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# An Educational Math Game for High School Students in Sub-Saharan Africa

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**Abstract.** The concept of educational games is to aid students in understanding various subjects in an interactive and engaging environment. Subjects like mathematics have continued to pose a challenge to many secondary school students in developing countries like Nigeria as seen from recent low performance in the Senior Secondary Certificate Examination (SSCE). Lack of interest is one of the key factors that contribute to the low performance hence there is need for a system that can help to improve student's interest in mathematics and subsequently their rate of success. The goal of this study is thus to develop an educational game software to help stimulate students' interest in mathematics and to also help them in understanding and improving their performance in the subject. The game was created by leveraging on the Unity game engine platform and the programming language used for development was C#.

**Keywords:** Education software · High school · Math game  
Sub-Saharan Africa

## 1 Introduction

Research proves that one of the best ways to learn transpires not when students are idly seated and passively listening to a lecture, but when they are engaged in a form of active learning [1]. The educational process these days leverages on constantly changing technology [2, 35]. The most common development in technology that tends to affect education the most are games [3]. Educational games are designed to teach people about different cultures or historical events, increase knowledge on certain subjects [34], strengthen development and promote the learning of a certain skill as they play [4]. For example, games like chess were used to learn and develop strategies of war [5].

Gaming has not only modified the way learning takes place, but it teaches different valuable skills of its own [6]. Today's computer games have attention-grabbing characteristics which challenge the normal traditional learning/educational system [7]. Hence, such games create opportunities for changes that can help to advance the

educational system [2]. The conventional approach to learning where students sit to receive lectures and tutorials is no longer adequate as it provides a one-way learning environment [8]. These days, students prefer to have a more self-paced learning approach [9]. With the new learning pedagogy and teaching techniques, most universities are beginning to embrace the idea of having a student-centered learning approach [10]. The most suitable tools for this are computer games because they fit in the student-centered learning approach [11]. Computer games are not just for entertainment, they are capable of providing a substantial self-learning environment for students [12]. For instance, in simulation, the gamer or learner is given full control of the gameplay. As a result, it is suitable to apply to the education context. Based on this circumstance, a simulation environment can be created for students to practice particular skills or techniques [12].

In 2002, there were several areas where professors began to make use of computer simulations, such as Physics, Chemistry, Oscillations and Electronics [13]. The idea was to incorporate carrying out virtual experiments based on real experiments on modern personal computers rather than the traditional experiments. These applications helped students to learn and understand the theories behind different chemical reactions and test natural occurrences by introducing different parameters as numbers and variables in a safe environment.

Computer games have also been widely applied in the learning process of the education field due to the increase of computer use in the market [14]. By using computer games as a learning tool, it assists in aiding the students learning and improving understanding. This is because an educational game provides the much-needed interaction context for a student. Students can interact with the game and immediately get feedback or response. Today, most learning centres, ranging from primary school to universities, are fully equipped with the necessary computer facilities, hence this gives reason to think about how to fully utilize them [15]. Using computers as learning and teaching tools is one of the best approaches [12].

Recently, math games, as a specific subdomain of STEM (Science, Technology, Engineering and Mathematics) educational games, have received significant attention from the research community [16]. Although the average man needs some knowledge of mathematics to go about his daily activities, students tend to find the subject quite challenging especially in developing countries like Nigeria. The performance in this subject is quite low especially in the SSCE (Senior Secondary Certificate Examination) and NECO (National Examination Council) written by students in Nigeria. Between the year 2000 and 2011 the average percentage of students that passed this subject (A1–C6) was 40.38% [18, 19]. This means a greater percentage failed the subject which causes them to change from careers that could have benefitted them and the country for the better [17]. Lack of interest is a key factor that contributes to the high failure rate in mathematics hence there is need for a system that can help to improve student's interest in mathematics and subsequently their rate of success [20, 21].

The goal of this study is thus to develop an educational game to help stimulate students' interest in mathematics and to also help them in understanding and improving their performance in the subject. The rest of this study is outlined as follows: Section two reviews existing educational games in order to gather requirements for a new game. In section three, the analysis and design of the proposed mathematics

educational gaming system is presented. Section four discusses the system implementation while section five compares the newly developed system to existing ones. Section six concludes the paper with recommendations for further studies.

## 2 Related Works

The earliest game that was used for educational purposes was developed in 1967 by Seymour Papert and Wally Fuerzeig called 'Logo' [22]. Logo blended mathematics and programming by allowing users to program a small cursor called a 'turtle', to move and draw lines through series of codes. By 1970, schools began to implement it to teach young students. This section gives a review of existing educational mathematics games. They include; Math Apocalypse, Sudoku, the X detectives, Math millionaire, Ratio stadium and Math apprentice.

Math Apocalypse is a mathematical game that was developed by Esteban Gallardo [23–25]. It is suited for students within the age of 13 and below. This game was designed to help students develop their multiplication, addition, subtraction and division skills. The idea was to use their mathematical skills to fight off an alien invasion by solving the presented problems. It was developed as an online game as well as an android application. In order to play it online, a user would require Adobe flash player. Users are given the opportunity to select the level of difficulty which ranges from 1 to 9 with 1 being the least difficult and 9 being the most difficult.

Sudoku is another math-based game that has been around for many years and was originally called Number Place [26]. It caught on first in Japan, where number puzzles were more dominant. The game comprises of a  $9 \times 9$  grid with numbers. In order to play the game, the player would rely on the use of logic. Some benefits of the game include the fact that it (i) improves the memory of the player (ii) stimulates the mind (iii) increases the ability to concentrate and (iv) keeps the brain active. This game has been developed on different platforms including the web and on mobile devices.

The X detectives is an online math-based game that teaches students to help a detective solve cases using mathematics [27, 28]. Students navigate through the various buildings using a car controlled by the arrow keys. The student while playing applies some mathematical techniques in solving problems that involve symmetry, translations, rotations, algebraic puzzles, integers and functions as well as graphs while justifying the solutions. The game consists of four buildings; the Gadget Shop, X detective Headquarters, Transformation room, and the Function Factory. The player visits each building and attempts the activities there and once done, more buildings are unlocked to begin assisting Kai the spy guy with his mission to find Agent X.

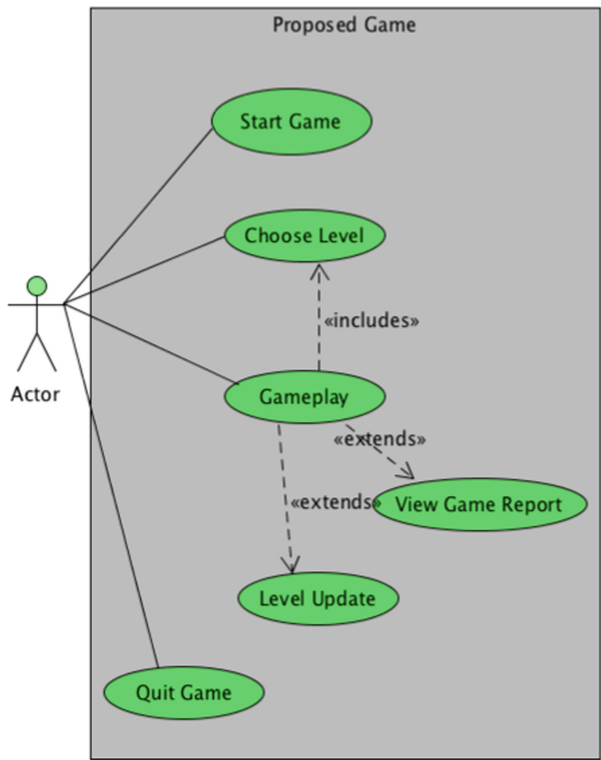
Math millionaire tests a student's knowledge of mathematics with a series of questions [29]. It follows the same design as the popular game show, 'Who wants to be a Millionaire', but focuses solely on mathematics. It has three lifelines; ask the audience, phone a friend and 50:50. If a player is unsure after using the lifelines s/he can walk away thus ending the game. The game helps reinforce mathematics in an entertaining way. It also captures the attention of students who feel restless or tired. In addition, it helps increase students understanding and memory.

Ratio stadium is a racing game developed by Arcademics, which can be single or multiplayer [30]. It allows students to race each other while matching equivalent ratios. The speed of player’s bike is determined by how fast s/he can answer the ratio problems. It teaches students to simplify fractions and identify equivalent ratios.

Math Apprentice is a game that teaches students how mathematics is used in every day careers [31]. It helps students answer the lingering question in mathematics that is ‘When will we ever use this in real life?’. In the game students intern at any one of eight different companies in a growing metropolis. An employee greets them and explains the mathematics behind the job then they are presented with specific problems to solve or explore the math concepts on their own. The main aim of this game is to connect mathematics to real world careers and introduce students to more advanced mathematical ideas.

### 3 Methodology

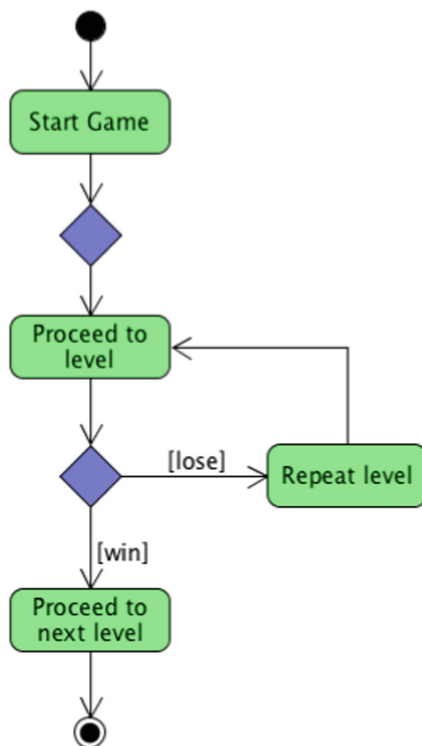
From the studies reviewed in the previous section, it is clear that math-based games should have a clear focus. In other words, the game should be designed to aid in the understanding some specific mathematical concepts. The games should also target



**Fig. 1.** Use case diagram for proposed math-based game

specific platforms that are readily accessible to the intended audience. The proposed game was modelled using a number of unified modelling language (UML) diagrams. This includes the use case diagram which shows the various interactions of the user with the system; the activity diagram which shows the flow of activities in the game; the class diagram which shows the various entities that make up the game and the interaction between them. Figure 1 depicts the use case diagram which consists of one actor – the player and six use cases namely: gameplay, choose level, level update, start game, quit game and view game report.

Figure 2 shows the activity diagram for the proposed game. From the diagram, when a user starts up the game, s/he can choose the level to start playing based on competence. Once a level is selected, the game will proceed until the player wins or loses. If the player wins, s/he proceeds to the next level otherwise they would have to repeat the level as depicted in the diagram.



**Fig. 2.** Activity diagram for the proposed math-based game

Figure 3 is the class diagram that comprises of five entities namely: the main menu, the levels – and pause game.

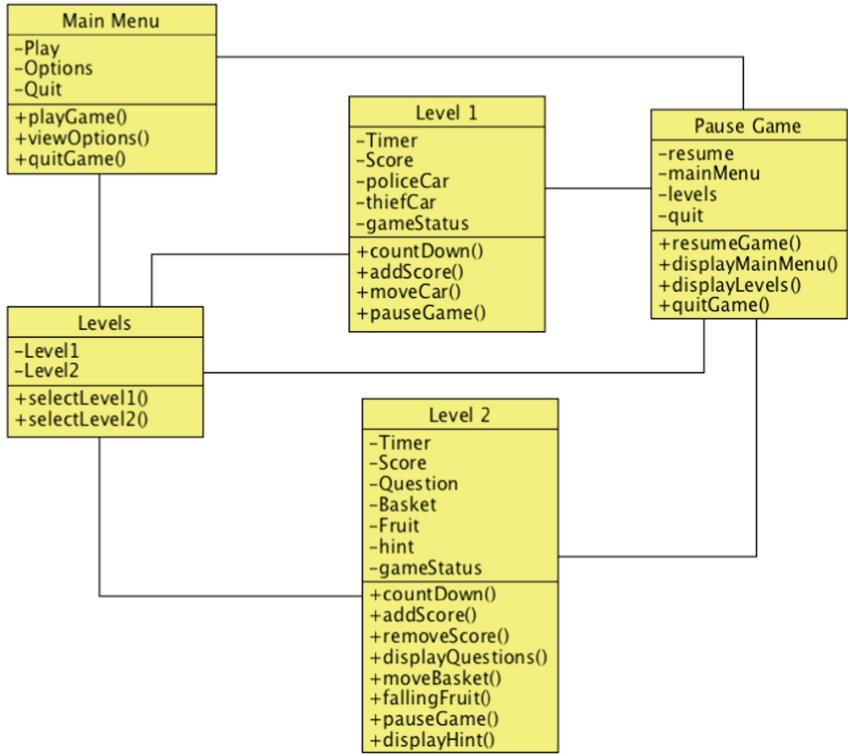


Fig. 3. Class diagram for the proposed math-based game

## 4 System Implementation

For the development of the game, the Unity game engine platform was leveraged, and the programming language used for development was C#. In this section, the game interfaces are shown and explained in detail.

The first interface that a user comes across when the game is started is depicted in Fig. 4. It shows three options that can be selected by the user. Play option starts the game play. Options allows the user to adjust the game settings such as the level of the difficulty of the game or the level to play while quit ends the game.

Suppose a user selects the Options from Fig. 4, s/he will be taken to the Levels interface which shows the various levels of the game similar to the X detectives game. This is depicted in Fig. 5.

Each level in the game teaches a different concept. However, until the user completes the first two levels s/he cannot proceed to the next levels. In level 1, basic mathematical concepts required to master surds are presented in an interesting scenario. The player is a police officer chasing a bunch of thieves who have just robbed a bank. The objective of the game in this level is to catch the thieves by outrunning them with the police vehicle. To achieve this feat, the player is required to respond to questions



**Fig. 4.** Main interface of the game



**Fig. 5.** Levels interface of the proposed game

that pop up from time to time so to increase the acceleration of the police car. If the police car is able to outrun the vehicle used by the robbers before the time elapses, then the player wins the game else s/he may have to try again. Level 1 is depicted in Fig. 6.

Level 2 teaches surds. It is done using a hospital cafeteria setting. The objective of this level is for the user to catch the right fruit that solves the given question. This is based on the six rules of surds. The level begins with an introductory interface where the objective of the level is explained as depicted in Fig. 7.

Once a user clicks proceed, the game begins with the display of a question, the user's score and the countdown timer. Once the timer is up the game ends but if the user catches the right fruits for the question (representing the sequence of steps to solving the question) then they advance to the next question. An explanation on how to proceed is shown when the user presses the hint button as shown in Fig. 8.



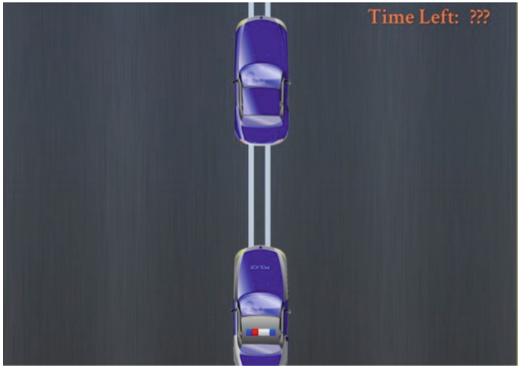


Fig. 6. Level 1 interface

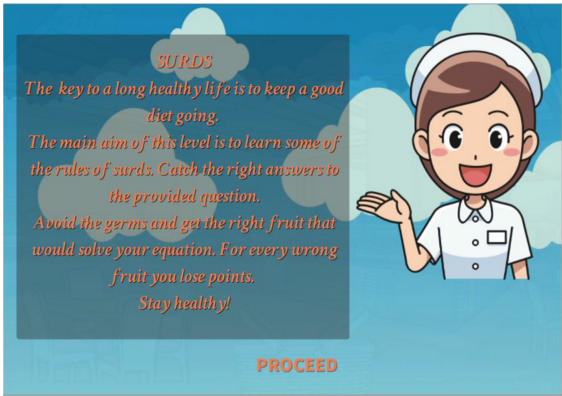


Fig. 7. Level 2 introduction



Fig. 8. Level 2 in progress

## 5 Comparison and Discussion

The application developed in this study is work in progress. However, in this section, comparison is made between the newly proposed system and the existing systems in terms of the design rationale; deployment platform(s); the age range that would find the application useful; whether or not the application is single or multiplayer and number of levels supported.

From Table 1, it can be observed that most of the existing systems (except for Sudoku) target kindergarten to middle school students in the age range of 5–13 [32]. Hence, they tend to focus on building arithmetic skills as in the case of Math Apocalypse, developing forensic skills through mathematics (X detectives), testing general knowledge of various topics in mathematics (Math millionaire) and specific areas such as fractions and ratios (Ratio stadium) how they can be applied in the work place (Math apprentice). On the other hand, our proposed system targets high school students (14–18 years of age) especially those in sub-Saharan Africa who take part in the SSCE examinations to qualify to advance to institutions of higher learning.

**Table 1.** Comparison of proposed game with existing games

|                        | Math Apocalypse                       | Sudoku                               | X detectives                              | Math millionaire                       | Ratio stadium   | Math apprentice                       | Proposed system                            |
|------------------------|---------------------------------------|--------------------------------------|---|--|---|---------------------------------------|--|
| Design rationale       | Develop arithmetic skills in students | Enhance logical thinking in students | Develop forensic skills using mathematics | Test students' broad knowledge of math | Teaches students to simplify fractions and identify equivalent ratios | Teaches mathematics for the workplace | To stimulate interest in high school maths |
| Deployment platform(s) | Online, mobile                        | Online, mobile                       | Online                                    | Online                                 | Online  | Online                                | mobile                                     |
| Age range              | 5–13                                  | All ages                             | 5–13                                      | 5–13                                   | 5–11  | 5–13                                  | 14–18                                      |
| Single or Multiplayer  | Both                                  | Both                                 | Single                                    | Single                                 | Both  | Single                                | Single                                     |
| Levels supported       | 9 levels                              | N/A                                  | They are unlocked progressively           | N/A                                    | N/A   | 8 levels to be covered                | Levels unlocked progressively              |

Also, unlike the existing games that tend to be deployed as mostly online games, the proposed system is mobile based considering the proliferation of mobile devices among high school students in sub-Saharan Africa [33]. At the moment, the game is single player and the levels are unlocked progressively similar to the X detectives game.

## 6 Conclusion

Math-based games are still being looked into as a new aid to teaching. In this study the topics focused on are those that most students tend to have issues with. The game is designed to assist students in understanding the basics of these difficult topics. Hopefully with more improvements more steps can be given to the levels and more levels can also be added thereby expanding the range of topics student can learn. The

game was developed by leveraging the Unity game engine platform and so can be deployed to a wide range of media including game consoles, the web and of course mobile devices hence its viability. For future work, we intend to carry out empirical studies to compare the performance of students who use the game with those who do not and how it impacts on their performance in secondary school mathematics examinations being taken in Nigeria.

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