Design of a Digital Game-based Learning System for Fraction Algebra

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Abstract: Digital game based learning (DGBL) system is a promising area of research and debate, as it promotes contextualized learning, creates and harnesses motivation in learning capacities and encourages curiosity. DGBL takes place in a technological-mediated environment while engaging players in a learning activity through the support of computers. Several digital game based learning systems have been deployed for educational purposes to aid or support students in hands-on-learning experiences and constructive knowledge that involves mental reasoning processes. Hence, the research paper presented a development of digital game based fraction algebra learning system which is associated with game principle of snakes and ladders with underpinned concept of step-by-step procedure of solving mathematical problems. The system was tested by participants of FUTA staff primary school and the results of performance evaluation showed that the system could greatly support students to learn effectively the fraction algebra through game technology and would increase the students' thinking process.

Index Terms: Digital game based learning, fraction algebra, snake and ladder, mathematical problems

1. Introduction

The importance of education has been growing tremendously over the years especially in the modern days of digital technology. From ancient times, it has been noticed that practical learning has been more beneficial to the students in helping reinforce concepts better than books. Researchers and pedagogists tried to exploit advances in technology to integrate with traditional teaching techniques and develop methodologies with emphasis on "learning by doing" or "active learning" to help students learn better [1]. It has been observed that the latest advent of technology fascinating the children of today is the array of digital games. In recent years, it has been repeatedly suggested that embedding games into education can be a way to improve students' affect, interest, and motivation towards education, and in turn improve their learning [2].

Game-based learning (GBL) is a system where students play games with defined learning outcomes. Digital game-based learning (DGBL) takes place in a virtual environment with fantasy elements while engaging players in a learning activity through the use of a technological tool such as a computer [3]. DGBL is a promising area of research and debate, as it promotes contextualized learning, creates and harnesses motivation in learning capacities, and encourages curiosity [4,5].

Research has proven that if mathematical concepts are embedded in these digital games, and considering the level of engagement children play these games with, it can significantly help to learn these mathematical concepts better in a more enjoyable manner coupled with their level of commitment [6]. Game design can be used specifically in mathematics education, as it promotes creative thinking and problem-solving skills that can be transferred to the classroom [7].

There are numerous applications that have been developed to take the advantage the gaming technology tends to offer when combines it with teaching and learning. But, the exploration of this technology in the area of mathematics as a subject has not fully utilized, especially when most students see the subject to be very difficult because it requires

critical thinking and reasoning when solving mathematical problems in step-by-step procedural fashion. The use of game technology creates fun that makes for attraction or attention in gainfully engagement of problem solving. The learning of algebra using computer-mediated tool is also developed in [8, 9] but the use of gaming technology is not incorporated into it. Subsequently; Agbonifo and Onu [10] also developed a system using game theory of chess to solve algebraic expression using elimination by substitution, but solving algebraic fraction is not integrated into the system. Therefore, the research paper develops a digital game-based learning system using game logic of snakes and ladders to learn the concepts algebraic fractions in step-wise fashion.

2. Digital Game based Learning

According to Prensky [11], described digital game-based learning as any marriage of educational content and computer games. In an educational environment, the use of digital computer games offers the acquisition of knowledge construction opportunities [12]. Gaming is also considered as an activity that is interactive, entertaining and can make learning enjoyable [13]. Games can also be seen as the engagement of critical thinking through problem solving skills [14].

Games offer a unique structure to complement traditional strategies and infuse teaching with energy, spark innovative thinking and provide diversity in teaching methods which make learning concepts more palatable for students. Games encourage creative behaviour and divergent thought and are excellent ice breakers [15]. Games will often act as learning triggers inducing lively discussion on learning concepts amongst students following gameplay.

Keller [16] proposed ARCS model which enhances student learning motivation using the systemized instructional strategies as classified below and game characteristics employed in various design strategies. Keller conducted a study that made sure the processes reduce extraneous cognitive loads, enabling learners to establish schema through assimilation and accommodation, and increase germane cognitive loads.

The Attention, Relevance, Confidence and Satisfaction (ARCS) model is classified below with their subcategories, game characteristics and definition.

In the Attention category, digital games are designed with effects such as rich pictorial and auditory variations and using multimedia characteristics to induce players' curiosity. In addition, the use of story contributes to various types of knowledge learning. It comprises of different sub-categories such as perceptional arousal, inquiry arousal and variability. Its game characteristics are multimodal presentation and story, fantasy and fun.

In the Relevance category, the game tasks include tasks that accumulate toward achieving game goals, learners are often required to undertake a series of tasks to complete the final goal of the game [17]. Its sub-categories include goal orientation, motive matching and familiarity and it boasts of game characteristics such as tasks, goals, and sense of winning.

In the Confidence category, digital games constitute interactions between humans and machines, presenting players with a sense of performing actions. Its sub-categories are learning requirements, success opportunities and personal control. Its game characteristics are rules, control, play and interactive situations.

In the Satisfaction category, learners successfully complete tasks and accumulate scores, the sense of winning naturally induces a sense of achievement. Its game characteristics are sense of winning, outcomes and feedback. It comprises of sub-categories such as natural consequences, equity and positive consequences.

3. Related Works

Bouhineau *et al.*[8] carried out a study and concluded that Aplusix is a computer based system that favours the students' learning of algebra in school. Its basic training mode consists of letting the students perform their own calculations, it has a two-dimension editor of algebraic expressions, providing feedback on the correctness of the calculations and at the end of the given solution. Furthermore, the students gained autonomy and improved knowledge. Aplusix has a workspace area where the users type the solution to equation problems in a step-by-step manner. This is just a computer-mediated system and there is no incorporation of game technology into the system.

Feng *et al.*[18] developed a computer game which encourages players to combine numbers in different ways with arithmetic operators. It has been implemented in such a way that the players can either compete against another real-life player or the computer itself. This collaborative nature of the game encourages students to learn concepts better via teamwork and competition. This game mechanism encourages students to learn fractions in a dynamic grouping environment. A future improvement for the game is proposed that would be needed to maintain individual data logs of each student's learning process, which could be further analysed to build students' specific models and detect the cognitive aspects. The focus of problem-solving is not on fraction algebra.

Turtiainen *et al.* [9] conducted a study on UFraction as one of the latest story based fraction games that was developed for mobile devices and was tested on eighth grades students in five South African schools; and on students and teachers of the University of Pretoria, South Africa. The story in UFraction revolves around mother leopard and her cub senatala, which the students tend to identify themselves with. This platform facilitates development of multiuser, networked mobile applications on Java enabled mobile devices. The goal of the game is to solve problems

using Hungarian Mathematical manipulative, which are collections of twelve coloured rods, each having a different colour and length. Though, the system is based on story-based structure of solving fractions but not on fraction algebra.

Cognitive Tools (CT) is another educational tool by Kong [19] which uses exploratory process to teach students the procedural knowledge of adding and subtracting fractions. These fractions can have like and unlike denominators. The CT is a web-based learning tool. It uses graphical representation of fractions to utilize students' initial knowledge of the part-whole concept of fractions. Teachers found this tool effective in tutoring students and likewise the students found this tool stimulating as well. This tool was used in pre-test-post-test control group empirical study and has been discovered to have potential for the development, which could enhance collaborative learning of fraction concepts among students in classroom. The system did not incorporate fraction algebra which is another mathematical concept in problem-solving.

Agbonifo and Ogunmoroti [20] developed a digital lego-based learning environment for fraction ordering and it is a digital game which involved a boy plucking fruits before he gets home within a specified time. To pluck the fruits, he needs to break some fraction cube in ascending order within a timeframe hence making the game align with the learning process. If the cubes are broken in the digital was tested amongst ten pupils in one of the private schools around the Federal University of Technology, Akure (FUTA). The area of focus of the system is on fraction ordering and not on fraction algebra.

Bouzid *et al.* [21] developed a beta-prototype educational digital game for supporting elementary mathematics learning that focused on reducing the intensity of emotional barriers and boosting concentration, motivation, autonomy and interaction. The finding shows that the impact of the build-from-scratch DGBL approach pays off in primary school.

Agbonifo and Onu [10] developed a digital game based on chess mediated environment which provides the player with the problem-solving sequences of simultaneous equations using elimination method. The game has a storyline where a king in one kingdom is abducted by opposing kingdom and a brave knight embarks on a mission to rescue the King. The rule of the game is to resolve two simultaneous equations of order 1. This is finding the values of the two unknown variables (x and y) which act as the keys needed to unlock the enemies' gate and the King's prison gate with a fraction of time allocated to each scene. The digital game-based learning system did not accommodate solving of algebraic expression with fraction.

4. System Design

The section describes the storyline of the game, system architecture, flowchart and modules.

A. Game Description

i. Storyline of the game

The storyline of this game is based on snakes and ladders concept but the player is not required to go through boxes 0 – 100) and go through up or down by using ladders in the original concept of snakes and ladders game. Now the player has to make the snake hurdle through the 4-step ladder by solving the fraction question presented to him where he would use instructions displayed on the screen to solve the fraction algebraic question. With the instructions displayed, the user should be able to learn and solve as many questions as possible. For the user to obtain the maximum score, he should be able to supply the answers at each step of the ladder before proceeding to solve the main fraction algebraic question.

ii. Game Play

Firstly, the player has to solve all the simple fraction questions on the ladder by making the snake entity successfully get to the top of the ladder before solving the fraction algebraic question that would be presented to him. There would be steps and instructions as to how he should be able to solve the algebraic question. The following steps below highlights how the user can traverse before obtaining the maximum score:

(i)   The player should be able to solve all the fraction question
(ii)   In the first process above, if the player gets each question correctly, the snake is moved up by one step.
(iii)   If the player is successfully able to beat the time count, then he/she is added to the top of the leader-board and can replay the game again as he/ she wishes to.

With the game play and story development, the user has to ensure that the snake has to be at the top of the ladder before testing his knowledge on the subject matter by solving the fraction algebraic question. Steps/instructions displayed to the player should be able to guide him in achieving the ultimate goal.

iii. Timing System Used of the Game

The timing system defines how well the player is able to beat the time in achieving very high scores and being top of the score chart. Most timing system in games is counted downwards so as to give the player a sense of attention and confidence as in the ARCS model. The unit of timing system used in the project is in seconds.

iv. Scoring System Used for the Game

The scoring system connotes who gets the highest score and the processes on how the scores are being achieved. The process of scoring is simple, in that whenever the player accomplishes a task within the game, the player is rewarded with more points to get his/her desired score. The scoring system is limited to numeric score. As long as the player follows the rule of the ladder game and solves different algebraic questions, more points are added to him. This is how scoring systems work in most games and the unit of the scoring system is in numbers (points). Most players would always want to be at the top of the leaderboard as it encourages competition amongst players which makes them to be classified as champions.

B. System Requirements

The system is developed using the Visual Studio Integrated Development Environment (IDE). The system runs on almost any Windows platform. The server side has both the application logic layer and the database layer and it is required to be a high end machine. The minimum requirements at the server side include Structured Query Language (SQL) Server, browser and SQL Server full text search. The minimum requirements at the client side include Intel Pentium IV/M processor running at 400MHz – 1.7 GHz, 512 MB RAM and SVGA Monitor.

C. System Architecture

The system architecture is depicted in Fig. 1 which is based on Microsoft .NET Framework that provides powerful technology such as Windows Forms to simplify developing applications and components that work seamlessly on the windows machine. It consists of components such as game interface, game input, game logic, database and the corresponding output. The game interface is a communication platform through which the user can access the system. The game input to the system by the users is carried out through mouse and keyboard allowing users to navigate through the game process. Inputs to the game are player name, password, and steps into each stage as required by responding through clicking. The game logic employs the propositional logics.in the development of the game which defines the logical outcome of the game and all the working processes. The game uses combination buttons (ladder steps) to successfully fast track the snake by reaching the top of the ladder to start the main game which is done by solving a fraction algebraic question. The database, Microsoft Structured Query Language (MSSQL) Server is used to keep record of scores and results of the user engagement and experience in the game. While the output represents the outcomes of the game based on the inputs provided via keyboard and mouse clicking events and the logics with which user response are implemented.
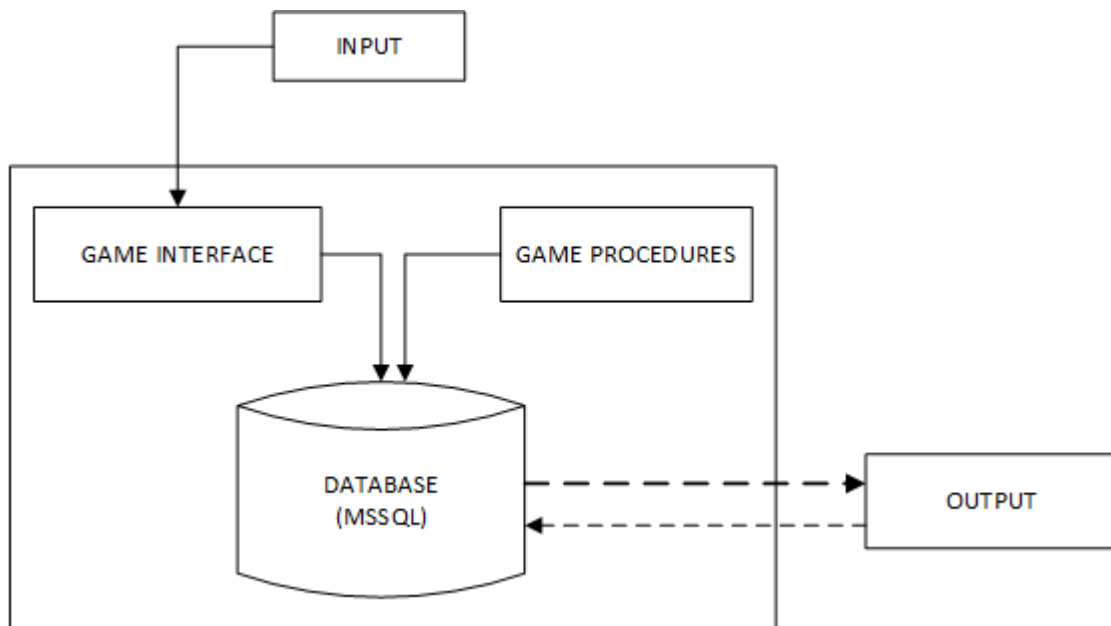

Fig. 1. System Architecture

D. System Flowchart

The flowchart of the fraction algebraic system is depicted in the Fig. 2 which shows a procedural representation of event happening within the game. As the game is launched, it provides the player with menu options to play, exit, check scorer board for high scorer or even check what the game is about. If the option selected is exit, the game exits. If the option selected is high score it checked the database. If the option is "play", it registers the player and verifies if the user is registered, hence, the player can start playing the game according to the rules of the game. Once the user clicks on the start button, a fraction algebraic question is displayed on the system for the user to solve. There is a timer of 420 seconds (7 minutes) counting down and if the game timer is equals to zero seconds, then the game prompts a message telling the player that he has exceeded the time frame, else, the user continues until he achieves the correct answer and maximum score is obtained. If the player completes the task required by the game, points are being awarded and saved to the database.
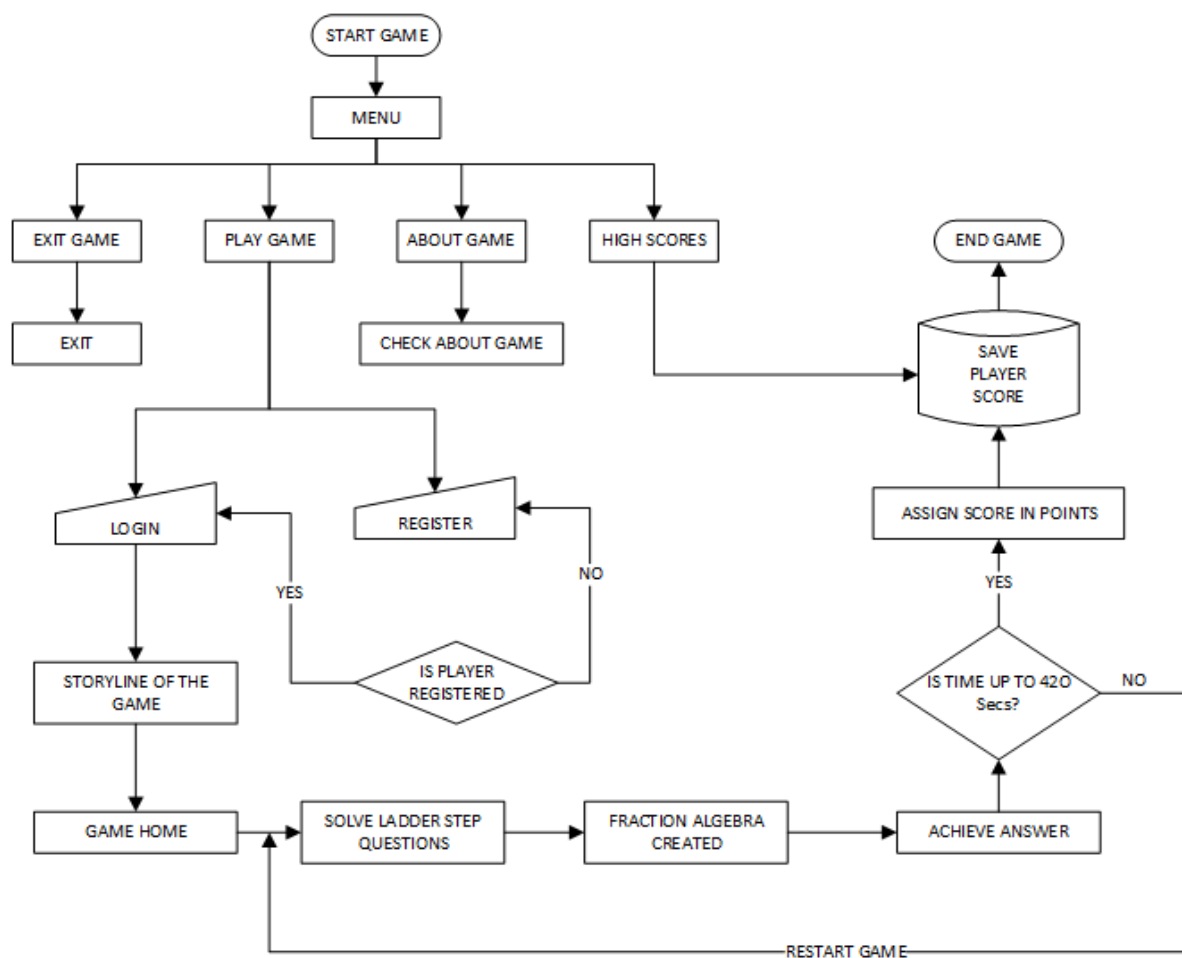

Fig. 2. System Flowchart

E. System Modules

System modules are the set of programs that are composed of one or more independently developed linked modules which gives the system efficient and effective performance. Fig. 3 shows the interface of C# class file developed in the Visual Studio.NET suite for designing the game interface (Fig. 4) which runs on a library called the .NET Framework.
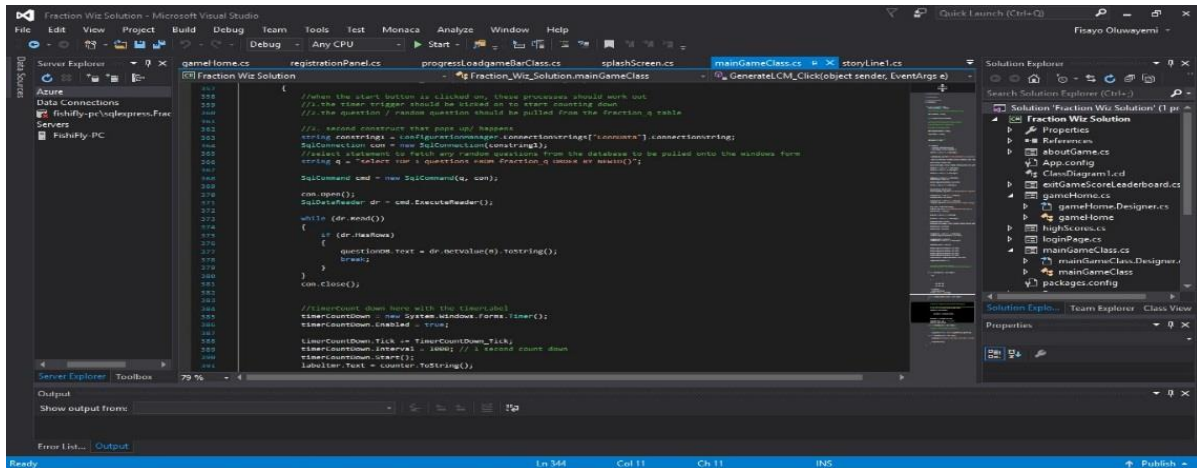
Fig. 3. Design Process of the Game

Fig. 4 describes the game interface which displays the interaction of the player with the system and consists of the components such as Play, High Scores and Exit Game. The Play button takes the player into the login page to register his/her login details and for subsequent authentication and verification processes It also checks if such player has registered in the SQL database in order to grant the player login access. The High Scores button displays a list of high scores achieved by the player and the exit game button ends the game.

Fig. 4. Game Interface at Runtime

Fig. 5 presents the platform for player to solve fraction algebraic which consists the various components such as timing, score, 4-ladder steps and fraction algebraic question. At the start of the game, fraction algebra would randomly be generated where the player provides step-wise solving of the question in 4-ladder steps. The outcome of one step is an input to the next step until the final solution of the question. There are various hints provided in each of the steps that would assist the player on problem solving. A fraction algebraic question pops up for a player to solve with the game logic panel at the right side. If the player follows each instruction carefully, he would be able to proceed to the top of the last ladder. There are bar levels situated at each step of the ladder to boost the player's level of confidence. Once each step is solved right, a snake appears at each step of the ladder indicating his progress.
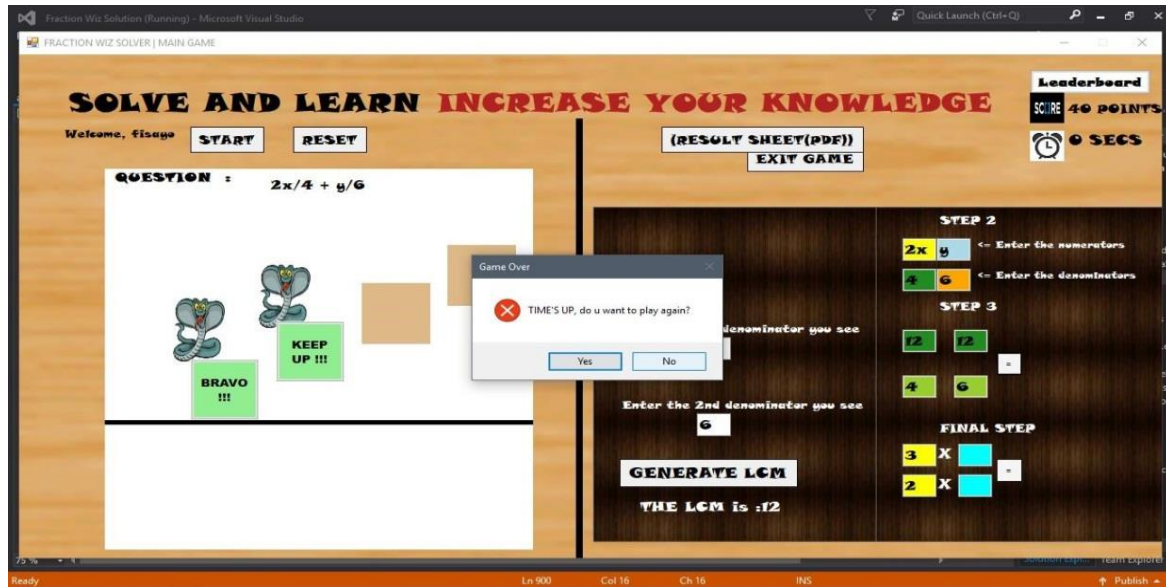
Fig. 5. Sample of a Player's Process of Problem Solving

5. Sample of Game Logic

This section explains the game logic of the system as follows:

The Values that are to be entered in the 2 white boxes with the hint "Generate lowest common factor (LCM) button" are the 2 denominators of the fraction algebraic LCM question.
Value in the first white box = denominator 1 of the random question
Value in the second white box = denominator 2 of the random question
After entering the values, the button is being clicked to generate the LCM for the player; after which he proceeds into the STEP 2 of the game.
At this STEP 2, the player is required to enter the numerators and denominators of the random question given to the player in the coloured boxes: yellow, aqua, green and orange.
The first two boxes yellow and aqua are for the numerators while the second two boxes green and orange are for the denominators.
The player then proceeds into the STEP 3 part of the game where he is required to enter the LCM being generated from the two (2) white boxes values entered at the STEP 1. For example, in Figure 5, the algebraic question is generated after the player clicks on the start button.
$(2x/4 + y/6)$ – Fraction algebra question is generated at the start button. When the values 4 and 6 are entered in the white boxes, it generates the LCM from the given question. This LCM value is to be entered twice in the dark green boxes followed by the denominators of the algebraic question.
When these values are entered correctly, the division process takes place which inputs the correct values inside the yellow boxes in the final step.
At the final step, the player is required to enter the numerators of the algebraic question presented after which the final solution is displayed.

6. System Result

The Table 1 depicts the sample of twenty players' scores out of sixty four players from FUTA Staff School that actively participated in this game. The varied scores show that those that have more points demonstrate the high level of understanding in subject matter.

Table 1. Sample of Game Score of Players

PLAYERS' IDENTICATION	SCORES
Player1	110
Player2	40
Player3	80
Player4	130
Player5	60
Player6	120
Player7	150
Player8	130
Player9	120
Player10	150
Player11	120
Player12	200
Player13	70
Player14	170
Player15	160
Player16	110
Player17	120
Player18	100
Player19	200
Player20	40

7. Performance Evaluation

The system was tested by a set of pupils in primary 4 (39), primary 5 (21) and primary 6 (4) with a total of 64 pupils. There were thirty four (34) female and thirty (30) male. The survey analysis was conducted in FUTA staff primary school in which the pupils actively engaged themselves with the digital game based system in the learning of fraction algebra.

There were thirty seven (37) questions drawn which are distributed across the criteria in this category: Ease of use (8), Intuitive User Interface (8), Optimisation (8), Improvement for Calculating Skills (8), and Correctness of Results (5). The data were obtained by assigning values of 4, 3, 2 and 1 to the linguistic term "Strongly Agree", "Agree", "Strongly Disagree" and "Disagree" respectively. The survey was distributed to a set of sixty four players. The analysis of the respondents with respect to the questions for the criteria is presented in Table 2. The responses of the players were analysed to determine the performance of the system based on the criteria using mean and standard deviation (SPSS 17.0). The result of the analysis is presented in Table 3 which considering the minimum and maximum values for each criterion with respect to the mean and standard deviation demonstrates that the system performs relative good. This indicates that the majority of the participants made positive affirmation that they strongly agreed or agreed with the followings: the system is easy or simple to use, the user interface is friendly, flexible and easy to navigate; system's response time in solving the problem with time frame allotted is efficient; the system enhances the students' knowledge in step-by-step problem-solving skills of fraction algebra; and that the modality in which the system presents the results or learning outcome is in a. realistic mathematical concepts connotation and hints are provided to assist players in the understanding of providing solution to fraction algebraic problems in a logical reasoning manner.

Table 2. Analysis of the Respondents with Respect to the Questions

QUESTIONS	STRONGLY AGREE	AGREE	STRONGLY DISAGREE	DISAGREE	TOTAL
Ease of Use	22	30	5	7	64
Intuitive User Interface	25	26	5	8	64
Optimisation	28	29	3	4	64
Improvement of Calculating Skills	27	29	4	4	64
Correctness of Results	26	30	4	4	64

Table 3. Result of Analysis of System Performance Evaluation

	N	Minimum	Maximum	Sum	Mean	Std. Deviation
Ease of use	64	16.00	32.00	1552.00	24.2500	4.57391
Intuitive User Interface	64	15.00	32.00	1582.00	24.7188	4.62385
Optimsation	64	12.00	34.00	1671.00	26.1094	4.48673
Improvement of Calculating Skills	64	13.00	32.00	1672.00	26.1250	4.59986
Correctness of Results	64	8.00	20.00	1023.00	15.9844	3.11928
Valid N (listwise)	64					

8. Conclusion

The method of solving mathematical concepts always involves hands-on-approach that requires stepwise theoretical-based solutions to the mathematical questions or problems. In the same vein, critical and constructive thinking are most crucial components needed in problem solving process. From experience, the use of solving with paper and pen has been proven to be difficult and boring on the part of learners due to the nature of the concepts. From the literature, the integration of gaming technology to solve mathematics problems has been of great assistance to all learners in various levels of institutions of learning. Hence, this digital game-based system is developed to support mental reasoning skill in problem solving process and includes game step bars to boost the player's confidence when solving to achieve a defined solution. The system would serve as a supporting tool to complement the teaching methods and strategy of instructors or teachers, thereby promoting clearer understanding of the concept on the part of the students.

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