Math Role-Play Game Using Lehmer's RNG Algorithm

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***Abstract*—Due to the COVID-19 pandemic, schools in Malaysia have been physically closed for more than 40 weeks and the students have to learn online. As Malaysia transitions to endemicity, many younger students struggle to keep up with their education due to significant learning loss caused by school closures and the challenges of virtual classes, including distractions and reduced engagement. This study aims to address these issues by developing an educational application that integrates gaming elements, focusing on arithmetic for Year 6 primary school students. The application engages students through interactive gameplay, requiring them to solve math problems to progress, thereby promoting a fun and effective way to enhance their arithmetic skills and mitigate learning loss.**

***Keywords*—Lehmer's RNG algorithm; online educational; gamification**

I. Introduction

COVID-19 pandemic has changed to being endemic and become more common, students start to return to school and learn face-to-face in physical class. Before that, the schools are closed and students conducted their classes with online learning. Some teachers will ask the students to open the webcam but most of them did not know what the students doing behind the screen. After a long time of school closure, a huge problem was occurred and be discovered which is 'Learning Loss' [1]. Due to the lengthy summer break, when kids did not learn for a while and were unfamiliar, learning loss first occurred. Even though pupils had been learning online, there was still a problem with learning loss when the school closed. Numerous academics have provided compelling data and statistics to support their claims that this issue exists, showing that student test scores are lower than they were prior to the epidemic [2-5].

The issue of learning loss is crucial and demands attention since it has a significant negative impact on Malaysian students, particularly those from less-educated or ignorant parents. Some of the B40 (the bottom 40% of income earners) family's youngsters find it challenging to participate in online learning in Malaysia [1]. The goal of online learning is to help students finish their coursework on time, yet they learn less and find it difficult to make up on their learning after 40 weeks of break from class. One of the reasons is that it is difficult to maintain elementary school children' interest in online learning since they lack the capacity to seek out information on their own. Additionally, because they are not being watched, most pupils rarely study independently when under lockdown. The pupils in primary school may have not be able to achieve the desired outcomes, and this problem may continue to secondary school [5].

The objective of this paper is to create a learning game for Malaysian Year 6 primary school pupils. The application, which will be deployed on a personal computer (PC) platform, will concentrate on the math curriculum's arithmetic topic. The math for grade six comprises fraction and decimal multiplication and division. There are many degrees of difficulty for the application, and English is the in-game language. Playing the game and responding to the questions helps students gain arithmetic proficiency. A captivating tale will be created for the Role-Playing Game (RPG). In order to save the princess, students will take on the role of an explorer and attempt to rebel against the demon king. To harm foes, students must correctly respond to the question they are provided by the adversaries within the allotted time. Students will be attacked by the opponents if they fail to respond to the question or take too long. The student either wins the game by killing the final boss or loses the game when their health reaches 0. To get pupils to play the game, a compelling tale is necessary. The game is designed to integrate educational content seamlessly with engaging gameplay, ensuring students remain motivated to learn while having fun. Built-in feedback mechanisms will help students track their progress and identify areas for improvement. The adaptive difficulty levels ensure that the game challenges students based on their proficiency, promoting continuous learning. Java and the NetBeans IDE will be utilized in this study's application development. Additionally, usability testing will be conducted to evaluate the game's effectiveness in improving students' arithmetic skills.

II. Literature Review

A. Current Situation of Education

Today, every child must have access to education. Every element of life is inspired by education, which also provides the road for personal growth. From their education, students may assure a bright future, develop knowledge, and boost their confidence [6]. According to the United Nations International Children's Fund (UNICEF), the closing of schools across the world has an impact on, puts students at danger, or causes them to lag behind [7]. Additionally, more than 1.5 billion children were affected by the epidemic, and the most vulnerable kids suffered grave consequences, according to a United Nations

assessment [8]. The number of students worldwide who will be impacted by school closings in 2020 is shown in Fig. 1.

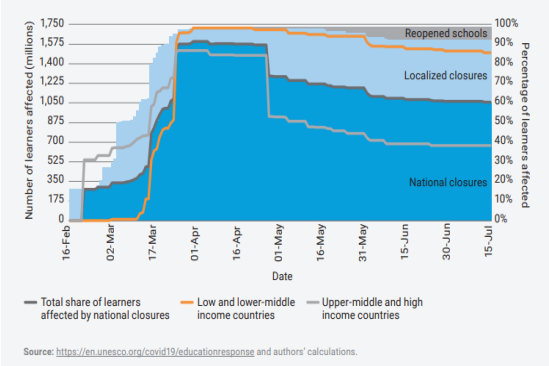


Fig. 1. Number of children affected by school closures globally.

In Malaysia, the government has mandated that students remain at home and do their coursework online [9]. The Malaysian government has made significant contributions to education by giving B40 families and students free internet connection so they may do their coursework online [10]. Although a great alternative to traditional classroom instruction, online learning still has several drawbacks, like restricted Internet accessibility, difficulty in interacting with others, a lack of learning materials, and more. These problems have an impact on students' educational experiences, particularly in some rural parts of Malaysia [11] brought the learning loss problem in result.

Although not a new issue, learning loss manifests itself more frequently in another way. Learning loss originally happened in the summer and was referred to as "Summer learning loss" since some countries, including the United States and Canada, have extensive summer vacations. The prolonged summer break disrupts the instructional pattern, and pupils risk forgetting what they have learned [12]. Despite the COVID-19 epidemic, students were still able to learn online, but there were still issues with learning loss. The next sections will cover several studies and publications that use a lot of statistics to support their arguments. Due to the closing of the schools, these two learning deficits have comparable features. Online learning needs self-discipline because pupils can't focus on the screens [13]. Additionally, it may be challenging for kids from low-income households to access the Internet, which has an impact on their ability to study [14]. The problem of learning loss during the pandemic was created by the closing of schools and a shift in the teaching approach.

Numerous studies using extensive data have found the impacts of learning loss. The majority of the researchers that analysed the test scores of pupils before and after the shutdown of the schools discovered evidence of student learning loss. Additionally, several research noted the rise in inequity, with some student groups suffering greater learning losses than others [15]. In order to evaluate the arithmetic, spelling, and reading exam results for primary students in grades 8 to 11 in the Netherlands, research was done, according to the Proceedings of the National Academy of Sciences of the United States of America (PNAS).

Despite learning remotely for eight weeks when schools were closed, the pupils' arithmetic and spelling test scores fell by 2.15 and 0.76 percentile points, respectively (Fig. 2). According to estimates based on the aforementioned finding, pupils generally underperformed by 3.16 percentiles, or 0.08 standard deviations (SDs). The impact of learning loss is 60% worse for pupils from less-educated parents where it is concentrated [2].

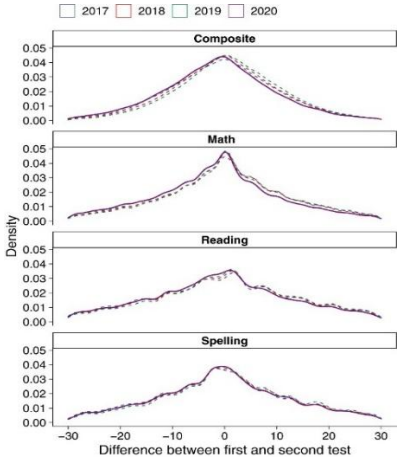


Fig. 2. Difference in test scores of years 2017 to 2020.

Additionally, another study used data from 5.4 million American kids in grades 3 through 8 who took arithmetic and reading tests during the first two years of the epidemic to conduct research. Between autumn 2021 and fall 2019, students' average math exam scores declined from 0.20 to 0.27 SDs. The reading test scores are 0.09 to 0.18 SDs lower (Fig. 3), and the difference in performance between kids attending primary schools with low and high levels of poverty has grown by 0.10-0.20 SDs [16].

Although the school closures took place in the early stages of the epidemic, this study did not take into account whether the pupils had engaged in remote learning. The arithmetic score has decreased for two years, while the reading score has decreased between the fall of 2020 and the fall of 2021 [3].

According to another news from UNICEF, school closures resulted in significant learning losses in math and reading plus the learning losses are roughly proportional to the length of closures in some countries. Students aged 10 to 15 has significant learning losses in math and reading from the results of two states in Mexico. Many other countries also faced this problem, for instance, South Africa, India, Pakistan and Brazil [8]. Since the schools have been closed for about 40 weeks in Malaysia, the learning loss on Malaysia students must be more serious [1].

The causes of learning loss might vary depending on the circumstances. It is clear from this experiment that the COVID-19 pandemic's propagation is its primary cause. To protect pupils from the pandemic's risks, the majority of governments have stated that schools would be closed. The solution is then put into place to allow the students to continue their education—remote learning or online learning. The aforementioned elements are closely related to one another. Zhdanov et al. (2022) categorized the factors impacting the learning losses as

the following themes: “change in teaching methods”, “opportunities to reach education”, “less time for learning”, “less control / feedback” and “emotional factors” (Fig. 4) [17].

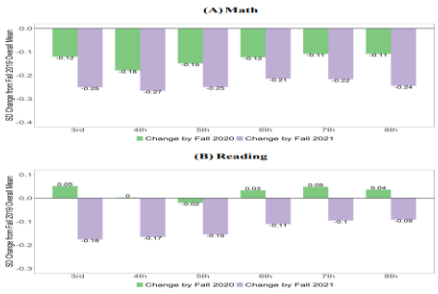


Fig. 3. Trends in test scores in fall 2020 and fall 2021 compared with fall 2019.

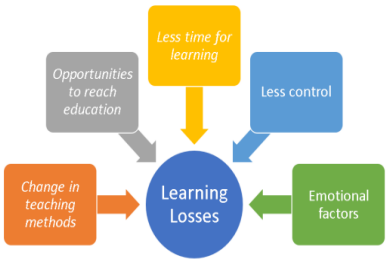


Fig. 4. Affecting factors to learning losses during COVID-19.

B. Maintaining the Integrity of the Specifications

Many schools, colleges, and universities have also begun to employ e-learning apps or platforms in the education in order to reduce the pandemic-related learning loss and improve the learning experiences. The students may always remain linked, from any location. As a result, its importance and utility have increased as a result of the COVID-19 epidemic.

Additionally, a lot of schools, colleges, and universities have started implementing e-learning platforms or applications in the classroom to reduce the learning loss caused by the epidemic and enhance the learning experiences. The students can always keep in touch, from any location. As a result, the COVID-19 pandemic's emergence made it more important and valuable. When it is discovered that the pupils are having academic difficulties, it will already be too late because there is no single evaluation to examine the students until form 5 since the two public examinations, Primary School Achievement Test (UPSR) and Form Three Assessment (PT3) have been abolishment [18].

Numbers and their operations are the subject of the scientific discipline known as mathematics [19]. Galileo defined mathematics as "the language in which God has written the cosmos" in his definition. He believes that learning math is necessary to comprehend the universe and that it is an essential language [20]. In addition, as previously noted, learning loss has a significant influence on the arithmetic subject in basic education. As a result, in the current context, minimizing and reversing the learning loss is crucial.

C. Gamification with Education

A game is a playing activity that is used for fun or learning. People are under stress as a result of the COVID-19 outbreak since they are unable to leave their homes. They begin playing a game for enjoyment and relaxation. Game and gamification are two distinct concepts. Gamification is the process of applying game concepts and components to non-game activities [21]. Combining education with games creates gamification in education, which mostly occurs in the context of online learning. As a result, it is an appropriate response to the current circumstance, and pupils are accustomed to this kind of instruction. Gamification in education may enhance the learning process, grab students' attention, and make the subject matter more entertaining [22].

In Indonesia, Udjaja, Guizot, and Chandra (2018) use gamification to enhance learning in elementary math. They develop an interactive learning game by fusing gaming aspects with math resources. They seek to make math learning more engaging so that children can readily comprehend the arithmetic information. Consequently, both teachers and students find the game-based learning approach to be engaging. Most pupils are now more interested in learning math, and they see the value in doing so [23].

D. Game Genres

Table I categorizes various game genres and provides a brief description of their key features. Each genre emphasizes different gameplay mechanics, offering unique player experiences. For example, action games focus on combat and intensity, while puzzle games emphasize critical thinking and problem-solving. Role-playing games immerse players in characters and storylines, while sandbox games allow open-world exploration and creativity. These genres highlight the diversity in game design, catering to a wide range of player preferences and objectives [24-25].

TABLE I. GENRES AND DESCRIPTION OF GAMES

Game Genres	Description
Action	Games with action intensity and combat as its main attraction.
Adventure	Games that focus on exploration and puzzle solving.
Multiplayer online battle area (MOBA)	Games that place the focus on player control, map and resource management.
Puzzle	Games with puzzles as its key game mechanic.
Real-time strategy (RTS)	Games that include real-time reasoning and problem solving.
Role-playing	Games that allow players to take control of a character and immerse in their situation.
Sandbox	Games that associate with player choice, open environments and non-linear gameplay.
Simulation	Games that focus on creating a game world and it is matching with the real-world situation.
Shooters	Games with different weapons for aiming and shooting at targets.
Survival	Games that focus on resource management to keep the player character alive.
Platformer	Games with 2D side-scrollers and simple controls.

However, in order to implement the gamification in education, it is important to know that not every game type is suitable to the teaching environment. Amory et al. (1999) have conducted research to discover the most suitable game type and game elements. They tested on the adventure, RTS, shooting and simulation games. They found out that the students prefer playing the adventure and RTS rather than the other two. This may be caused by the user interface and game play. The research also shown that login, memory, visualization, mathematics, reflexes and problem solving are the important game elements [26].

Instead, eleven game types identified by [24] and [25], role-playing game and sandbox game has been implemented in the education. Role-playing game has been used to teach vocabulary [27] and Japanese [28]. Also, it is proved that the role-playing games are able to improve the knowledge and encourage students to learn. The game was utilized as a learning material in the class, provide a good environment and experience to students. The example of the sandbox game is education edition of Minecraft. It allows the users to gather resource and use the resource to create anything they want. It motivates the creativity of students and can be used to teach various subject, for instance, math, history and visual arts. It is proved that the math ratings of 4th grade students in Australian schools have increased when using Minecraft for math's learning [29].

Furthermore, Hussein et al. (2019) conduct research of the past relevant literature between 2006 to 2017 years to find out the effects of educational gaming in teaching science of primary levels. They discovered that RPG is the most popular game genre. Students are able to control the game avatar and communicate with Non-Player Character (NPC) which allow the students immerse in the learning environment [30]. Another research also conducts research of the past relevant literature but from 2016 to 2020 finds out that adventure games is the most preferred game genre while sport and simulation, RPG and puzzle games are often used [31] (Fig. 5).

Hassan, Mailok and Hashim (2019) conducts research on the relationship between gender and game genres by collecting data from Diploma students in Malaysia. In overall, the most popular one is Adventure games. Adventure and puzzle games are the most popular game genre for female while action and strategy games are the most popular game genre for male. Male do not prefer music or dance games while female do not prefer cross genre games [32]. Fig. 6 shows the table of the game genres selection based on gender.

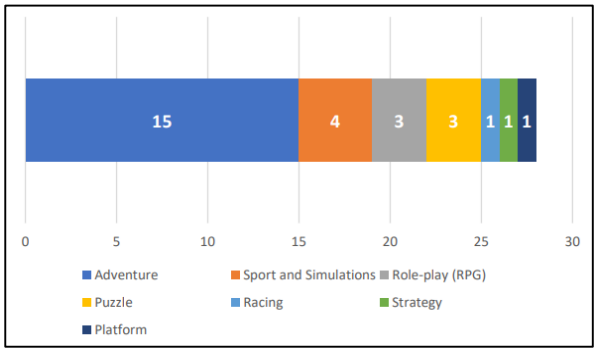


Fig. 5. Frequency of game genres.

No	Game Genres	Female	Percentages (%)	Male	Percentages (%)	Total	Percentages (%)
1	Adventure	26	63.4	57	76.0	83	71.6
2	Board/card	17	41.5	27	36.0	44	37.9
3	Puzzle	26	63.4	27	36.0	53	45.7
4	Platform	20	48.8	34	45.3	54	46.6
5	Strategy	23	56.1	58	77.3	81	69.8
6	Sport	15	36.6	42	56.0	57	49.1
7	Action	21	51.2	58	77.3	79	68.1
8	Shooting	24	58.5	51	68.0	74	64.7
9	Simulation	15	36.6	30	40	45	38.8
10	RPG	10	24.4	42	56.0	52	44.8
11	Music/Dance	23	56.1	22	29.3	45	38.8
12	Cross Genre	9	22.0	29	38.7	38	32.8

Fig. 6. Game genre selection based on gender.

To develop a gaming application, the problem statement, objective and scope must be clearly determined. Then, developer has to create the game design or prototype. Developer can start coding the application when all the details are finalized. The application will then test by the developers and external testers. Finally, the application can be released after testing [33]. On the other hand, [23] implement the game development life cycle (GDLC) to develop the math education game. It consists of initiation, pre-production, production, testing and release. Initiation phase is to create the game concept with simple description. Pre-production phase is to create and review the game design plus create a game prototype. Production phase is to produce the game assets and coding. Testing phase is to test the functionality and usability of game internally. Release phase is the final stage which the game is ready to be released to public. Tan and Suparjoh (2022) also implement GDLC to create the educational game for mobile but it has one more, beta phase before the application is published. After the internal testing, the game will be tested by third-party or external tester in beta phase [33-34].

E. Game Algorithm

Other than that, algorithms can be used in the production phase in order to make the gaming application more effective. Developers may use algorithms and implement them into the application. Candra et al. (2021) used A-star (A*) algorithm to design the pathfinding and develop a tree planting game. A* algorithm uses the heuristics function to plan a path between multiple nodes efficiently. It uses the best-first search and finds the shortest path by calculating the cost from initial node to destination node [35]. Galam et al. (2019) conduct research on the performance A* algorithm and Dijkstra's algorithm. Dijkstra's algorithm is also a pathfinding algorithm that use to search for the shortest path but it has to build the shortest paths to all other nodes in the graph which is not efficient. Therefore, 68 uses the simpler A* algorithm to create the tower-defence game because he or she thinks A* algorithm can be considered as a low-fill version of Dijkstra's algorithm. In conclusion, the A* algorithm is frequently used in game development [39].

Also, Lehmer's Random Number Generation (RNG) algorithm is used to generate a simplified initial world state in a role-playing game [36]. The researcher compares the RNG algorithm with the random number generators inside the C++ library and discover that the average speed of the algorithm is faster than the other methods (Fig. 7). Thus, it will be better to include the RNG algorithm in order to improve the software performance.

Lehmer's RNG algorithm is based on a general formula which is 'Xk+1 = a · Xk mod m'. The multiplier 'a' is an element

of high multiplicate order of modulo 'm' and the modulus 'm' should be a prime number or power of prime number. The seed 'X0' is coprime to 'm' and has to be set at the beginning along with other variables. Fig. 8 shows the code example of Lehmer's RNG algorithm in C#.

Alhassan et al. (2019) and da Silva and Villela (2016) use the breadth-first search (BFS) algorithm to generate and expand nodes of a tree data structure. It includes a simple first in first out (FIFO) queue which mean the parents of same level will be checked before moving to their children. All the node of level n will be expanded before any node of level n+1. Alhassan et al. (2019) uses it to create a puzzle game whereas da Silva and Villela (2016) uses it to create a mobile game [37-38].

Zain et al. (2020) uses Minimax search algorithm and Alpha-Beta pruning algorithm to develop a tic-tac-toe game. Minimax search algorithm is a backtracking algorithm based on the game theory, decision theory, statistics and philosophy [40]. It uses to find the optimal path and maximize the player's chance to win whereas minimize the opponent's chance to win. Alpha-Beta pruning algorithm is an optimization algorithm for the minimax algorithm [40]. It reduces the computation time by removing all the unnecessary bunches when it finds a better path. In minimax algorithm, it will continue evaluating all the nodes until it reaches the root node. Monte Carlo algorithm is used to develop card game and puzzle game [41-42]. Monte Carlo algorithm is a searching algorithm that conducts simulations to evaluate unknown patterns or unknown actions to know their values by using a rollout policy [41]. It requires a lot of information to make the simulation.

Method	Avg. Time
rand()	0.001160
std::random	0.067793
Lehmer	0.000269

Fig. 7. Average speed of RNG methods.

```
public class LehmerRng
{
  private const int a = 16807;
  private const int m = 2147483647;
  private const int q = 127773;
  private const int r = 2836;
  private int seed;
  public LehmerRng(int seed)
  {
    if (seed <= 0 || seed == int.MaxValue)
      throw new Exception("Bad seed");
    this.seed = seed;
  }
  public double Next()
  {
    int hi = seed / q;
    int lo = seed % q;
    seed = (a * lo) - (r * hi);
    if (seed <= 0)
      seed = seed + m;
    return (seed * 1.0) / m;
  }
}
```

Fig. 8. Code example of Lehmer's RNG algorithm.

Table II shows the summary of algorithms that can be used for game development. It includes the name and the basic function of the game development algorithms. Hence, specifically tailored to address key challenges in game development. These algorithms ensure efficiency, improve gameplay mechanics, and enhance user experience by solving complex problems like shortest path searches, and probabilistic outcomes in a structured and reliable manner.

TABLE II. USES OF ALGORITHMS IN GAME DEVELOPMENT

Game Development Algorithm	Description
A* algorithm	To search the shortest path between the initial and final state.
Lehmer's RNG algorithm	To get a random number by using the equation. ($X_{k+1} = a \cdot X_k \bmod m$)
Breadth-first search (BFS) algorithm	To search a node in the tree structure level by level.
Dijkstra's algorithm	To find the shortest path between nodes in a graph.
Minimax search algorithm	To find the optimal move by decision making and game theory.
Alpha-Beta pruning algorithm	To optimize the minimax algorithm by decrease the evaluation times.
Monte Carlo algorithm	To estimate the possible outcomes of an uncertain events.

III. METHODOLOGY

There are three phases in the game education application development. The first phase is on collecting data from the user stakeholders. Questionnaire will be used as quantitative research method to get the basic information. The target audiences for the questionnaire include the year 6 students, educators, parents and guardians in Malaysia. Moreover, interview will be conducted as qualitative research method with selected students to have in-depth understanding. The collected data will be used to identify the learning experience, learning performance, the needs of learning materials and more.

The second phase will be based on software development. Waterfall methodology will be used to develop the application. It consists of five phases which are requirements analysis, design, implementation, testing, deployment, and maintenance. The author will start analyzing the requirements after data collection and create an application design. Then, the author will code and test the application to ensure its performance. The application will then deploy to the target audience and be maintained.

The third phase is to test the application with both functional testing and usability testing. Functional testing is used to check the errors or bugs within the application by implementing the black box testing. The output will be compared with expected result and they must be same. Usability testing is used to test whether the application can help the students to improve their math skills. Testers will have to do a short math test before and after they play the game. Both testing will be conducted during the testing phase in waterfall methodology.

F. Phase 1 – Data Collection

Quantitative research is a type of research that uses to collect information that can be measured and analyzed. It focuses on data that is structured and can be represented numerically [43]. This study will use questionnaire as the research approach to collect data from the persons that related to the students, such as, educators, parents and guardians. The questionnaire is estimated to have 12 questions. Qualitative research is a type of research that aims to find out about people's experiences and help to understand what is important for people. It concerns with subjective 'meanings' rather than objective 'facts' [44]. This study will use interview method as the research approach and conduct interview with three Year 6 primary school students.

Different perspective can be gotten from the interviewees about the learning performance of students.

G. Phase 2 – Waterfall Methodology for Software Development

Waterfall methodology consists of five phases which are requirements analysis, design, implementation, testing, deployment and maintenance. It is one of the software development life cycle models that allow us to plan the development process in a systematic manner.

- Phase 1 – Requirements analysis focus on capturing the requirements or problems faced by the target audience. The objective is to understand all the requirements which includes scope, costs, timelines and limitation. This phase involves gathering input from stakeholders, teachers and students, to ensure the application meets their needs. Additionally, it identifies potential challenges, such as technical constraints or user accessibility, to ensure a clear development roadmap.
- Phase 2 – During design phase, programmer has to decide a plan for the solution. An application design will be created in this study.
- Phase 3 – Implementation is the phase that the coding start. Software design has been confirmed in the previous phase and programmer start to develop the application based on that design. The application use Java as the programming language and NetBeans IDE as the platform for development.
- Phase 4 – The aim of testing phase is to test the application so that it will achieve the expected result. Also, the application will be tested to find out there is any bug or not. Programmer has to debug if there are errors or bugs in the application.
- Phase 5 – The application must deploy to the target audience and need to be maintained in order to have improvement in the future if necessary.

H. Phase 3 – Software Testing

Functional testing is a type of software testing that use to verify and validate the functional requirements of the software. It involves black box testing and every function will be tested by entering the input and comparing the output with the expected result. The application should able to generate the question automatically and know the answer entered by the user is right or wrong. Usability testing is used to test whether the application can improve the knowledge. Hence, the target audience is Year 6 primary school student. If the students are unable to learn from the application, then the expected result of the study cannot be achieved.

IV. Design and Development

The target audience, users, and stakeholders were surveyed by the author to determine the needs and expectations for the system. The data gathered can be used to comprehend fundamental needs and identify potential issues. Functional requirements, non-functional requirements, and user requirements can all be improved after examining the replies. The design of the suggested educational gaming application is then displayed using UML diagrams, including use case diagrams, activity diagrams, sequence diagrams, and more.

Questionnaire and interview are conducted before the design and development. Four components make up the questionnaire. The target audience, year 6 primary school pupils, and stakeholders, such as teachers, parents, and guardians, were all included in the first section's demographic information gathering. In the second portion, the author discusses how pupils learn and how they perform before and after school closures. The third segment is where the student's experiences and facts regarding the gaming are gathered. Respondents are prompted to react with their thoughts on the educational gaming applications in the last section.

Besides that, like the questionnaire, the interview questions are divided into four pieces. The interviewees' demographic data is gathered in the first phase. It is intended to identify the interviewees' learning performance and experience in the second portion. The third piece asks the interviewers about their gaming history, while the last section collects their system needs and expectations. Initial requirements for the game education application are recognized and defined based on questionnaire and interview responses as well as the author's gaming history. Table III shows the functional requirements, non-functional requirements, and usability requirements.

TABLE III. Application Requirements

Functional Requirements	• Main menu with play, load, control and quit buttons • In-game setting menu with save game, control and exit game functions • Character control • Turn-based battle system with math arithmetic questions • Inventory system • Level-based progression with health point (HP) and experience point (XP) • Display game scenes • Difficulty levels • Game clearance timer • Random questions with random number generation (RNG) algorithm
Non-functional Requirements	• Provide accurate questions and examine the answers correctly • Provide fast response on player control • User-friendly
Usability Requirements	• Basic animation in combat scene • Basic examples of questions in menu

I. Design

(Fig. 9-11) illustrate aid in defining the gaming education application's architecture, features, and functionalities.

J. Development

There are many scenes in the game education application and the author uses state engine to differentiate them. The state engine includes ‘titlestate’, ‘playstate’, ‘optionstate’,

'dialoguestate', 'combatstate', 'characterstate', 'victorystate' and 'gameoverstate'.

Title screen is the first screen when the users open the application. Users can start a new game by pressing 'New Game' button, continue previous game by pressing 'Load Game' button, find out the game control and question examples by pressing 'How to Play' button and close the application by pressing 'Quit' button. The users require to select difficulty after pressing 'New Game' button. Difficulty levels will affect the question complexity and the time given for users to answer a question. 'Easy' is 90 seconds, 'Normal' is 135 seconds, and 'Hard' is 180 seconds.

After pressing the 'New Game' button or 'Load Game' button, the application will change to play state. In this state, the application will render and display the tile map, character, non-player character (NPC) and more. Option screen are shown when the state engine change to option state by pressing 'Esc' on keyboard. It will open the interface of options menu and allow the users to save, control the volume of music and sound effect, change difficulty level, read game story, game control, question examples and end game. When the users press the buttons of 'Difficulty Level', 'Game Story', 'Game Control' and 'Question Examples', it will open the same interfaces as the title screen.

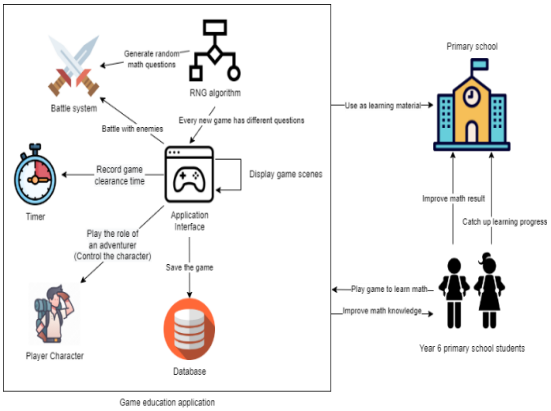


Fig. 9. Rich picture diagram.

```
public float uniform()
{
        System.out.println(r_seed);

    // highest and lowest for a rar
    long hi = r_seed / q;
    long lo = r_seed - q * hi;
      long lo = r_seed % q;

    // calculate random number
    long t = (a * lo) - (r * hi);

    // if positive
    if (t > 0)
    {
        r_seed = t;
    }
    else
    {
        r_seed = t + m;
    }

      System.out.println(r_seed);
    return r_seed;
}
```

Fig. 10. RNG algorithm.

Moreover, users can enter the dialogue screen by pressing 'E' on keyboard while the character is beside the NPC. The state engine will change to combat state when users can press 'Enter' on keyboard while the character is beside the enemy. The health points of enemy and character are shown in the combat screen. Users can choose to 'Attack', 'Skill', 'Item' or 'Run' in the combat. When the users press the 'Run' button, it will back to the map and change to the play state.

The RNG algorithm's Java code is seen in Fig. 10 The most crucial component of the application that enables it to produce unique numbers each time is this one. A variety of questions will be constructed using the generated numbers once they have been put in an array. Users will get the important objects after defeating the enemies. Users must keep answering the questions correctly until the health points of enemy goes to zero. Furthermore, users can enter the character screen by pressing 'Q' on keyboard in the play screen. The interface will display the level, health point, attack damage, current experience, experience to level up and inventory.

When the users clear the game, the state engine will change to victory state and show the interface of victory screen. The game clearance time will be displayed to let the users know how much time they spend to clear the game. Users can press the 'Quit' button to go back to the title screen. When the health point of character become zero because users did not answer the question correctly or overtime, the state engine will change to game over state and show the interface of game over screen. Users are able to press the 'Retry' button to go back to the play screen or press the 'Quit' button to go to the title screen.

In addition, the application is connected to the MySQL database with phpMyAdmin at localhost by using XAMPP. The application will store the data of current date, time, game clearance time, victory or game over, difficulty level, number of questions answered correctly, total number of questions generated in the game. The number of questions is separated according to the question types in the database. Fig. 11 depicted below shows the game interface of the application.

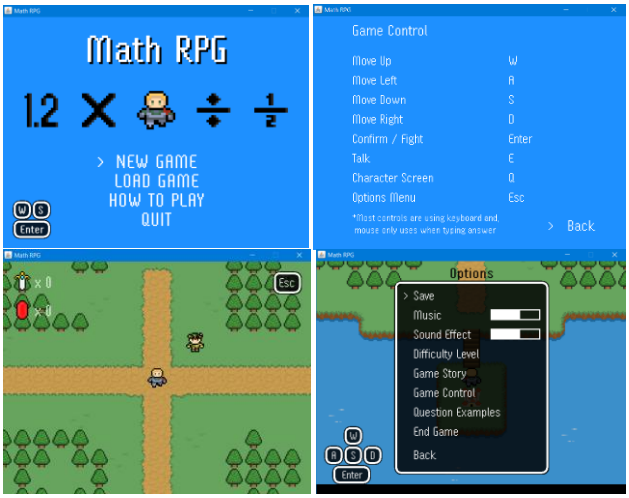


Fig. 11. Game interface.

V. TESTING

In order to make sure the game education application can fulfill the aim and criteria; the author will carry out functional and usability testing on it.

A. Functional Testing

Black box testing is used in functional testing to identify errors or bugs within the application, ensuring the predicted and actual outcomes match. Test cases enable developers to verify that various system features are functioning as expected and that the system meets the requirements. Table IV – VII presents the test cases conducted using the application, highlighting the thorough approach taken to ensure system reliability. This method ensures that critical features are tested rigorously, providing confidence in the system's performance. Additionally, the testing process helps in uncovering hidden issues that could impact user experience.

TABLE IV. TEST CASES

Tester	Chong Bin Yong
Test Date	11/20/2022
Application Developer	Chong Bin Yong

TABLE V. TEST CASE 1

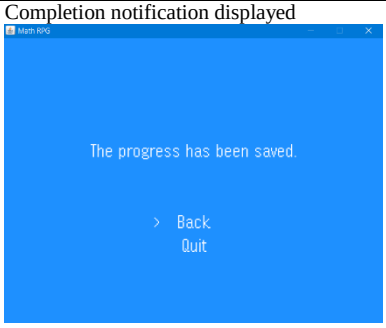
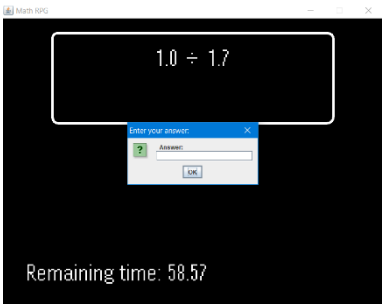
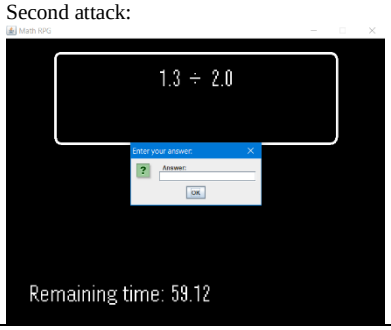
Test Objective	Validate the 'Save' button in options menu
Potential Test Inputs	1. Press 'Save' button
Expected Test Outputs	Completion notification displayed
Test Procedures	1. Enter the game 2. Press 'Esc' to open options menu 3. Press 'Save' button 4. View the screen displayed
Actual Test Results	Completion notification displayed 

TABLE VI. TEST CASE 2

Test Objective	Validate the 'Load Game' button in title screen
Potential Test Inputs	1. Press 'Load Game' button
Expected Test Outputs	Enter the game with previous saved process
Test Procedures	1. Press 'Load Game' button 2. View the screen displayed
Actual Test Results	The saved process is loaded while entering the game 

TABLE VII. TEST CASE 3

Test Objective	To test the random questions generator
Potential Test Inputs	1. Press 'Attack' button in combat scene
Expected Test Outputs	Different questions are generated each time
Test Procedures	1. Enter the game 2. Combat with one of the enemies 3. Press 'Attack' button 4. View the screen displayed
Actual Test Results	The questions are different every time the user wants to attack First attack:  Second attack: 

B. Usability Testing

Usability testing is performed to determine whether a game-based educational application can assist students in developing their mathematical abilities. After playing the game, test subjects were asked to fill out a questionnaire, and some testers had to do a quick arithmetic exam both before and after playing the game. The usability testing involved four Year Six primary school children as participants. Each participant completed the questionnaire, and two of them conducted the short math test for both pre-test and post-test evaluations.

The questionnaire focused on assessing the user interface, engagement level, and overall game effectiveness in enhancing learning. The pre-test and post-test results were analyzed to determine the improvement in arithmetic skills after using the application. These results provided valuable insights into the application's impact on learning outcomes and highlighted areas for further refinement. Fig. 12 illustrates the usability testing process for Participant 1, showcasing the steps taken during the evaluation.

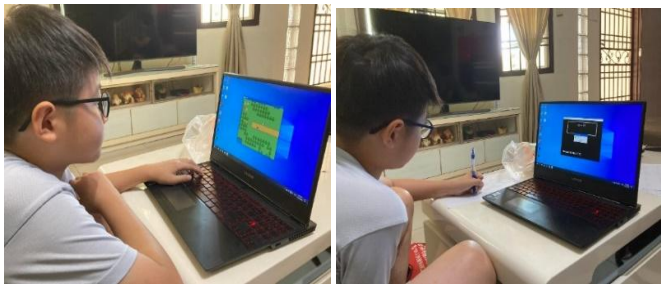


Fig. 12. Usability testing of participant 1.

The results of the post-test indicated an improvement in mathematical skills after interacting with the game. Table VIII – IX show the pre-test and post-test for the participants that have been using the application.

TABLE VIII. PRE-TEST

Questions	*Answers*	*Participant 1*	*Participant 2*
Q1. 5.2 × 2.7	A1. 14.04	14.04 (Correct)	14.04 (Correct)
Q2. 6.2 ÷ 9.8	A2. 0.63	No answer (Wrong)	No answer (Wrong)
Q3. $\frac{5}{9} \times \frac{1}{7}$	A3. $\frac{5}{63}$	$\frac{5}{63}$ (Correct)	No answer (Wrong)
Q4. $\frac{8}{9} \div \frac{3}{10}$	A4. $\frac{80}{27}$	$\frac{80}{27}$ (Correct)	No answer (Wrong)
Q5. 4.5 × 2.5 × 2.0	A5. 22.5	3.65 (Wrong)	No answer (Wrong)
Q6. 5.7 ÷ 4.6 ÷ 4.9	A6. 0.25	No answer (Wrong)	No answer (Wrong)
Q7. $\frac{5}{7} \times \frac{5}{4} \times \frac{9}{4}$	A7. $\frac{225}{112}$	No answer (Wrong)	No answer (Wrong)
Q8. $\frac{10}{9} \div \frac{1}{3} \div \frac{5}{8}$	A8. $\frac{16}{3}$	No answer (Wrong)	No answer (Wrong)

After the game, a brief arithmetic exam is administered to participants to determine their math proficiency. Eight arithmetic problems covering fraction and decimal multiplication and division were also included in the quick math test. Although the questions alter from the ones on the pre-test math test, the question format remains the same. The participant is given the same amount of time—5 minutes—to do the brief math test. Table IX shows the results of post-test.

TABLE IX. POST-TEST

Questions	Answers	Participant 1	Participant 2
Q1. 7.7 × 3.7	A1. 28.49	28.49 (Correct)	7.6 (Wrong)
Q2. 8.6 ÷ 2.2	A2. 3.91	4.0 (Wrong)	0.3 (Wrong)
Q3. $\frac{6}{4} \times \frac{5}{4}$	A3. $\frac{15}{8}$	$\frac{15}{8}$ (Correct)	$\frac{13}{12}$ (Wrong)
Q4. $\frac{1}{8} \div \frac{2}{4}$	A4. $\frac{1}{4}$	$\frac{1}{4}$ (Correct)	No answer (Wrong)
Q5. 7.5 × 4.1 × 10.0	A5. 307.5	347.5 (Wrong)	No answer (Wrong)
Q6. 6.6 ÷ 5.5 ÷ 1.5	A6. 0.8	0.8 (Correct)	No answer (Wrong)
Q7. $\frac{10}{3} \times \frac{4}{7} \times \frac{5}{10}$	A7. $\frac{20}{21}$	$\frac{20}{21}$ (Correct)	No answer (Wrong)
Q8. $\frac{3}{7} \div \frac{6}{1} \div \frac{9}{1}$	A8. $\frac{1}{126}$	$\frac{18}{7}$ (Wrong)	No answer (Wrong)

Participant 1 answered 5 out of 8 questions correctly and his answers of questions 2 and 5 are also similar with the correct answers. Participant 2 did not answer any questions correctly. For participant 1, he is able improve the arithmetic skill after playing the game. For participant 2, he will try to answer the question after playing even though the answers are wrong.

In the opinion of author, participant 1 has the basic arithmetic knowledge and know how to do the questions before playing the game but participant 2 did not know how to do because of poor math knowledge. Therefore, participant 1 improved a lot after playing whereas participant 2 did not have much improvements.

A questionnaire is given for the participants to answer after playing the game in order to get their opinion or feedback related to the application. There are 25 questions in the questionnaire which first 20 questions are scale questions (1-5) and last 5 questions are open-ended questions. For the scale questions, 1 means 'Strongly disagree', 2 means 'Disagree', 3 means 'Neutral', 4 means 'Agree' and 5 means 'Strongly agree' while question 20 uses the scale as the ratings for the game application. Table X shows the questions and Table XI shows the results of the questionnaire.

TABLE X. QUESTIONNAIRE

Question	Description
Q1	I think that I would like to use the application.
Q2	I found the application unnecessarily complex.
Q3	I thought the application was easy to use.
Q4	I think that I would need the support of a technical person to be able to use this application.
Q5	I found the various functions in the application were well integrated.
Q6	I found there was too much inconsistency in this application.
Q7	I would imagine that most people would learn to use this application very quickly.
Q8	I found the application very awkward to use.
Q9	I felt very confident using the application.
Q10	I needed to learn a lot of things before I could get going with this application.
Q11	I am able to learn math quickly using this application.
Q12	I believe I score high marks after using this application
Q13	The application tells me my weakness of math.
Q14	The information provided with this application is clear.
Q15	It is easy to learn math using this application.
Q16	The information provided with the application is effective in helping me learn the math.
Q17	The interface of this application is pleasant.
Q18	This application has all the functions and capabilities I expect it to have.
Q19	I am satisfied with this application.
Q20	Rate this application as learning material.
Q21	What was the best thing about this application?
Q22	What was the worst thing about this application?
Q23	Do you understand what the game story is talking about?
Q24	How long do you think a math question will take to complete?
Q25	How many math questions do you think you have to do to learn it?

TABLE XI. RESULTS OF QUESTIONNAIRE

Questions	Participant 1	Participant 2	Participant 3	Participant 4
Q1	4	2	3	3
Q2	2	2	3	4
Q3	4	5	5	4
Q4	2	3	2	3
Q5	3	4	5	5
Q6	2	2	1	1
Q7	4	4	5	3
Q8	3	1	2	3
Q9	3	1	4	4
Q10	4	3	3	3
Q11	3	4	4	3
Q12	4	4	4	3
Q13	4	1	5	4
Q14	3	3	4	3
Q15	3	5	4	4
Q16	4	4	4	4
Q17	3	5	4	3
Q18	3	3	5	4
Q19	4	3	4	4
Q20	4	5	4	4
Q21	No opinion	The interface is nice	The application is easy to understand	Fun to play
Q22	No opinion	Questions are difficult	No opinion	A little hard to learn to use the application
Q23	Yes, roughly understand	Do not know much	Yes, roughly understand	Yes, able to understand
Q24	Between 1 minute and 1 and a half minutes	Around 3 minutes	Around 2 minutes	Around 1 and a half minutes
Q25	4 – 6 questions	20 questions	12 questions	10 questions

Overall, the participants are eager to use the game-based learning tool. They consider the application to be well-designed and simple to use. The software received a 4.25 average rating. Most users also think they can improve their arithmetic skills and test scores after using the application. They may learn math with the aid of the application, which also identifies users' areas of difficulty. In this study, the participants have a favorable attitude toward the game-based educational application. The amount of time they estimate it will take to finish a math problem is directly related to how many problems they estimate it will take to master it. By looking at the results of the pre- and post-tests for participants 1 and 2, it can be seen that these features are likewise influenced by the participants' arithmetic proficiency.

VI. CONCLUSION AND FUTURE WORK

After the application development and testing, it has been discovered that the application is not good enough because it is not very effective if the student is not good on doing arithmetic questions. The limitation of the application can be considered as future work. The author has planned the future work of the game education application. It is important to have a plan for the application development so that the users will continue to use the application and more users will be attracted to use it.

The authors will include application programming interface (API) into the system so that it can be run on the web browser and students can play the game online. A registration and login system will be built for students and educators to create their accounts and each account has its own ID. Students can play the game whereas educators can check the results according to the ID number of students after logging in. Besides that, the functions of the application will be improved and more functions will be added into the application. For example, users are allowed to interact to more game scenes and items in order to make the game more interesting. The users will traverse in different maps and they will be allowed to control the character by using both mouse and keyboard controls since the application has mostly used the keyboard controls so far.

Furthermore, the authors will add more game settings so the users will have more controls on the application. They can choose how long they want to spend on the question by separating the required completion time from the difficulty levels. Better game teaching will be also added instead of showing the game control only. More save slots and full screen mode will be added for users to choose in the application. The author will find more participants to conduct the usability testing so as to get more data related to the application performance. Feedback will be collected from the users to improve the application whereas any bugs found will be fixed in the updates.

Moreover, better math teaching will be added into the application despite showing the question examples only. More detailed steps will be shown in order to give the users a better understanding of solving the arithmetic questions. Most math homework is calculated to allow students to multiply or divide exactly in primary school. Therefore, the users may be confused when doing the arithmetic questions with remainders especially division questions. It becomes important to let the user understand how to solve this kind of questions or allow the application to generate the question that can be calculated exactly.

The authors believes that the educational math role-playing game using Lehmer's RNG algorithm could provide a solution to students to assist their learning.

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