at the top of the maze to keep count of the time taken to solve the maze puzzle.

2. Literature review

2.1 Maze game for child edutainment in virtual reality

Lack of problem-solving skills is the main obstacle to students improving academically. This study uses game-based education because games make learning fun, help students to pay attention and stay focused throughout the whole process (Prensky, 2001; Brynes, 2016). This is important because our targeted users are primary school students. It is also true, for the elderly (evSky, 2008).

A maze game is chosen because it can significantly improve HOTS. The child must trigger his executive function skills to derive and conclude a solution for the maze. Examining helps problem comprehension as the child needs to visualize problem scenarios more effectively. He/she also needs to consider all sorts of criteria and decide which criteria to use prior to decision-making. An area which has become more popular is visual motor integration for pediatric therapy (Mathews, 2019).

Besides helping to develop skills in examining the problem and in identifying possible solutions, maze games help with memory. For example, if the child is stuck at a dead-end in the maze, he/she needs to recall the steps that have brought him/her to his/her current position and reverse his steps to return to a previous position to look for another possible solution, similar to informed search strategies. With better memory, is better efficiency in dealing with the problem.

However, ease of use/maneuver are important for technology adoption. For example, the Augmented Reality project in Figure 2, requires two hands to comfortably rotate the maze. One hand holds the phone and the other hand the maze. This makes it difficult to rotate the maze. The ease of use depends on design and objectives. Hence, we surmise that the game is more suitable for those who are used to object manipulation using both hands and that the complexity of the maze is lower.

2.2 Virtual Reality (VR) maze-related game

Virtual Reality (VR) maze games can project objects for students to interact with the maze, thus making possible improvements in planning, strategizing, understanding, responding, formulating criteria and decision making (Prensky, 2001). In the virtual world with the maze map, the child moves the ball by rotating the maze map using their hands. Brynes' (2018) findings with printable mazes also indicate positive outcomes in handwriting.

Most existing VR maze games are from a first-person view, where the player is in the maze, and has to find his/her way to achieve the objective. These projects are helpful in training Higher Order Thinking Skills. However, these projects usually require Oculus Rift and a controller to virtually "move" the player inside the maze. Oculus Rift is not budget-friendly, especially for primary-school students. A project developed by Tibog (2017) (Figure 3) is very interesting but may be too complicated for the targeted users, i.e., primary school children. Besides the inherent complexity of the game, both hands are required to rotate the maze. It is also necessary to have a stationary Web camera.

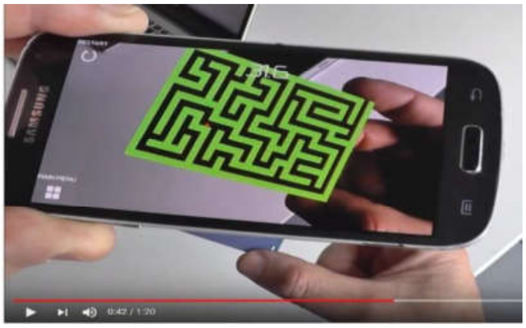


Figure 2. Augmented Reality maze game

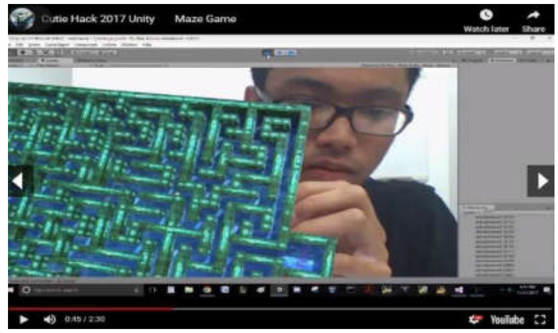


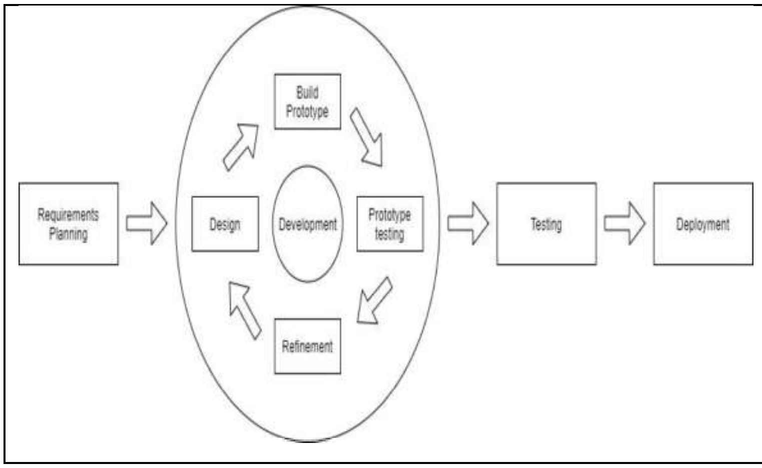
Figure 3. Unity Maze Game by Tibog

From the above review, we surmise that the game should be handsfree and enable the user to view the environment for safety reasons. We thus refer to EverXFun (2017), and the VR maze game with Google cardboard in Figure 4. As illustrated in Figure 4, the game is played by rotating the whole physical cardboard to maneuver the ball from start to finish, while avoiding the holes. The maze game is completely physical, except for the "lives" at the top-left corner.

Figure 4. How to Make Genius Game from Cardboard at Home

3. Methodology

The methodology used in this project is Rapid Application Development (RAD) (Figure 5a) because the vital functional requirements are not set or fixed. The flowchart is presented in Figure 5b. A simplified technology acceptance test based on Davis, Bagozzi and Warshaw's (1989) Technology Acceptance Model (TAM) is used in the design and tested in the beta testing. Constructs in TAM are ease of use, usefulness, attitude, intention to use and behavioral intention to use.



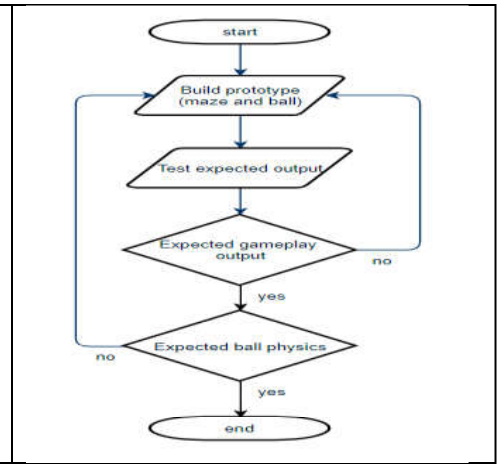


Figure 5a. Rapid Application Development Model

Figure 5b. Flowchart

4. Requirements Planning

This involves identifying the functional and non-functional requirements for children using Augmented. Examples of considerations are the environment of the children while using Augmented, how the children use Augmented, how the game is played, how to improve eye-hand coordination in the game.

Ideally, in terms of the location/environment, the user should be in an indoor environment without any nearby obstacle. Furthermore, the location needs sufficient lighting for the camera to scan the maze. In terms of set-up, the user needs to wear the Google cardboard with the application to view the maze. Functional requirements are presented in Table 1a and non-functional requirements in Tables 1b, and 1c.

Table 1a. *Functional requirements*

Functional Requirements	**Description**
Display the maze	A physical picture is used as a trigger to display the maze in the app. The application uses camera to scan the physical picture and displays the maze in the application.
Display the ball	When the maze is displayed, the ball shall be displayed as well in the application. The ball must be spawned at the start point (blue space).
Maze corresponds to physical picture (image tracking)	When the physical picture rotates, the maze in the application rotates.
Ball contained in the maze	The ball shall not fly around or outside the maze.
Ball movement responds to the change of state of maze	The ball shall land on the maze and is able to move when the maze rotates or changes angle.
Ball and maze blocks have collision	The ball and maze blocks should have collision so that the ball does not pass through the blocks. The ball can only move on space without the maze blocks.
Game ends when the ball reaches end point	The game ends when ball reaches the end point.
Open timer	The timer is displayed and starts as soon as the maze and ball are displayed. The timer starts from 0 and there is no time limit. The timer should stop when ball reaches the end point.
Display the timer	The timer stored of the current game will be displayed at the end of the game.

Table 1b. *Non-functional requirements*

Non-Functional Requirements	**Description**
Availability	The game should be able to run on Android and iOS.
Safety	The system should not have actions that can potentially harm the user.
Usability	The system must be easy to use.
Performance	The game difficulty should be triggering higher intensity of HOTS that is suitable for primary school students.

Table 1c. *Non-functional requirements for the ball*

Non-Functional Requirements	**Description**
Reliability	The ball should be contained in the maze and not randomly float or fly around.
Speed	The ball should have relevant speed to the rotation and tilt of the maze.
Visibility	The ball should be easily seen and found in the maze. (include different color or pattern to the ball)

5.1 5. Design

An enhanced AR maze game mounted to Google cardboard similar to Figure 4 is developed, with the above requirements in mind. Since the game is in virtual space, it can be played anywhere. However, it is better for the child to play indoors and in a static location due to safety reasons. A static location is also recommended for better immersive experiences and focus. Moving around can cause distraction and also affects the tracking of the marker.

The Higher Order Thinking Skills (HOTS) to be satisfied are analysis and evaluation. The maze game design (Figures 6a, 6b) involves creating a square-sized maze that will pop out from a physical image. The physical image is to be held physically by the child. A ball is placed in the virtual maze for children to maneuver from a start point (blue block) to the end point (green block). The ball will spawn in the blue space, and whenever the ball touches the green space, the game is ended. Maneuvering the ball requires hand-eye coordination where the child rotates the physical image. When the game starts, a timer will start counting and stops when the game has ended. The time will then be stored in the game to be displayed.

The expected ball physics are:

a) Ball maneuver corresponds to how the map rotates
b) Ball's movement considers speed (inertia, speed, slowing down, etc.)
c) Ball has collision.

The expected gameplay outputs are:

a) Ball spawn in the spawn point (blue space)
b) Ball is contained in the maze (do not randomly fly off the maze)

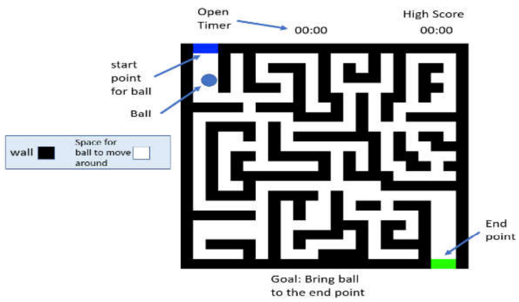


Figure 6a. Game Design

Figure 6b. The two mazes and Google cardboard

6. Development

6.1 Prototypes 1 and 2

The objective is to build a prototype for pilot testing/feedback purposes and which can be re-designed easily. The prototype created is simple and straightforward with respect to functional requirements. In the prototype, a maze is designed and built in 3D Unity. The maze can only spawn when a specific picture is found through the camera of the application (Augmented Reality). A ball is spawned at the start as well when the maze is spawned. In the early stage of prototype testing, the physics and movement of the ball reacting to the rotation of the maze are tested.

For this maze-game, marker-based augmented object is the priority for choosing the SDK. A marker is used for this project so that the child has a physical item for "hands-on" control and to rotate the map. Although popular SDKs such as ARCore, ARKit and Vuforia all have the ability to create a marker-based augmented object, Vuforia is chosen for its better performance in 3D tracking of the marker (Design, 2017). This application also targets availability. ARCore is compatible with certain Android devices while ARKit is specifically for iOS devices. Vuforia has the advantage of being compatible with Android and iOS.

7. User testing feedback

7.1 Prototype 1 and 2 user testings

Feedback cannot be obtained via interview or questionnaire as the children are too young to provide feedback without stressing them. Hence, the prototyping approach is used. The initial prototype is presented to 10 testers (teenagers and adults aged between 15 to 20) to verify the functionality of the system and collect comments. The comments are then analyzed and filtered to refine the functional and non-functional requirements. The 10 testers agree that the prototype is playable. Categorized comments collected from prototype 1 (some comments are similar across users) and observations/changes made are presented in Table 2.

Table 2. *Categorized comments collected from prototype 1 (some comments are similar across users) and observations/changes made.*

Comment 1: Nice, I can see the environment of my surrounding when playing the game, should be safe, I guess.	Justified a non-functional requirement Safety. By enabling the virtual world to view the current surroundings is a good safety feature so that the user is aware of the space they are currently at. Such feature can limit the user's movement to

	decrease risk of hitting or hurting themselves in the space.
Comment 2: The game needs more effects that excites the kids, like some glowing or flickering effects.	Realized the graphical/visual requirement is important to excite users.
Comment 3: I notice the ball flies and restart to the start point randomly, can you fix it?	Reliability becomes more important - a non-functional requirement specifically for the ball physics. The ball should not be unstable during gameplay.
Comment 4: The ball moves a little too fast in my opinion.	Speed, a non-functional requirement specifically for the ball physics, is very subjective to each users' preference. However, a suitable and relevant speed for the ball must be decided in the game. Finally, the speed of the ball is set to correspond with the rotation and angle of the maze.
Comment 5: I find it hard to see where the ball is, the ball color sometimes blends into the walls.	Comment highlights the importance of visibility, a non-functional requirement specifically for the ball physics. Otherwise, during gameplay, the child may lose track of the ball as the ball camouflages into the wall blocks. The color of the ball is thus changed to light blue.

For the second user testing, changes based on user feedback are: a) addition of audio when the maze appears or disappears in the application, b) creation of a higher difficulty level for the maze.

7.2 Beta Testing (Technology Acceptance Model and HOTS) and discussion

7.2.1 Beta Testing (Technology Acceptance Model)

The targeted users for beta testing are primary school students. Prototype 1 is tested on 5 primary school students from different schools. Testing is scheduled individually with each student. Upon scheduled testing with the students, they are given the maze, the application and Google cardboard and asked to play the maze game 3 times (reach the end goal 3 times). However, no instructions are given to them as to how to play the game. This is to test the "perceived ease of use" construct in the Technology Acceptance Model. The students find the game easy to use.

7.2.2 Beta Testing (HOTS: a) analysis/evaluating? b) memorization? c) visual motor (eye-hand coordination represented culminating in speed as performance)

Table 3 presents the results of 3 performance tests by the 5 primary school students in terms of their completion time (in secs):

Table 3. *Students performance (speed) for each 3 rounds*

Primary School Student	**Test 1**	**Test 2**	**Test 3**	**Average**
1	32.29	26.19	25.22	27.90
2	40.44	39.51	33.41	37.79
3	44.12	20.22	18.51	27.62
4	33.37	22.10	140.55	65.34

5	21.42	36.11	22.41	26.65

7.2.3 Observations

After the beta testing phase, several questions regarding the thought process of the gameplay are asked. and observations made. These answers are obtained by analyzing the gameplay of the primary school students and their feedback/thought processes during gameplay.

Student 1 has played the game seriously with the purpose of self-improvement and obtaining higher score. This implies that the student thinks about the improvement in the time taken for the ball to reach the finish point more quickly. To improve the high score, he questions the physics of the ball and finds that the ball moves at different speed when rotating and tilting at different angles. Consequently, the student manages to solve the problem by making good use of the speed of the ball to reach the finish. The game has triggered problem-solving skill and evaluation and understanding skill for student 1. If given a more difficult game, he is expected to perform well.

Student 2 completes the game more slowly than a majority of the students. Also, during his gameplay, there is a noticeable lack of hand-eye coordination. The student mentions he knows the route to the finish but is frustrated when maneuvering the ball to the finish. During the 3 runs, he manages to improve his completion time after realizing that the problem he has to solve is the rotating and tilting as the physical maze affects the movement of the ball. Since hand-eye coordination involves processing or performing an action and evaluating the result, this game can improve his visual motor skills in the long run, allowing him to interpret actions and consequences more effectively.

Student 3 is the fastest to complete the game in 3 runs. The first run is slow as he does not make much evaluation of the routes. He constantly moves the ball to various routes but recovers it quickly. This student actively triggers his memory; remembering and identifying routes used and not used. After completing his first run, he uses the same route for the second and third runs. This student evidences slight improvement in his problem-solving skill when the ball is stuck in an area. Though he does not examine and evaluate much, his memory seems to improve most.

Student 4 finds 2 different routes to finish the game on the first and second runs. On the third run, he explores the map and watches the reaction of the ball to the maze. Instead of finishing the game normally, during his gameplay, he notices the ball is able to leave the maze (note: ball is contained inside the maze, it is not expected to leave the maze). There should be a bug that he encountered during gameplay. Therefore, he tried shaking the maze vertically and horizontally, tilting and rotating aggressively. He encounters the problem of forcing the ball out of the maze (exploiting). From this point, the game improves his thinking-out-of-the-box skill and examining skill.

Student 5 is adventurous in the gameplay. For the first run, he manages to maneuver the ball quickly to the finish. For the second run, he chooses to go through other route and becomes stuck in an area. When the ball is stuck in an area, he is required to bring the ball back to its previous position where other possible routes can be chosen. However, he manages to remember the steps, rotation and bring the ball back to a previous point to pursue other possible routes. The completion time for the second round is more than the first. The game has triggered his problem-solving skill, memorizing and examining skill while bringing the ball back to previous point. By increasing the complexity of the maze, it is expected that the student will be able to improve his HOTS more significantly.

Students 1 and 2 have developed similar problem formulations and hypotheses and have experimented with rotating and tilting at different angles, Student 3 remembers/recalls successful routes and doesn't explore other routes. His strategies are similar to those of a chess player. Student 4 uses trial and error, Student 5 remembers successful routes to a certain point and backtracks when unsuccessful to explore other routes. Hence, though all students have analyzed and evaluated the problem in trying to solve the problem, differences arise from observation, uninformed and informed hypothesis testing and serendipity in thinking out of the box. This reconfirms prior findings summarized in Lee and Lau (2015) and Lee and Wong (2015; 2018) on the importance of problem/hypothesis formulations. It also hints that such results can be predictive in the long run.

8. Conclusion

In conclusion, primary school students sometimes have difficulties keeping up with the current education level due to HOTS implementation in educational institutions. We are interested in several HOTS such as analysis and evaluation as these influence decisions making during problem-solving. Primary school students with inadequate problem-solving skills may face even greater gaps in knowledge in the future.

For this project, an edutainment augmented reality maze game specifically targeted to primary school students to improve their problem-solving skills is developed. The end of the game is achieved by moving a ball from start point to an end point within the shortest time possible. The game has provided students more experience in decision making and problem-solving. However, due to the small sample size, more needs to be investigated to confirm observations and for more sustainable outcomes. Future work may involve investigating whether the skills acquired in playing this game would subsequently translate to higher order thinking skills in other educational contexts and extension to VR games.

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