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Review

LogicHouse-v1: A Digital Game-Based Learning Tool for Enhanced Teaching of Digital Electronics in Higher Education Institutions

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ABSTRACT

A drastic decline in the number of students that are enrolled for Engineering is now being experienced in developed as well as developing countries. Learning is becoming boring as a generation brought up on technology is losing the ability to pay attention in traditional classes for a long stretch of time. This has led to the idea that other teaching methods do exist and can be applied in teaching/learning. This work leveraged the use of Digital Game- Based Learning (DGBL) in Engineering classrooms to develop a serious game named LogicHouse Version 1 (LogicHouse-V1 or LogicHouse for short). The game, is a web-based serious game prototype that targets selected topics in Digital Electronics course. This course is a core component of undergraduate curriculum in Electrical & Electronics Engineering, Computer Engineering, Information Technology, Communication Engineering, Computer Science and other related Science Technology Engineering and Mathematics (STEM) courses. LogicHouse involves a virtual broken house where the player has to play the various levels to fix the house and gain points along the way. This game was designed based on the Learning Mechanics-Game Mechanics (LM-GM) model and the Unified Modeling Language (UML). Furthermore, the design was implemented using Adobe Illustrator, Procreate, Unity Engine, C#, Microsoft Azure Playfab and deployed on itch.io. Preliminary evaluation results indicate that students are interested in the game and its application. Based on this, there is a prospect of improved performance in any course in which the game is implemented.

Keywords
DGBM; LogicHouse; LM-GM; STEM; UML.

INTRODUCTION

In the last decade, there has been a decline in the success rate of Engineering students worldwide, which has also led to a gross reduction of students willing to study Engineering courses. The United States education system recorded that over the last 60 years, around 50% of Engineering students drop out before graduation (Geisinger et al., 2013). The continuous reduction in the number of students interested in Engineering programs can lead to loss of workforce and innovation in Engineering and other related fields. This can lead to a decrease in the diversity and inclusion in Engineering institutions and companies, hence increasing the potential pres- ence of bias in hardware and software systems (Ntoutsi et al., 2020).

The ability of students to pay attention has also suddenly become crucial since the dawn of the 21st century, especially among students in the higher education institutions. Motivation and attention are intertwined, "If you do not keep me entertained enough to pay attention, I cannot be motivated enough to put in any effort". Thus, lack of adequate motivations leads to discouragement in the learning process (Prensky, 2001). Prensky (2002) further argued that learning based on the conventional mechanics is getting outdated and the new era of learning is largely through modern tools such as real gameplay, which provides opportunity for students to learn while having fun. Notably, the adoption and use of digital games for augmenting

engineering education towards enhanced student's motivation are still limited in comparison to domain like busi- ness and medical education. This is of great concern with respect to fundamental engineering courses that underlie the Fourth Industrial Revolution(4IR) such as engineering mathematics, software engineer- ing, cryptography and digital electronics, just to men- tion a few (Udeozor et al., 2023). Thus, Academics in engineering worldwide are seeking for techniques to improve their students' learning motivations by experimenting with game based learning and other modern pedagogy such as experiential learning, con- structivist learning, blended learning as well as prob- lem-based learning (Adetiba et al., 2012; 2014; Karel et al., 2013; Kiili, 2005a; Pranantha et al., 2012; Tan, 2019).

In this paper, a solution to the current pandemic in Engineering education is proposed by introducing Digital Game Based Learning (DGBL). This provides a stimulating classroom environment for students while guiding them to understand Engineering con- cepts easily by using Digital Electronics as a focus course. Game-Based Learning (GBL) is a learning and teaching approach using games, through elements in games and gaming mechanics, which facilitates engagement and learning of curriculum-based con- tents (Karel et al., 2013; Kiili, 2005a; 2005b; Tan, 2019; Zualkernan et al., 2012). Therefore, in this paper, we report the design and development of Digital Game- Based Learning (DGBL) prototype web application referred to as LogicHouse, for a Digital Electronics course. This course provides the foundational know- ledge for design of digital electronics systems such as computers, embedded devices, robotics, IoT solutions, communication devices and etc.

The paper is organized as follows. Section 2 reviews related works and section 3 presents the materials and methods. Section 4 presents the results and discussion. The paper concludes with section 5.

2. Review of related works

Across the wide Engineering disciplines, a few digital game-based learning has been developed and tested with appreciable success. Digi Island (Harper et al. 2011) was designed to aid the learning and teaching of digital circuit optimization using Karnaugh maps (K-maps). It was developed using the Microsoft XNA

Game studio based on the Microsoft.NET framework. Pranantha et al. (2012) developed a serious game prototype for Digital Electronics made up of other mini-games covering topics such as Numerical con- version and Logic gates. Potts et al. (2011) attempted to teach Digital Electronics using the quiz style application. Results showed that the students responded favourably to this teaching method and it improved their retention of the taught materials.

According to Butler-Purry et al. (2009), video games have become an essential part of children in today's culture. The authors were aware of the decreasing success of traditional teaching methods, and developed a prototype 2D and 3D game for Digital System courses at Texas A&M University. This game was developed using Microsoft XNA Framework with C# and was tested with PCs. Game- based learning does not have to be only serious games; they can have fun elements as well. Ye-Xuan et al. (2013) ran a previous test using the game- based learning approach but later realized that the students engaged better when the game was avail- able on social platforms and had a pet factor. This also occurred with EduTorcs, where Coller (2010) used the constructivist theory of learning as a foun- dation for developing the game for mechanical engineering undergraduates in the Dynamic Systems and Control class. The author observed that the stu- dents were thoroughly engaged than the previous years and a 5% increase in undergraduate students' enrolment for the course in subsequent years.

In a remedial course reported in Martin-Dorta et al., (2014), Virtual Blocks was designed to teach the students how to build models with cubes and develop their spatial ability in Engineering. It is a 3D mobile game developed using Java and OpenGLES. Dib and Adamo-Villani (2014) is a role-playing game in which the player/ student has to travel across states in the United States of America to help build- ing constructors, designers and owners increase their environmental and economic performance. With the epistemic game Nephrotex (Rogy, 2010), role playing occurs as the students simulate working in a product design company as entrepreneurs. This is to instill entrepreneurial mindset in the students so that they can be innovators to be sought after in the industry. Del Carmen et al. (2012) investigated the effects of playing the draft video game Food Analysis Simulator (FAS) by Food Engineering students of Universidad de las Am´ericas Puebla (UDLAP).

Students' results after exposure to the Video Game demonstrated a significant improvement in their knowledge, positive change in the students' scores and achievement of course learning goals.

Xenos and Velli (2020) presented an ethics game that is based on storytelling, in which players are faced with ethical dilemmas on software engineer- ing. The choices made by the players' affect how the story unfolds and could lead to optional endings. The game was used to mediate the learning activ- ities of the students in software engineering course. An evaluation using 144 students produced insights on the students' academic performance and per- ceived educational experience. The results showed an improvement in students' knowledge about soft- ware engineering ethics through playing of the game, with female students having higher score and gaining more knowledge than their male counter- part. Callaghan and Cullen (2014) developed a 3D immersive game world, Circuit Warz, for electrical and electronics Engineering students to learn advanced circuit theory. The game was designed and developed using the Unity 3D engine and later integrated into the MOODLE learning environment. Karel et al. (2013) developed two games with MATLAB and designed them using tools which included GUIDE. The resultant games were called PEXESO and Fields Frenzy. Internal Force Master (IFM) (Ebner and Holzinger, 2007) is an online game designed to enable Masters students of Civil Engineering to achieve their focus. Shortfall game (Bellotti et al., 2014) was developed for second year MSc students to manage a supply chain from raw materials to production with importance placed on the environmental impact of the player's choices.

The foregoing related works reveal the serious attention currently being paid to DGBL across the various Engineering disciplines. Potts et al. (2011) efforts on GBL for Digital Electronics only focused on the use of quizzes within the game environment. Therefore, in the work at hand, we extended this effort on Digital Electronics to cover the use of DGBL for Boolean algebra and number system with proper alignment of learning mechanics, game mechanics and the Bloom's ordered thinking skill levels.

3. Materials and methods

This section provides a detailed description of the design and development process of LogicHouse. Learning Mechanics–Game Mechanics (LM-GM) model was adopted to define the parameters in developing the educative and entertaining game. Software engineering visual aid tools and relevant UML diagrams were also used to present the design of the game.

3.1. Software architecture

As shown in Figure 1, the LogicHouse game was designed and implemented as a client/server appli- cation. The player interacts with the game and gen- erate data through the client side on a web browser as well as the itch.io web platform. On the other hand, the server-side stores and manages all the data generated from the game. This was imple- mented with Microsoft Azure Playfab, which is a Backend-as-a-Service (BaaS) platform.

3.2. Serious game and learning mechanics–game mechanics model

Serious Game (SG) is a typology of digital games for education and training that are designed not only for entertainment purposes but primarily for peda- gogical goals. It aims at exploiting the game appeal and the player motivation for knowledge and skills acquisition (Doughty et al., 2009; Michael and Chen, 2006). One of the key features of SGs is to exploit game features in order to engage people in useful serious activities and motivate them to explore new experiences (Arnab et al. 2015; Lim et al., 2013). Also, SGs provides an enhanced technological plat- form for complex skills learning (Westera et al., 2008). Learning Mechanics–Game Mechanics (LM- GM) model (Arnab et al. 2015) is a conceptual toolkit for realizing the core principles of a SG. The Learning Mechanics-Game Mechanics (LM-GM) model provides a template for digital game authors to design and implement different pedagogical strat- egies for players to realize both educational and entertainment objectives. The framework allows game designers to factor-in their own experiences as well as the needs of the actual end-users and other stakeholders while developing games.

In addition to the LM-GM model, a framework for SG design at the conceptual level presented in Westera et al. (2008) is shown in Figure 2. It contains four major components, namely: i) the world of game play; ii) the learners' world; iii) the teachers' world; and iv) the game management world.

The LM-GM model and the framework by Westera et al. (2008) were leveraged for the design of LogicHouse in this work. In the context of LogicHouse, the learners' world extends the game play context. It represents the students that are enrolled for the Digital Electronics course as well as the tasks and assignments to be carried out by the student in the world of game play. The teachers' world allows the lead lecturer and teaching assistants that are respon- sible for management and assessment of the course to assess progress, provide feedback and provide necessary pedagogical interventions. Details of the analysis, design and implementation of the game play world and game management world are presented in the subsequent subsections.

3.3. Design of the game play world for LogicHouse

As earlier indicated, LogicHouse is a SG developed to create a game-based learning environment for Boolean Algebra laws and Number Systems in Digital Electronics curriculum. The analysis and design of the game play world is described in this section. The analytical map between the game and the LM-GM design model is presented to illustrate how the Learning Mechanics (LM) and the Game Mechanics (GM) ensure that fun and education occur simultaneously in the game.

3.3.1. Game story and mapping of LogicHouse with LM-GM

At the beginning of the LogicHouse game, the whole neighborhood of a virtual building is dark due to a broken-down core reactor. The player/stu- dent is required to solve a series of logic challenges in order to fix the reactor to lighten up the neigh- borhood. There are two main rooms (dining and guest) in the LogicHouse virtual building with each room corresponding to different Digital Electronics challenges. The dining room grants the player access to solve basic Boolean Algebra problems whereas the guest room provides access to multiple choice questions on Boolean Algebra and Number System. The player must answer a series of questions cor- rectly and apply the laws of Boolean Algebra in a race against time. Solving all these challenges will bring light back to the neighborhood and the LogicHouse will be bright again. The flowchart that explicitly illustrates the process flow in LogicHouse game is presented in Figure 3.

Using the LM-GM model, the game mechanics in LogicHouse were mapped to their respective learn- ing mechanics. This mapping is necessary in order to illustrate that the design of LogicHouse considered the educational purpose of the game.

The analysis of the first level, which is the Boolean algebra level (dining room) is shown in Figure 4. The mapping of the components of LM (a, b, c, d, e, f, g, h, i) to GM (1, 2, 3, 4, 5, 6, 7, 8, 9) on the LM-GM model for this level are illustrated in Figure 5.

Level 2 of LogicHouse (i.e. Guest Room scene), which is a multiple-choice question segment is pre- sented on the game map in Figure 6.

Table 1. illustrates the mapping of LM, GM, as well as implementation and usage of the mechanics in LogicHouse for the two game levels. This map- ping with Bloom's ordered thinking skills reinforces critical learning outcomes that are essential for a course in digital electronics. These include lower order skills (i.e. retention, understanding and applying) that are acquirable through LMs such as instruc- tional, guidance, discover, action/task, tutorial as well as question & answer with the corresponding GMs detailed in the Table. The acquirable Bloom's higher order skills based on the implementation of LogicHouse and subsequent playing by the enrolled students are evaluating, analysing and creating through LMs such as assessment, feedback, observation, motivation, incentive, competition and responsibility.

3.3.2. Game Engine for implementing the game play world in LogicHouse

A game engine is a software framework that acts as a middleware for developers. It allows emphasis on scripting and design rather than physics, graphics rendering and other complex systems. The Unity Engine was adopted in this work to implement the game play world for LogicHouse. It provides toolkits for creating three-dimensional, two-dimensional, Virtual Reality(VR) and Augmented Reality (AR) ele- ments as well as simulations and other gaming experiences. It supports Operating Systems (OS) such as

Android, Windows, iOS, Fire OS and Tizen OS and allows developers to create applications with few lines of codes. In this work, the Unity Engine was used in conjunction with C# to bring the game idea to life. The intellectual property constraint usually associated with game applications was taken care of since the utilized content of the Digital Electronics course as well as the game design were created by the authors. The Unity Engine design interface is shown in Figure 7.

3.4. Design of the game management world for LogicHouse

This involves the design and implementation of a web application to manage different LogicHouse game runs, handle users' authentication, manage game play and user data as well as for adding different game scenarios.

3.4.1. Process model and UML based design of LogicHouse

Software development process involves the division of software development tasks into sub-processes to improve design and product management. Example of software process models include the waterfall, incremental, Agile, DevOps and etc (Batra and Jatain, 2020). The incremental development model was adopted for this work. It involves iterative require- ment elicitation, design, implementation, testing and release of several software versions with new, improved and added functionalities for each incre- mental iteration or versions. Unified Modelling Language (UML) diagrams are used to design and represent complex systems as simple and under- standable artefacts. Some of the diagrams used in UML include Use case, Class, Activity, Sequence and etc (Adetiba et al., 2009; Ibrahim et al., 2011).

i. LogicHouse Use Case Diagram: Use Case dia- gram provides functional requirement specifica- tions for the system being designed and also depicts the interactions between different Actors (i.e. users) as well as the system. The Use Cases are represented with an oval shape whereas the Actors' interactions with the different Use Cases are represented with arrowed lines. For space constraint, two Use Cases are reported for LogicHouse in this paper, namely; Student and Teacher. Figure 8(a,b) show the two Use Cases. The student can log in to the game online, play the game, check their scores on the leaderboard and change settings in the game. On the other hand, the teacher can view the students who have logged in and have access to their scores on the leaderboard.

ii. LogicHouse Class Diagram: A class is used to cre- ate objects, provide initial values for attributes, and implement methods in object-oriented pro- gramming (Karleigh et al. 2021; Sommerville, 2021). The class diagram in Figure 9 provides a graphical view of the major classes designed to

implement the world of game and game manage- ment world of LogicHouse. Some of the major classes as shown in Figure 9 are:

(a) BoolSumPlayer: This class directly controls the player and the result of the player colliding with other logic boxes like AND (A) or OR (1).

(b) PlayFabAuthService: This class works in conjunc- tion with PlayFabClientAPI to authenticate the various users that logs into the game.

(c) GameManager: This class manages the timer, the mission and updating of the PlayFab (a Microsoft Azure backend platform). It basically manages the whole game.

(d) ButtonScript: This class controls all the buttons in the game and ensure that they provide the required actions.

iii. LogicHouse Sequence Diagram: Sequence dia- gram is used to describe the different elements of LogicHouse game management world web application and how messages or actions are exchanged between them. A sequence diagram is usually read from left to right with a top to bottom sequence of actions. There are three lifelines in the diagram, namely; User, Game System and Playfab. As shown in Figure 10, there are three major sequences of operations in LogicHouse, which include:

i. Login and user authentication by Playfab;

ii. Playing the game and user score updating in the leaderboard in Playfab; and

iii. User request on leaderboard and data return by the Playfab server.

3.4.2. Implementation and publishing of LogicHouse application

This section presents the implementation tools for LogicHouse after the detailed design of the world of game play and the world of game management web application as presented in the foregoing sub sec- tions. The backgrounds and User Interface (UI) were implemented using Adobe Illustrator and Procreate. Adobe Illustrator is a vector graphics editor and design application used to capture creative vision with shapes, color, effects and typography (Brian, 2016). It was used to design the placeholder assets during the development phase before the final user interface. Procreate is a graphics editor application used for digital painting. This application was used to create the final image assets in LogicHouse.

Microsoft Azure Playfab is a backend platform used with live games to manage services, get real-time ana- lytics and monetize games (Sebastian and Joanna, 2022). This was adopted to implement the server-side of the application in order to analyze the data pro- vided by users, such as how long they spent in a session, scores, and progress rate. PlayFab sends a daily update of how many people logged in and played the game. It also provides details and grants access to the leaderboard, which creates the opportun- ity to earn extra grades for participating in the activity. LogicHouse was published online at itch.io to enable students/players have access to the game anywhere and at any time. Itch.io provides space for game developers to publish, sell, and distribute their video games to end-users/players. At the beginning of the LogicHouse game, the whole neighborhood is dark due to a broken-down core reactor. Solving all the challenges at level 1 (Boolean Algebra) and level 2 (multiple choice question on Boolean Algebra and Number System) will illuminate the neighborhood and LogicHouse virtual building will be bright again.

4. Implementation and performance results

LogicHouse was successfully built and hosted on itch.io. This section presents the results obtained after the implementation of

the LogicHouse design.

4.1. User Interface background

The outcome of the development of the background and UI of LogicHouse using Adobe Illustrator and interactivity, engagement and repetitive play by the players/students thereby acquiring appropriate peda- gogical behaviors while being entertained.

4.2. Gameplay

Gameplay is simply the game flow of LogicHouse. It indicates the mechanics used and how the player is expected to interact with the game. The current URL for loading LogicHouse on itch.io is https://joyajayi. itch.io/serious-game-for-digital-electronics. Pasting this URL in the address box of a web browser (such as Microsoft Edge, Google Chrome, etc) will generate the loading screen as shown in Figure 12. After few seconds, the page will transit to the login page (see Figure 13), where the player is expected to log in to play the game. This automatically creates a Playfab account for the player and allows the administrator (Teacher) to monitor the player's (i.e. Student) activ- ities. The authentication and authorization mecha- nisms in LogicHouse require the use of institutional email accounts by both the Students and Teachers. This provides multiple layers of security (in game based assessment scenarios) since only persons with authentic affiliations to a given institution would be assigned institutional email credentials. After logging in, the player/student encounters a dull house as previously presented in Figure 11(a,b) with no light in order to indicate that the game has not been completed and the reactor not yet fixed. Upon selecting a room, for instance the guest room, the player is led to the multiple-choice questions, which challenges his/her knowledge in Boolean Algebra and Number Systems (Figure 14).

The players can view their scores and upon comple- tion, they are automatically added to the leaderboard. The leaderboard is open to the public and every player can view their positions globally. This is to foster a spirit of competitiveness known to be a motivation fac- tor among Students. Also, if the player decides to enter the dining room, he will have to play a game of fastest thumbs. They would be expected to become a new character at the end of the game, which depends on the Student's knowledge of the Boolean Algebra laws (Figure 15). This will also be updated on the lead- erboard both at the PlayFab backend and fronted as shown in Figures 16 and 17 respectively. This is the gameplay process of the developed LogicHouse.

If the player successfully completes these two levels, the LogicHouse neighborhood changes to a lit-up house and the core reactor fixed as shown in Figure 18.

4.3. Software performance testing

The tests carried out on LogicHouse are component testing, deployment testing and User Acceptance Testing (UAT). In Unity Engine, the game was created in different scenes and programmed in different classes that must be integrated to perform the required tasks. Component testing was carried out on each of the functions that require the game to work. A sample output of the testing result is shown in Figure 19, with report of players answering the questions correctly. This testing was carried out in order to ensure quality performance of the software after deployment.

Since LogicHouse was deployed to a web plat- form, it was tested on different browsers such as Microsoft Edge, and Google Chrome and the outputs were consistent on these browsers. Nonetheless, UAT of LogicHouse was carried out by enlisting a total of eleven (11) past and present students of Digital Electronics. For the scope of this study, 5-10 participants are adjudged adequate for UAT (Six and Macefield, 2016). After playing the game, a Google Form was sent to the participants to provide feed- backs on a scale of 1 (Not Satisfied) to 5 (Highly Satisfied) in respect of the usefulness and potential of the game for DGBL in Engineering education.

The questions on the Google Form were:

i. How satisfied were you with the game?
ii. How relevant and helpful is LogicHouse in Digital Electronics course?

The plot in Figure 20 indicates students' satisfaction with the LogicHouse game. About 72.7% (N ¼ 8) were well satisfied and also found the game relevant to Digital Electronics course.

Fig. 21 shows the response of the participants to the second question. As can be observed, 81.8% (N ¼ 9) of the respondents were well satisfied while the remaining 18.2% (N ¼ 2) were moderately satisfied.

A further UAT was carried out to evaluate the participants opinion on the possibility of introduc- ing the game into the curriculum of other engin- eering courses. The question asked on the Google Form was:

Now that you know of Game based Learning and have played a game that can be used. How much would you like Game based learning to be implemented in your Engineering courses?

As shown in Figure 22, 91% (N ¼ 10) satisfactory response provides a basis that the sampled students are opened to the possibility of introducing DGBL pedagogical approach in other Engineering courses.

Additional comments by three of the UAT partic- ipants, which connote positive sentiments for LogicHouse are as follows:

I felt it very intuitive and with more work, definitely a great learning aid to be adopted everywhere.

You did an excellent job on the game.

The transformative potential of game based learning is incredible. Great work. Congratulations!!

Despite the positive sentiments from participants as reported based on the UAT, challenges are inevitable in digital games. Some of the challenges that could be encountered by players include; network failure (being an online game), browsers rendering graphics elements imprecisely and compatibility with varying touch screen devices. Nonetheless, a few challenges were encountered during the implementation of LogicHouse. The Source Code Management (SCM) platform that was originally adopted was GitHub, but due to space constraint given the size of the codebase, Bitbucket was eventually adopted.

Documentation of Playfab also posed some tempor- ary chal-

lenges but this was surmounted by leverag- ing relevant online knowledgebases.

5. Conclusion

In this paper, we presented the analysis, design and implementation of LogicHouse, a digital serious game. The primary goal of the game is to help Teachers increase the motivation level of Engineering Students in and out of the classroom. The Digital Electronics course was used as a case study and theme for development of the serious game. The Unity Engine with C# was adopted to implement the game play world whereas the Microsoft Azure Playfab was engaged to analyze the Student's game progress as a critical component of the game management world. The component and deployment testing carried out on the digital game confirmed its optimal functionality. Furthermore, the UAT provide evidence that students' motivation level for engineering courses could improve by introduc- ing DGBL into the classroom. Since an iterative development approach is being used, we hope to further refine LogicHouse conceptual constructs in the future and extend it to cover more STEM courses. Another round of UAT will be conducted as we extend the scope of LogicHouse and comments obtained through the UAT will be leveraged to extend the capability of the game. More so, the introduction of LogicHouse to undergraduate cur- riculum will be piloted and the outcome will be leveraged to make recommendations for its inclusion into relevant academic curricula. Other use cases for LogicHouse such as professional training and autonomous learning will be explored for future upgrade of the game. We also hope to further enhance the game using Artificial Intelligence (AI) in order to incorporate adaptive learning capabilities. This will provide a progressive adaptation of the game's complexity to fit the player's competence. Mobile implementation of the game will also be explored to attract more participants as we leverage on the preponderance of smartphones and its asso- ciated mobility benefits.

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No potential conflict of interest was reported by the author(s).

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