International Journal of Computer (IJC)
ISSN 2307-4523 (Print & Online)
http://ijcjournal.org/

Design of a Digital Game-Based Learning Environment for Solving Quadratic Equations Using Completing-the-Square-Method

Oluwatoyin Catherine Agbonifo[a*], Akintoba Emmanuel Akinwonmi[b], Mosope Samuel Williamson[c]

[a,b]*Department of Information Systems, Federal University of Technology, Akure, Nigeria*
[a]*Email: ocagbonifo@futa.edu.ng*
[b]*Email: aeakinwonmi@futa.edu.ng*
[c]*Email: mosopewilliamson@gmail.com*

Abstract

Various preconceptions about the effectiveness of applying digital-games approach in tandem with traditional teaching methods subsist in spite of learners increasing usage of digital devices and digital games. This trend obviously underplays the existing technological advancements made in respect to digital devices and computer game programming. This research paper applied the digital game approach to the teaching of mathematics with a view to boosting learner's interest while mitigating boredom, difficulty and apprehension towards solving problems. It employed story-telling technique and role-play (both fun elements) to mathematics learning while still preserving the traditional stepwise approach to problem-solving in mathematics. A digital game-based environment was developed based on the battleship game. This environment was used to learn how to solve the quadratic equation using completing the square method. Performance evaluation was carried out to determine if the system aligns with the underlined objectives. The findings showed that using the digital game-based learning system helps in reducing learners' apprehension in solving the quadratic problem and improved their cognitive skills in solving quadratic equations.

Keywords: Digital game–based learning; quadratic equations; solving problem; completing-the-square-method.

---

* Corresponding author.

1. Introduction

Game-based learning is a means of education that uses elements of game to teach a skill or obtain a specific learning outcome [1]. Game-based learning (GBL) is a form of game-play that has described learning outcomes. It is intended to align the subject matter with game-play and player's ability to retain and apply the relevant subject matter to the real world [2]. Game-based learning defines a teaching method in which students explore important elements of games in a teacher-designed learning sense. Teachers and students work together to add depth to the gameplay experience [3]. Students work towards an objective within an active game-based learning environment by choosing actions and experiencing the consequences of those actions along the way. This permits students to err in a risk-free environment, to learn actively and to experience the best way to do things [4]. Prensky [5] emphasised that digital game-based learning is precisely about fun and engagement. It is also the coming together of serious learning and interactive entertainment into a newly emerging and highly exciting medium. The researcher further explained that there was a great deal of discussion about how people learn. It was opined that given the vast changes in technology, traditional educational and training theory no longer applied well. Hence it is important that learning contents should be made personal for today's learners through questions, discovery, construction, interaction and fun. There are many good principles of learning built into good computer and video games, these are all principles that could and should be applied to school learning. Though this is unlikely, given the current trend for skill-and-drill, scripted instruction and standardized multiple-choice testing [6]. The principles are particularly important for so-called 'at-risk' learners, who have come to school underprepared, and have fallen behind, or those who have little support for school-based literacy [7]. Mathematics is a core subject in schools all over the world since mathematical knowledge is important to all human endeavours, especially scientific and technological development [8]. Students often find learning of mathematics difficult, boredom and with little or no motivation. Digital Game-Based Learning aims to render learning of difficult or uninteresting subjects like mathematics more accessible, engaging and enjoyable [9]. Completing the square is a more advanced algebraic technique which is useful in solving a quadratic equation, this method offers an option for solving quadratic equations that are not factorable with integers alone. The method can be used to solve quadratic equations by changing the form of the equation so that the left side is a perfect square trinomial. Reference [10] highlighted that technology used by teachers is strongly influenced by their idiosyncratic attitudes towards the particular technology. Moreover, digital games are often considered more of a nuisance than an asset. Hence, it is important that teachers are up to date with information on the potential of games as a teaching approach in the classroom. Even though, many commercial games might be considered inappropriate for classroom environments, teachers can make informed decisions about which games will be appropriate for use in teaching the learning content [11]. Generally, game-based customized training improves learning experiences, professionally and timely [12]. Game-based learning for learners and curriculum facilitators may mimic real-world activities and experiences [13]. This research aims to help students become less anxious in solving quadratic equations with completing the square methods as opposed to other game-based learning projects that involve solving quadratic equations.

2. Review of Related Work

Reference [14] developed an online game-based learning platform called MathQuest. MathQuest is a role playing

game for students aged between 10-11 years old to learn numbers, twelve students were involved in the evaluation of the game. The students were given the demo and hands-on access to the prototype. A set of questionnaire was given upon completion of playing the demo. In addition, an interview session was conducted on 3 students to obtain their feedback for the game. Results from the questionnaire and interview showed that the students find the game exciting, full of fun and would enjoy a mathematics class conducted using MathQuest. The limitation of this game is that it is only based online, thereby making it inaccessible to students with poor or no access to internet connection. Yuh-Ming and his colleagues [15] carried out a study aimed to investigate elementary school students' acceptance of technology applying digital game-based learning (DGBL) to environmental education. A total of 32 fourth graders in an elementary school participated in a seven-week DGBL teaching experiment. After the experimental teaching session, a survey concerning "perceived ease of use", "perceived usefulness", and "user intentions" was conducted. The results showed that the DGBL system is suitable for both genders at all levels of experience. In addition, the 4th-grade students' "perceived ease of use", "perceived usefulness", "attitudes toward use", and "intention to use" reveal a high degree of positive and significant correlations. Furthermore, a path analysis verified that DGBL acceptance would be directly influenced by a learner's "attitude toward use" and "perceived usefulness." Finally, when designing DGBL for 4th graders, the rich learning content and ease of use is considered because they significantly contribute to a learner's intention to use the system, which may result in greater learning effectiveness. Chung-Ming and his colleagues [16] carried out a study in which a mathematical game-based learning environment is developed on e-books for helping children reduce mathematical anxiety and improve their self-efficacy, motivation, and achievements in learning mathematics. To evaluate the effectiveness of the proposed approach, an experiment is conducted on an elementary school mathematics course. With quasi-experimental research, a total of 69 pupils in three classes were selected as the research subjects. One class is assigned to be experimental group A, another class is experimental group B, and the third is the control group. Each group consisted of 23 students. In the experimental process, the three groups took pre-tests, had experimental instruction, and then took post-tests. The experimental results showed that the game-based e-book learning model effectively promoted the students' learning achievement, self-efficacy, and motivation of mathematics. Reference [17] presented a study where part of the findings of the research focused on the advantages of multimedia technology and the benefits of digital game-based learning. By using sample lessons from interactive multimedia courseware called "DigiGEMs," the study emphasizes the use of digital games as a vital tool in mathematics learning. The study sets out to examine if a positive attitude exists among young learners towards the learning of mathematical concepts. The DigiGEMs is targeted at primary school children aged between 7 to 9 years old, who can practice mathematical thinking skills in an appealing manner. The study also describes the efficacy of using multimedia and game-based approaches to motivate mathematical learnings among primary 1 to 3 students. Though, the findings validated the hypothesis that digital game-based learning is more effective than traditional class-based learning in acquiring mathematical knowledge, this did not sufficiently show that digital game-based learning invoked positive learners' attitudes towards mathematics. Wang and his colleagues [18] developed a microworld-based educational game, which provides simulated contexts encouraging students to explore, discover, and solve practical problems using the mathematics knowledge gained in the class. A quasi-experimental design of the game was implemented in the learning activity of the "Speedy World" unit in an elementary school mathematics course to examine the effectiveness of the game. A total of 107 sixth graders participated in the experiment. The results showed that the students who learned with the microworld-based game had better learning

achievement and motivation in the mathematics course than those who learned with the conventional technology-enhanced learning approach. In addition, the students also showed that they highly accepted the microworld-based game for learning mathematics.

3. System Design

This section discusses the game description, system architecture and system flowchart.

3.1 Description of the Game

The storyline of the game presents a scenario of a coastal kingdom that is under a naval attack from an enemy kingdom. The fate of the kingdom rests on her navy's captain (the player) who will lead the battle to destroy the enemy ships using artillery fire. The captain's job is to decide and call out the location of the enemy ships using an alphanumeric cell location to fire at them and get them destroyed. For every hit on an enemy ship, the player must solve a step in a sequence of a quadratic equation, points are then awarded for correct answers and the game continues until all enemy ships are destroyed. The objective of the game is to get the player familiar with the steps involved in solving quadratic equations using completing the square method. The game contains a 10 by 10 table. The rows are labelled as letters while the columns are labelled as numbers. Ships are arranged either vertically or horizontally across the rows and columns. For a hit, it means that a part of the ship is in that cell, if no part of the ship is located at that cell, then it is a miss. After each hit, the player must solve a step of the completing the square method for solving quadratic equations. There are five (5) stages to solving the quadratic equations using completing the square, each of which the player must complete to be awarded full points, which include;

Using $5x^2 – 4x – 2 = 0$ as an example:

a. Reduce the coefficient x^2 to 1 i.e. if the coefficient of x^2 is more than 1, divide through by the coefficient.

Step 1: divide all terms by 5

$\rightarrow x^2 – 0.8x – 0.4 = 0$

$\equiv Ax^2 + Bx + C = 0$

b. Move the constant term to the right term of the equation.

Step 2:

$\rightarrow x^2 – 0.8x = 0.4$

c. Complete the square on the left side of the equation and balance this by adding the same number to the right side of the equation.

Step 3: $(B/2)^2$

$\rightarrow (0.8/2)^2$

$\rightarrow 0.4^2$

$\rightarrow 0.16$

$\rightarrow x^2 - 0.8x + 0.16 = 0.4 + 0.16$

$\rightarrow (x - 0.4)^2 = 0.56$

d. Take the square root on both sides of the equation.

Step 4:

$\rightarrow x - 0.4 = \pm\sqrt{0.56} = \pm 0.748$

e. Solve for the value of x correct to 3 decimal places

Step 5:

$\rightarrow x = \pm 0.78 + 0.4 = -0.348$ or 1.148

If the player correctly calculates the values of the quadratic equation, this means the enemy ship has been destroyed. The player is expected to complete the tasks before the time is up else, he loses the game. He can restart.

3.2 System Architecture

The architecture of the system is depicted in Figure 1. The architecture consists of components which include input, game interface, input evaluation, game logic, javaFX platform, database and the output.

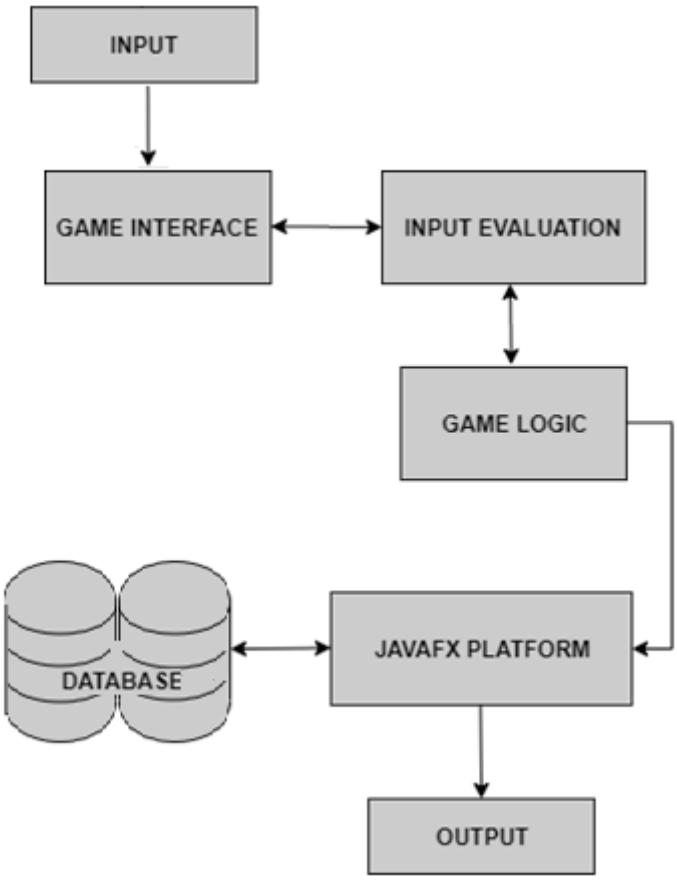

Figure 1: System Architecture.

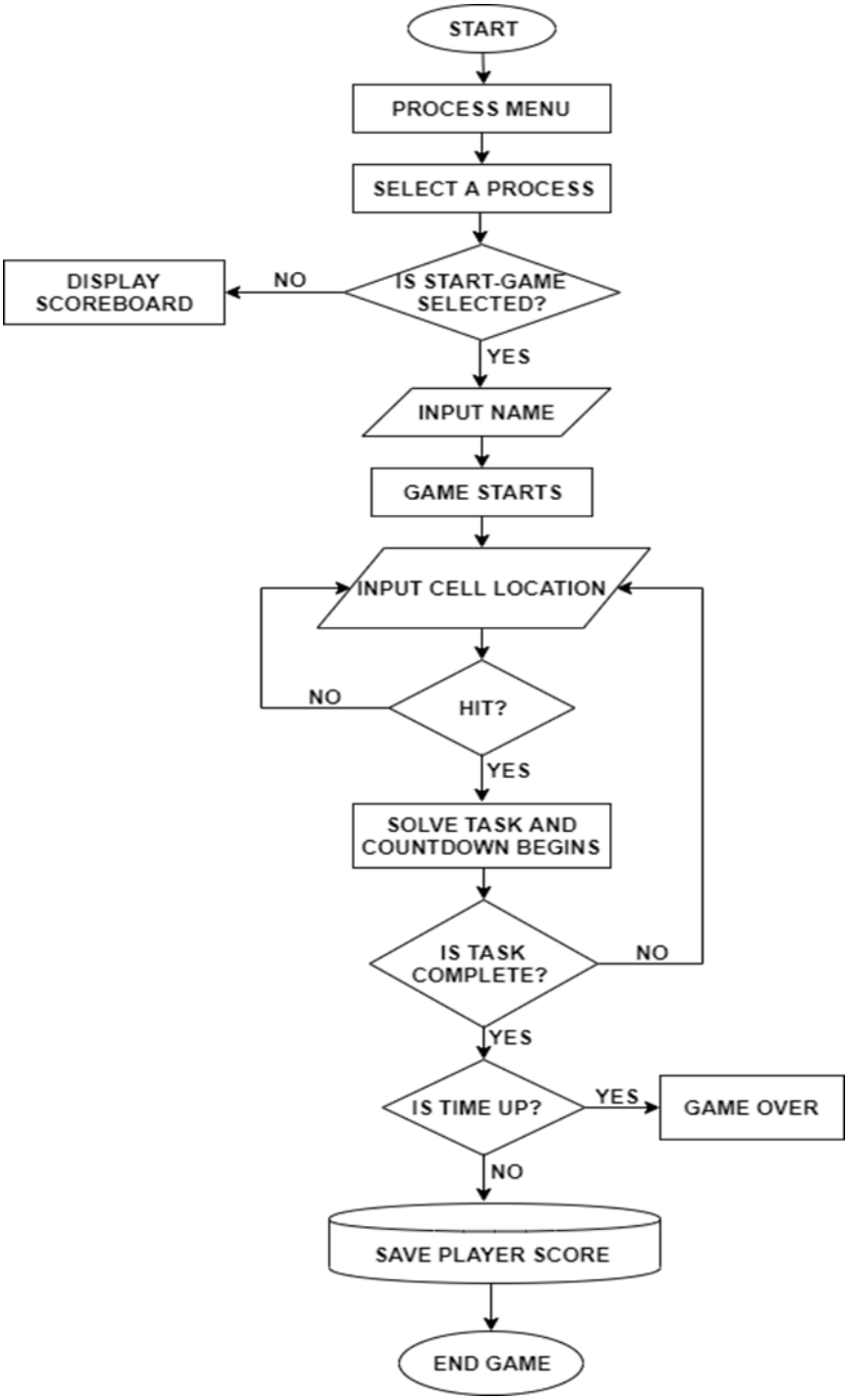

Figure 2: System Flowchart

3.4 System Modules

The game modules describe all the different stages in the game which include namely:

A. Game Entry point: The game entry point is depicted in Figure 3 with three buttons. The first button allows the player to start the game by opening to another screen where the player enters his/her name before the main game loads up, the second button shows a scoreboard which is a screen that shows the score of every player

that has played and won the game while the third button which is the exit button for the player to leave the game environment.

Figure 3: Game Entry Point.

B. Main Game page: After the student has successfully entered his/her name, the main game shown in Figure 4 loads up. The main game page consists of the battleship which is ten by ten matrix, a text box to input cell location, buttons to fire, pause and quit the game and a countdown timer.

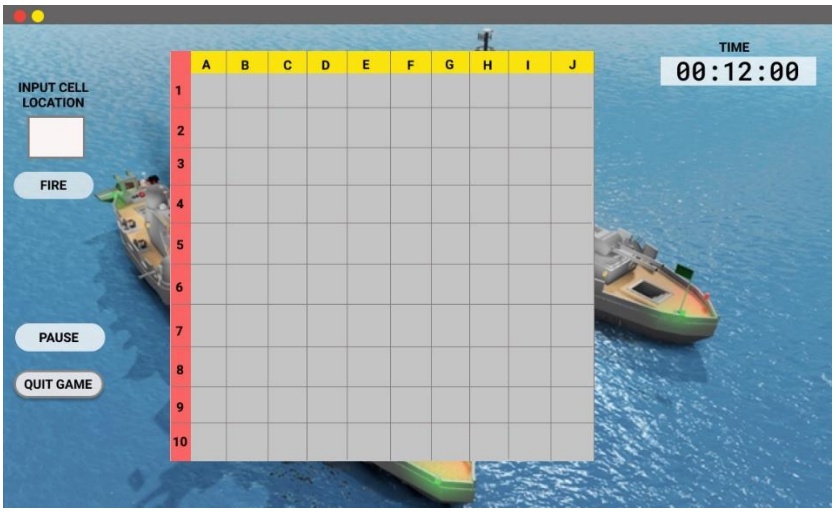

Figure 4: Main Game Environment.

C. Quadratic Equation Generation: The player inputs cell location in the text box, then clicks fire to execute the command. If the enemy ship is not present at that location, then it is a "miss" represented as a red cross while if the cell location corresponds with the location of the ship, then it is a "hit" represented as a green circle. When a player enters a cell location and having a hit, a random quadratic equation is generated and the countdown begins as shown in Figure 5. The timer starts once the player clicks start and there is a button to show hints to help the player with the gameplay.

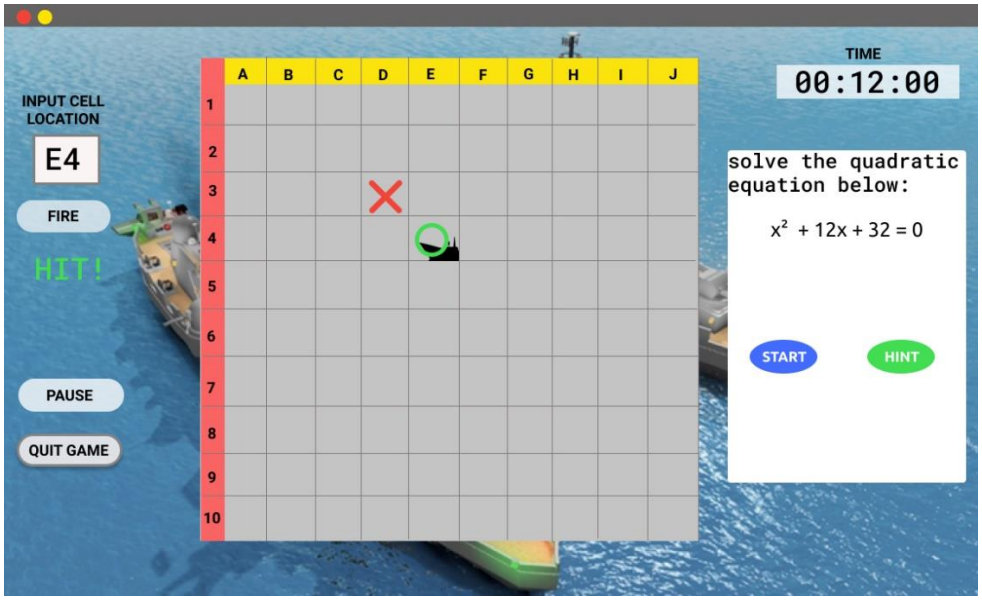

Figure 5: Game Page with Quadratic Equation Generated.

D. Step 1 of Problem-solving: Once the quadratic equation is generated, the player starts to complete each stage of the task, the first step as shown in Figure 6 is to divide all through with the coefficient of x^2.

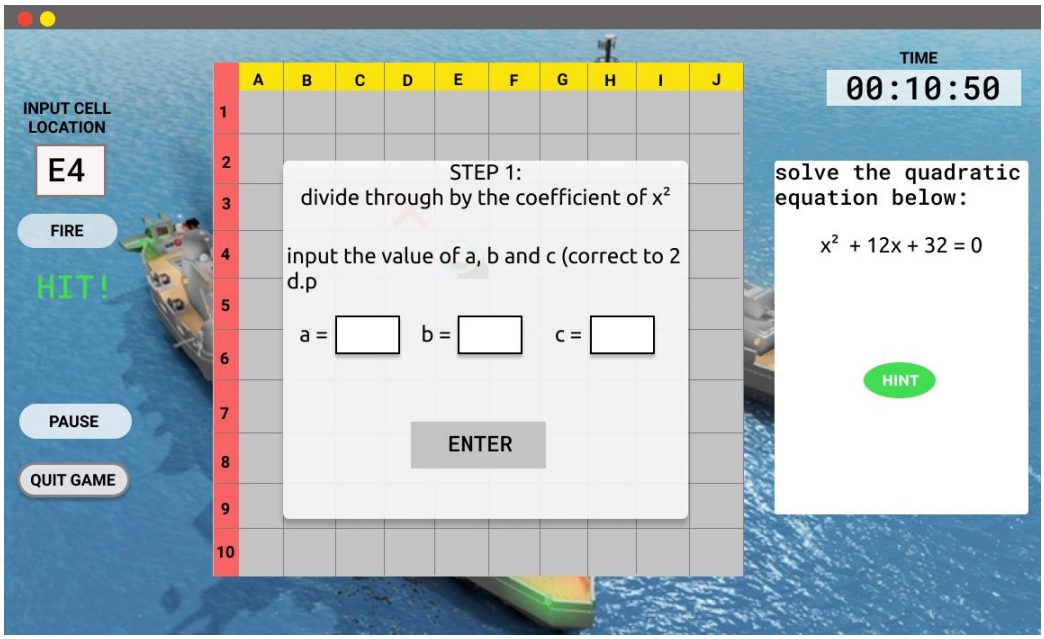

Figure 6: Step 1 where Player divides through by the coefficient of x^2

E. Input Validation: The player inputs his/her answers into the text boxes and the answers are validated by the game logic, the validation is depicted in Figure 7 where a green check mark represents a correct answer while a red cross mark represents a wrong answer.

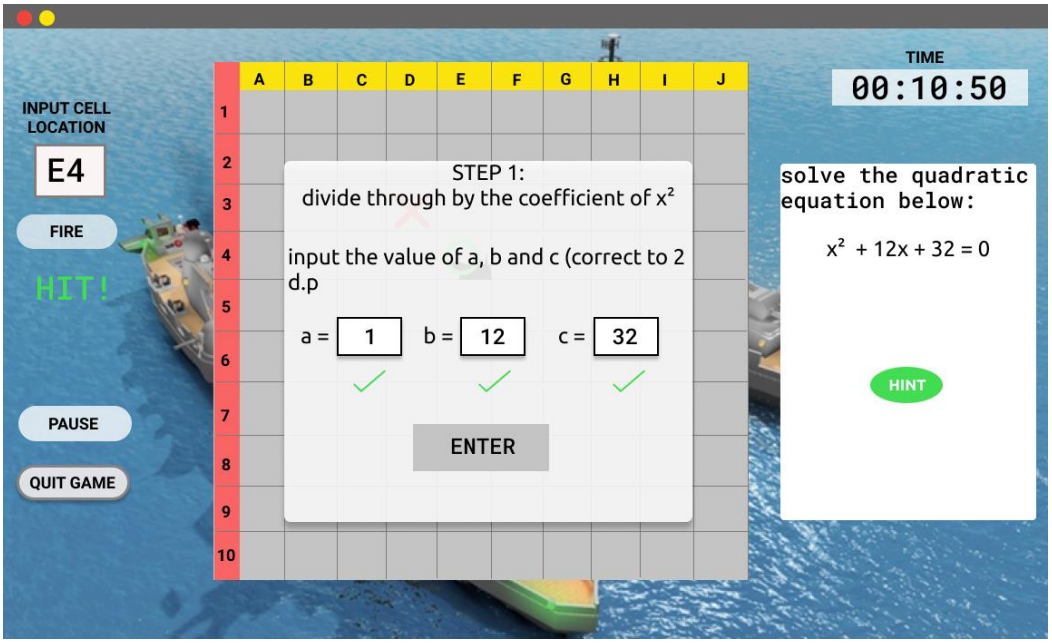

Figure 7: Green Check Marks for Correct Answers Provided by the player.

F. Step 2 of Problem-solving: The Step 2 is depicted in Figure 8 which involves the player moving the constant to the other side and adding half the square of the coefficient of x to both sides.

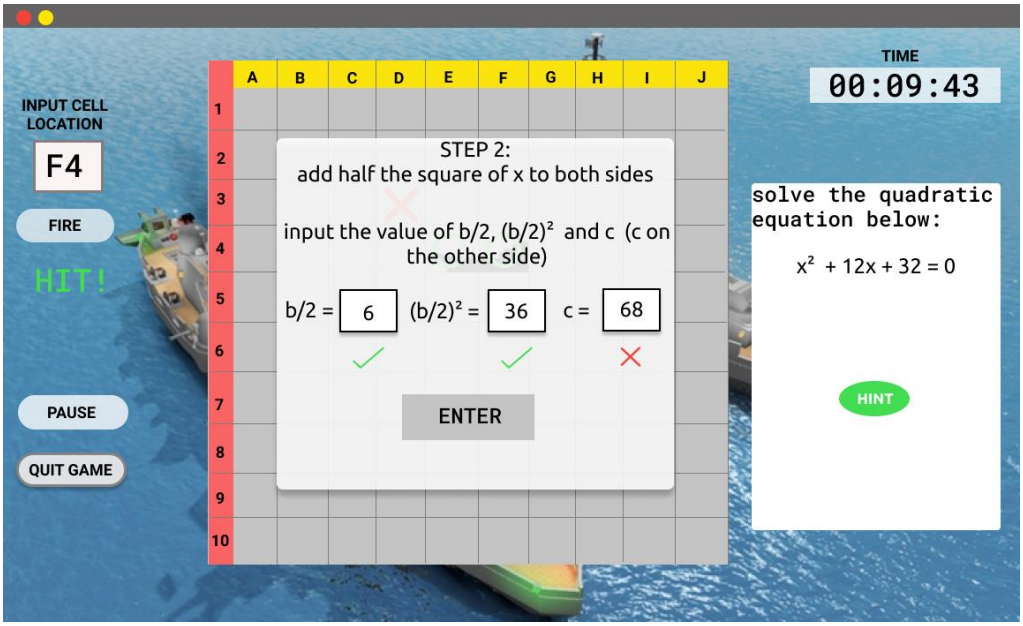

Figure 8: Step 2 with Red Cross showing Wrong Answer from Player.

G. Step 3 of Problem-solving: The next step is shown in Figure 9 where the player takes the square-root of both sides, particularly the constant term.

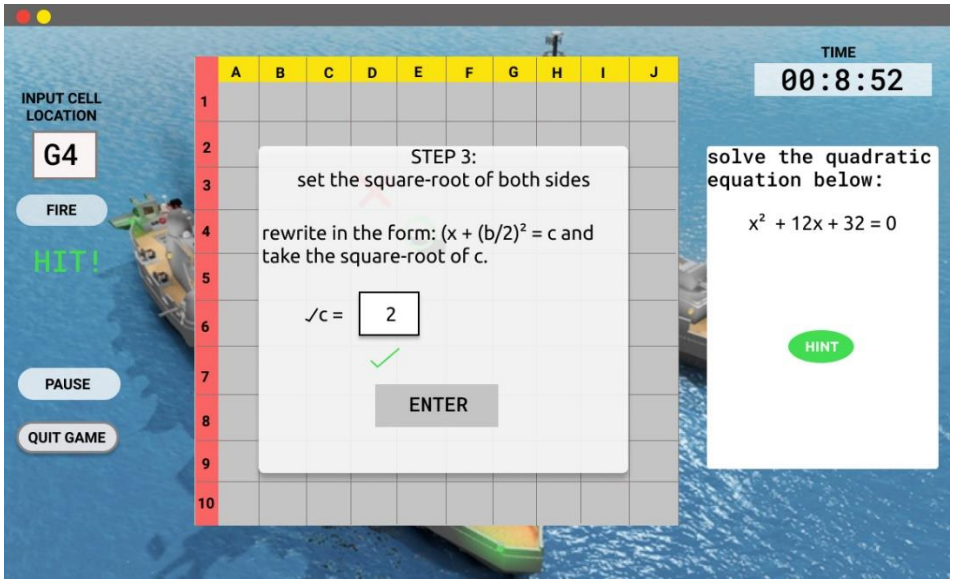

Figure 9: Step 3 where player takes the square-root of the constant

H. **Step 4 of Problem-solving**: The final step which is step 4 is shown in Figure10 where the player solves for the values of the roots of the quadratic equation. After the player completes all steps, there is a popup message "congratulating the player for completing the task" and there is an option for the player to download his worksheet or play again.

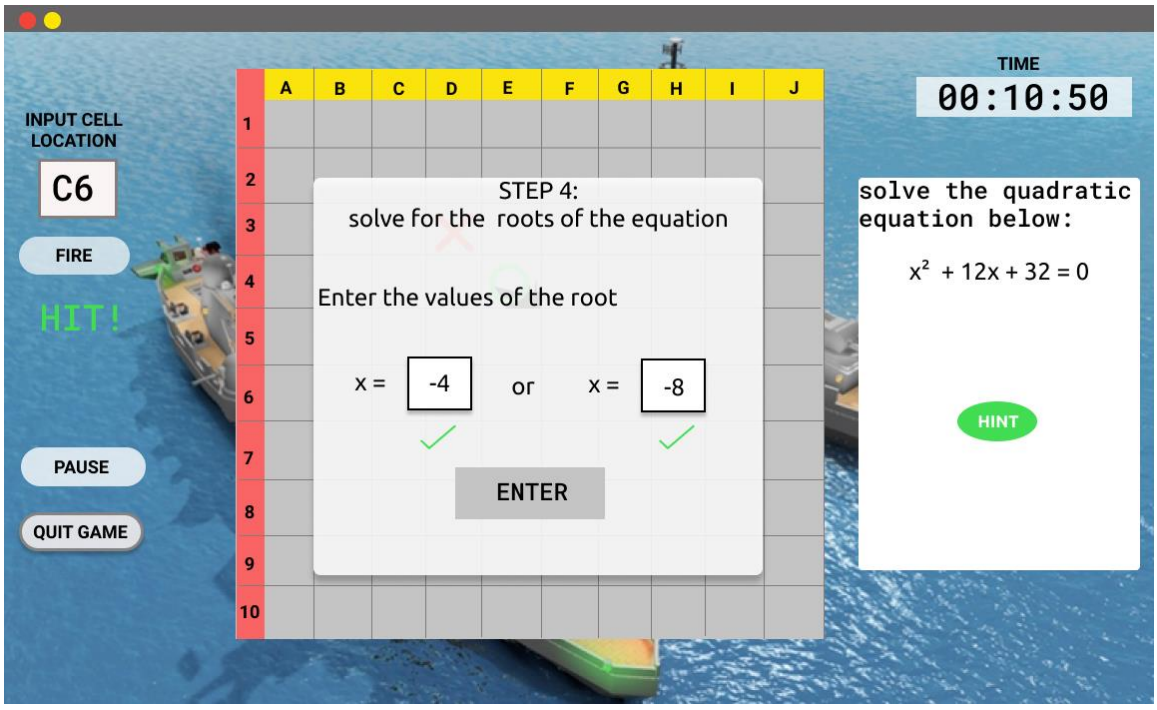

Figure 10: Solve for the Root of the Equation

I. **Scoreboard**: Figure 11 shows the scores of all the winning students from highest to lowest. The score is calculated by assigning 5 points per second left in the game when the player has finished all the tasks.

The back button on this stage also takes the game back to the main game entry point.

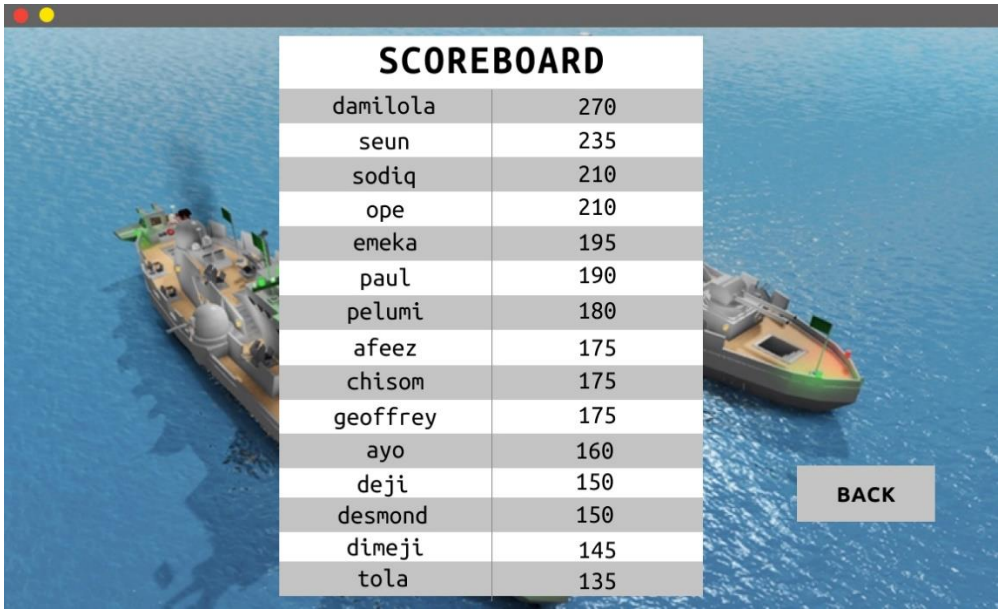

Figure 11: Scoresheet showing the scores of the players

J. Worksheet: Figures 12 and 13 show the worksheets of two (2) of the students. The user selects his/her preferred directory to save the text file and the text file when opened with a text editor. The usefulness of this feature is that students can later refer to this file to get more understanding about the concept they are trying to learn and it can serve as a class note.

Stepwise worksheet of the gameplay

EQUATION: $x^2 + 12X + 32 = 0$

STEP 1: Divide through by the coefficient of x^2

$x^2/1 + 12x/1 + 32 = 0$

STEP 2: move c to the other side and add half the square of x to both sides

$x^2 + 12x = -32$
$x^2 + 12x + 36 = -32 + 36$
$x^2 + 12x + 36 = 4$

STEP 3: complete the square of the equation and take square root

$(x + 6)(x + 6) = 4$
$(x + 6)^2 = 4$
$\sqrt{(x + 6)^2} = \sqrt{4}$
$(x + 6) = +2 \text{ or } -2$

STEP 4: solve for x

$x = 2 - 6 \text{ or } x = -2 - 6$
$x = -4 \text{ or } x = -8$

Figure 12: Stepwise Worksheet of the Gameplay by a Player.

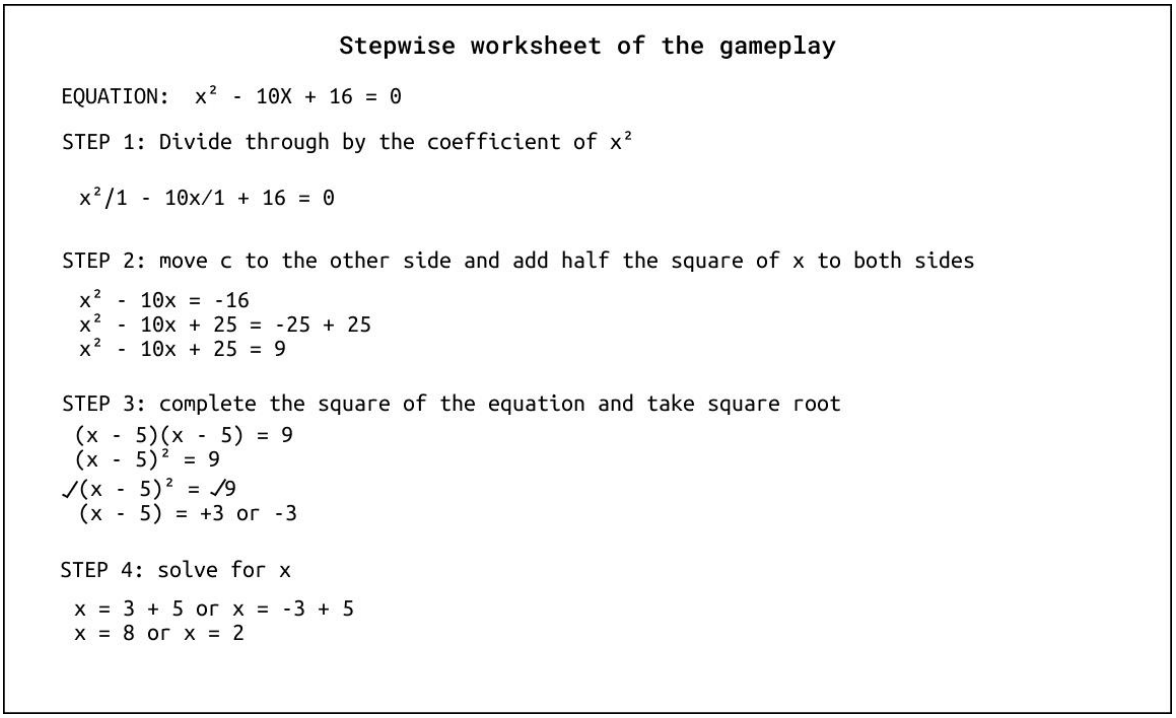

Figure 13: Stepwise Worksheet of the Gameplay by another Player.

4. Performance Evaluation

Performance evaluation was carried out using questionnaire with twenty question-items that spanned or distributed over the set of parameters or criteria such as capability (5), intended learning outcome and Game attribute (6), learning activity (3), reflection (3) and game achievement (3) is depicted in Table 1.. The questionnaire was administered to a set of forty (40) students of first year students of Federal University of Technology, Akure, Nigeria for 2018/2019 academic session. It used 5-point Likert scale with associated linguistic terms such as Excellent (5), Good (4), Average (3), Poor (2) and Very Poor (1). The data collection was based on the number of respondents to each question-item with respect to the points shown in Table 2 and analysed using frequency distribution and weighted mean.

Table 1: Variables combination with respect to Framework variables

Conceptual Framework Variables	**Questionnaire Variables**
Capability	A,B,C,D,E
Intended Learning outcome and Game attribute	F,G,H,I,J,K
Learning Activity	L,M,N
Reflection	O,S,U
Game Achievement	P,Q,T

Table 2: Respondents' Responses to the Questionnaires relative to Linguistic Terms

Item number	QUESTIONS	POINTS/NUMBER OF RESPONDENTS				
		5	**4**	**3**	**2**	**1**
A	Is the game linked to the challenge?	32	6	2	0	0
B	Was the challenge implemented effectively?	15	15	10	0	0
C	Is the objective of the game well integrated?	20	10	10	0	0
D	Does the game invoke positive learning attitude?	34	5	1	0	0
E	Does the game require critical thinking?	25	10	5	0	0
F	Is the Learning outcome connected across the steps of problem solving?	33	5	2	0	0
G	Is enough guidance provided while playing the game?	10	10	20	0	0
H	Is the game easily understandable without guidance?	35	2	3	0	0
I	Does the game play follow sequentially?	31	4	5	0	0
J	How easy is the game navigation?	29	6	4	1	0
K	Is the learning outcome incremental?	30	9	1	0	0
L	Is less anxiety towards solving quadratic equations motivated?	33	7	0	0	0
M	How would you rate the critical thinking required by the game?	34	5	1	0	0
N	How useful is the hint button?	32	8	0	0	0
O	How would you rate the scoring of the game?	30	8	2	0	0

P	How helpful is the game to your understanding of solving quadratic equations?	38	2	0	0	0
Q	Is the game challenging?	25	12	3	0	0
R	Is the game user friendly?	33	7	0	0	0
S	Is the game understandable?	29	9	1	0	0
T	Is the allocated time enough?	21	15	4	0	0
U	Is learning enhanced?	34	4	2	0	0

The number of respondents for each questions-items that spanned the criteria was computed using method of percentage representation of values as in the equation 1:

$$Percentage\ Point = \left(\frac{Points\ Obtained}{Points\ Obtainable}\right) * 100 \quad (1)$$

The percentage points are computed using equation 1 as shown in Table 3. The resultant percentage values obtained for the criteria demonstrate that the system is highly suitable for underlined objectives that relate to foundation of learning theories with game technology that promote an efficient learning performance in solving of quadratic equations using completing the square method.

Table 3: Percentage Points of the Respondents

VARIABLES	**POINTS**		**PERCENTAGE POINTS**
	OBTAINED	**OBTAINABLE**	
Capability	430	500	86%
Intended Learning outcome and Game attribute	546	600	91%
Learning Activity	264	300	88%
Reflection	234	300	78%
Game Achievement	279	300	93%

5. Conclusion

Digital Game-based learning is a type of learning that employs the use of computer mediated tool to create fun

and the art of learning. It has been proved overtime that this concept not only enhances the state of education but also increases overall learning performance if enough attention is given to it with respect to appropriating the tool of foundation of learning theories with digital technology. Most importantly, students found traditional mode of solving mathematical problems to be very boring and difficult to understand in order to construct knowledge. Hence, this research paper developed a digital game-based study environment for solving quadratic equations using completing the square method. The learning environment is simulated with all the features of a serious game that is intended solely to enable students to understand and relate with the concept that is intuitively communicated to them while in the same vein enjoying the game. The findings showed that introducing digital game-based learning supports the underlined objectives, it helps in reducing mathematical apprehension in students and imbibes stepwise approach to solving mathematics. The research could be improved by incorporating augmented reality game-based learning platforms to improve students' achievement.

6. Recommendation

The findings from this research paper showed that the use of digital game-based learning system would help to reduce learners' apprehension in solving the quadratic problems. The system would serve as a teaching and learning tool for both mathematics teachers and students of all institutions of learning. It would avail the students to have an engaging hands-on-experience problem-solving processes which would promote constructive and cognitive skills. The authors opined that the developed system holds potentialities which should be further explored to assist students and individuals with psychological learning challenges. The scope of application can also be extended to assisting learners with certain autism spectrum disorder and likes.

References

[1]. J. C. Read. Serious Games in Education. EAI Endorsed Transactions on Game-Based Learning, 2(6), pp. 1-5., 2015.

[2]. O. Heidmann. How to create a serious game? EAI Endorsed Transactions on Game-Based Learning, 2(6), pp. 150-158, 2015.

[3]. N. Charlier and B. D. Fraine. Game-Based Learning in Teacher Education. International Journal of Game-Based Learning, 2(2), pp. 1–12, 2012.

[4]. Y.-J. An and L. Cao. Examining the Characteristics of Digital Learning Games Designed by In-service Teachers. International Journal of Game-Based Learning, 7(4), pp. 73–85, 2017.

[5]. M. Prensky. Digital game based learning. St. Paul, MN: Paragon House, 2001.

[6]. L. Campbell. Educational principles. A Good Education, pp.68–87, 2018.

[7]. J. P. Gee. What video games have to teach us about learning and literacy? Palgrave Macmillan, USA, 2003.

[8]. J. Evans. Adult Mathematics and Everyday Life: Building Bridges and Facilitating Learning Transfer. Mathematics Education Library Perspectives on Adults Learning Mathematics, pp. 289–305, 2002.

[9]. C. Gatzidis. Learning with Digital Games. International Journal of Game-Based Learning, 2(1), pp. 90–91, 2012.

[10]. K. Becker. Digital Game-Based Learning: Learning with Games. Choosing and Using Digital Games in the Classroom, pp. 25–61, 2016.

[11]. M. Aubrecht. Games in E-learning. Interactivity in E-Learning Advances in Game-Based Learning, pp.179–209, 2012

[12]. J. Fishburn. What Game-Based Learning and Learner-Centered Teaching Can Learn from Each Other? 10th International Conference on Education and New Learning Technologies (EDULEARN18 Proceedings), pp. 6853-6858, 2018.

[13]. D. Laur. Authentic Learning Experiences: A Real-World approach to Project-Based Learning, Routledge, New York, NY 10017, USA, 2013.

[14]. A. Shafie and W. F. W. Ahmad. Design and heuristic evaluation of MathQuest: A role-playing game for numbers. Procedia-Social and Behavioral Sciences, 8, pp. 620 –625, 2010.

[15]. C. Yuh-Ming, S.-J. Lou, S.-H. Kuo and R.-C. Shih. Investigating elementary school students' technology acceptance by applying digital game-based learning to environmental education. Australasian Journal of Educational Technology, 29(1), pp. 96-110, 2013.

[16]. H. Chun.-Ming, I. Huang and G.-J. Hwang. Effects of digital game-based learning on students' self-efficacy, motivation, anxiety, and achievements in learning mathematics. Journal of Computers in Education, 1(2-3), pp. 151–166, 2014

[17]. P. H. Siew. Pedagogical Change in Mathematics Learning: Harnessing the Power of Digital Game-Based Learning. Educational Technology & Society, 21 (4), pp. 259–276, 2018.

[18]. S.-Y. Wang, S-C. Chang,, G-J. Hwang and P-Y. Chen. A Microworld-based role-playing game development approach to engaging students in interactive, enjoyable, and effective mathematics learning. Interactive Learning Environments, 26(3), pp. 411–423, 2018.