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Digital Game-Based Approach to Math Learning for Students

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DIGITAL GAME-BASED APPROACH TO MATH LEARNING FOR STUDENTS

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Abstract
Mathematics is an important subject that is pervasive across many disciplines. It is also a subject that has proven to be challenging to both teach and learn. Students face many challenges with learning math such as a lack of motivation and anxiety. To address these challenges, game-based learning has become a popular approach to stimulate students and create a more positive classroom environment. It can serve as an alternative or supplement to traditional teaching and can better engage students while developing a positive attitude toward learning. The use of games in a classroom can create a more exciting and engaging environment, while still reinforcing learning concepts. This paper explores the development of three math games to supplement classroom learning and analyses the game mechanics and designs implemented in each game.

Key Words: Game-based learning, Mathematics, Teaching Supplement

1. INTRODUCTION

1.1 General

Learning and comprehending math is essential for students, as it is a core fundamental across many disciplines [1, 2]. However, the structure and complexity of math, as well as pre-existing fears around the subject, make it a difficult subject to both learn and teach [3]. Researchers have found that computer games can have a positive effect on learning [4]. Therefore, Digital Game-Based Learning (DGBL) can help students and teachers overcome obstacles faced when learning and teaching math. Using digital games to aid learning can create a positive association with learning, gain the interest of students, and promote active learning [5, 6]. As a result, incorporating game-based learning in the classroom, specifically to supplement teaching math, can help better reinforce taught concepts and improve student attitudes toward learning math, thus addressing issues related to motivation in learning math.

1.2 Games

This paper outlines three digital games that were designed to supplement classroom learning by gamifying math concepts and creating interactive scenarios. The games require students to not only complete math problems but simultaneously strengthen their critical thinking skills.

The first game, called “Dinner for Dogs,” involves measuring out dog food to feed various dogs. The second game is called “The Last Chip” and challenges the player to determine how to get the last chip in a number of scenarios. The third game is a sorting game that is played against an AI. The goal of this game is for the player to sort their cards before the computer. Each game aims to solidify certain math skills by actively engaging the students in problem-solving.

The three games that will be outlined in this paper were designed to align with educational classroom standards, specifically those used in Virginia [7], as determined by a subject matter expert. Each game was prototyped and tested in a hands-on format before beginning the digital game development process. The games were designed for students in grade levels 3 through 8.

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The remainder of this paper is organized as follows. The background section will outline some challenges students face when learning math and how digital game-based learning has been used previously to address these challenges. The Design and Methodology section will present the developed games and the methodologies used to develop them. The conclusion section concludes the paper and provides a discussion of directions for future work.

2. BACKGROUND

Mathematics performance among K-12 students across the country has consistently been an area of concern [8]. This subject has proven to be difficult to both learn and teach [9]. In a 2017 study conducted by Bed Raj Acharya, the author identified several reasons that cause difficulties in learning math. Anxiety and lack of motivation toward learning the subject were two of the factors outlined by the author [10]. In fact, motivation toward learning math decreases as the difficulty of math concepts increases [11]. These challenges can prevent students from properly learning the material and affect their attitude toward learning math in general.

Castellar, et al. conducted a study on the effectiveness of games on cognitive and learning outcomes [12]. This study was conducted on second graders divided into three groups: a control group, a gaming group, and a paper exercise group. The control group did not receive any exercises, the gaming group played through a game, and the paper group completed exercises on paper. This study used pre-test and post-tests to determine the effectiveness of the arithmetic game and found that there was a significant improvement in the arithmetic skills of the students that played through the game, compared to the other two groups.

Additionally, there is research to suggest that some of the current challenges, such as anxiety and lack of motivation surrounding math, can also be addressed using game-based learning. Bai, et al. conducted a study on the effectiveness of a three-dimensional instructional game (DimensionX) on increasing motivation in middle schoolers and the results showed that student motivation was “sustained” throughout the game and student performance showed slight improvement [13]. A similar study was conducted using the same game with high school students by Kebritchi, et al. and this study also showed a positive effect in terms of performance and motivation on high school students [14]. These studies show that digital games are useful tools for helping students learn and increase motivation toward learning.

Despite some studies finding success in using DGBL in the classroom, not all studies have found similar results. A study conducted using a simple interactive math game based on cognitive load and game design theory found an improvement in student performance but not motivation [15]. Another study conducted on 33 elementary and middle schoolers using math games in the classroom found an increase in motivation among students, but not in performance [16]. The inconsistencies among studies could be a result of games not designed based on instructional theories [17] or games designed with too many entertainment features that distract the player from the intention of the game [18]. Mayer claims that one of the largest challenges in educational game design is maintaining a balance between features intended to motivate the players and features that foster learning.

These mentioned studies indicate that using game-based learning can potentially be used to fill gaps in teaching math and student comprehension as well as reduce anxiety students experience when learning. The purpose of the games outlined in this paper intend to address the challenges mentioned while also improving the overall performance of students in mathematics.

3. DESIGN AND METHODOLOGY

Games have the potential to create learning environments that create flow and enable learning. According to Csikszentmihalyi, flow is a state in which a person is completely captivated or immersed by the activity at hand to the point they are motivated to continue the task [19]. Flow can be achieved by integrating techniques such as providing challenging yet achievable goals, offering immediate feedback, and creating a sense of enjoyment. In addition to Csikszentmihalyi's work, Norman has identified seven basic requirements of a learning environment [20]. Listed below are the seven requirements:

1. Clear goals: Student should know what they are trying to achieve and how to achieve it
2. Appropriate Challenges: Create appropriate level of challenge that maintains students interest, but not so difficult as to create a sense of frustration.
3. Timely Feedback: Give students feedback on their progress
4. Supportive Environments: learning environment should be free from distractions and disruptions.
5. Engaging Activities: Environments should be design to hold learner interest.
6. Opportunity for social interaction: Students should have the opportunity to interact with others to promote learning.
7. Appropriate use of technology: Technology should be used to enhance learning, not distract from it

The games discussed in this paper are designed to meet these requirements to ensure an effective learning environment is developed. Furthermore, the games will incorporate techniques discussed in flow theory to captivate the student, creating a positive and engaging learning environment that leads to learner motivation. This paper will outline the implemented design methodologies that have been proven effective in other learning games and how these design features create flow and a positive learning environment for the student. It will also suggest how the game can be incorporated into the classroom to meet some of the learning requirements.

3.1 Overview

As outlined by James Paul Gee, learning requires that students feel like "active agents", and well-designed games allow players to act as active agents by interacting with the game and seeing the effects of their actions [21]. To promote learning and engagement in games, it is important that interactive tasks be incorporated into the game and that students receive feedback on their progress. Therefore, the developed games are designed to require students to complete interactive tasks and are provided feedback on their performance.

The concept of active learning through well-designed games and the use of non-player characters as tutors or guides are important aspects of promoting engagement and learning. As previously mentioned, interactive tasks and feedback play a vital role in keeping students engaged. However, non-player characters can also be incorporated as an effective tool to provide support and guidance to players. Non-player characters can assume the role of a "tutor" or "guide" in games to assist the player. Clinton Jeffery pointed out that non-player characters in games such as World of Warcraft that provide tutoring/training have proven to be very effective and "incorporates active learning" [22]. Additionally, NPC that assume this role in educational games are core features and are important pieces that motivate the player [23]. They provide instructions, support, and in some games, positive feedback.

The math games discussed in this paper include entertaining X-shaped characters that were designed for the games (Figure 1). These characters fit the theme of the games and provide the player with instructions and motivation throughout the game. Linek, et al. discusses the importance of designing NPC's effectively and developing personalities for these characters to

create a more positive experience for the player [23]. Designing the characters with attributes that relate to their purpose (such as the chef's hat, detective jacket, magicians' wand) and giving the NPC's names, helps develop the X character's personalities.

Figure 1: NPC X Characters

The use of NPCs in each of the games to create a more positive experience for the player creates flow and is valuable because they help achieve learning goals. The characters provide instruction before each level so the goals are clearly defined for the student and because NPC's can create a more positive experience for players, the players will be more engaged in the games.

As previously mentioned, each game was prototyped and tested in a hands-on format in schools, and teachers were provided with "kits" to play the games in the classroom with other students. Although the transition of the games into a digital format ensures they are more widely accessible, the social interaction piece diminishes. Given that social interaction is critical in creating an effective learning environment [20], these games are intended to complement lessons and should ideally be used in conjunction with opportunities for students to discuss their gameplay, watch each other play, or even sit in groups while playing on computers and interacting with each other.

Other features incorporated into the games will be discussed in the remaining sections. Each game's design mechanics, instructions, and flow will be discussed as well as how the design methodologies implemented meet the mentioned design requirements and achieve flow.

3.1.1 Dinner for Dogs

Dinner for dogs is a role-playing interactive game where the player assumes the role of a dog caretaker. They are tasked with feeding dogs a certain amount of food with limited resources and must use addition, subtraction, and critical thinking skills to determine how to feed the dog the correct amount of food. Role-playing allows a player to assume a role in the virtual game and determine how their actions impact the game [24]. It also helps lead to a state of flow by better engaging and immersing the player [25].

The flow chart below outlines the flow of the game (Figure 2).

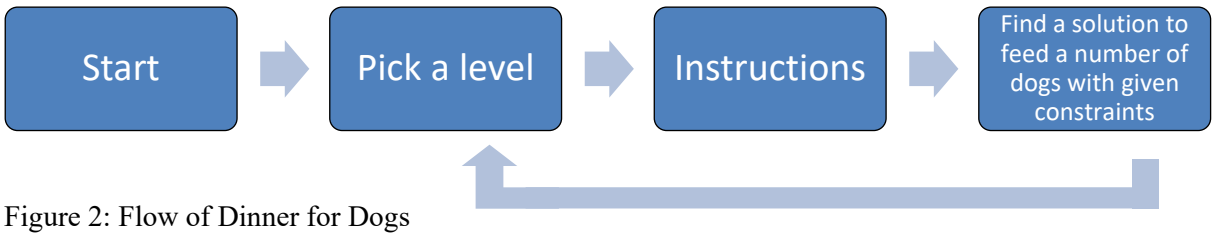

Figure 2: Flow of Dinner for Dogs

The NPC Albert, a chef, guides the player through the game by providing them with instructions. The player begins by clicking on a bowl with a level number (Figure 3). This shows the user the order that the levels should be completed but also allows the player to start at a different level if they have previously played the game. After completing each level, the player can choose to go to the next level, pick another level, or choose to redo the level they completed. This allows the user to have greater control over their learning by allowing them to review material that they found difficult or skip material they already know. Cairncross, et al. discusses user control to enhance learning. The discussion emphasizes that the control a user has over how information is delivered to them can enhance learning and that a "middle ground" is needed where the player is given a structured environment with some control [26]. By providing the user with levels that are numbered, they recognize that there is an order that the game should be completed, but they are still free to choose how they play the game. Additionally, providing students with different levels of varying difficulty allows them to pick a level that is challenging but not frustrating. This helps develop flow and an effective learning environment [19, 20].

Figure 3: Pick level screen

Each level of the game has the same end goal: to feed the dog a certain amount of food. But the constraints in each level vary and the difficulty of each level increases as the game progresses. Including levels with different levels of challenges has been shown to encourage deeper learning and motivate students [27]. Including different levels of challenges ensures that players of different skill levels will be appropriately challenged, without getting frustrated. Below is a table with the instructions provided to the user to play each level.

Table I: Instructions for each level of the game

Level	Instructions
Level 1	Feed the dog using a 3oz cup, 5oz cup, and an empty dog bowl. There is an unlimited amount of food. Use the dog bowl to feed the dog the correct amount.
Level 2	Feed the dog using a 3oz cup, 5oz cup, and an empty dog bowl. There is an unlimited amount of food. Use the empty dog bowl to feed the dog the correct amount.
Level 3	Feed the dog using a 3oz cup and a 5oz cup. There is an unlimited amount of food. Feed the dog using the 5oz cup.
Level 4	Feed the dog using a 3oz, 5 oz, and 8oz cup. One 8oz cup filled with food is all the food that is provided. All the dog food needed must end up in the 5 or 8oz cup.

In the first two levels they are given a dog bowl to place the food in and only have two cups to use for measuring. They must use addition and subtraction to determine how to place the correct amount of food in the bowl with an unlimited amount of food. They click the buttons on the screen to fill the cups or transfer the food. There are several tasks in the first level and all the food placed in the bowl is written out for the player on the dog bowl. The last, most difficult level does not give the player a dog bowl or an unlimited amount of food. Instead, the player is given three size cups: 3oz, 5oz, and 8oz, and is only given one full 8oz cup of food. By beginning with easier tasks and building difficulty as the game progresses, the user can acquire the necessary skills to complete the more difficult levels.

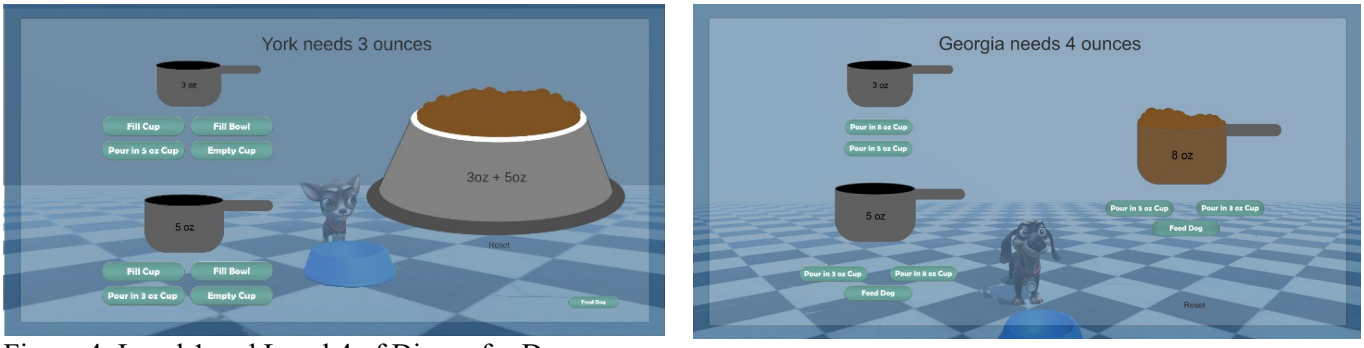

Figure 4: Level 1 and Level 4 of Dinner for Dogs

If the player feeds the dog the incorrect amount, they are told to try again. If they feed the dog the correct amount of food, the dog's food appears in front of them, and the dog shows that they are happy. This provides the player with immediate feedback which helps a player determine if they are correctly completing a task [28] and is a requirement of a learning environment [20]. It is also identified by Csikszentmihalyi as a major component for creating flow [28].

Tasking students with feeding a dog can increase the relatability of the educational activity for them. Kumar, et al. emphasizes the importance of including relatable elements in resources that are provided to students, as it leads to students being more invested in the content. Considering many students in our target audience likely own a pet at home and have observed their guardian feed their pet or take part in feeding them, the tasking in the game will be more relatable to them [29].

3.1.3 The Last Chip

The last chip game is a puzzle game that aims to improve mathematical problem-solving, communication, reasoning, connections, and representations. The objective of this game is to take the last chip. Each level has a different set of rules, but the end goal remains the same. The chips used in the game are double-sided with Sherlock, the famous detective, on one side (heads) and the other side features the Old Dominion University logo (tails).

This game uses an NPC character of Sherlock who is designed to appear as a detective. Sherlock's character further emphasizes the user's purpose in the game which is to use problem-solving skills to solve the puzzle and win the game. The flow chart below describes the flow of the game.

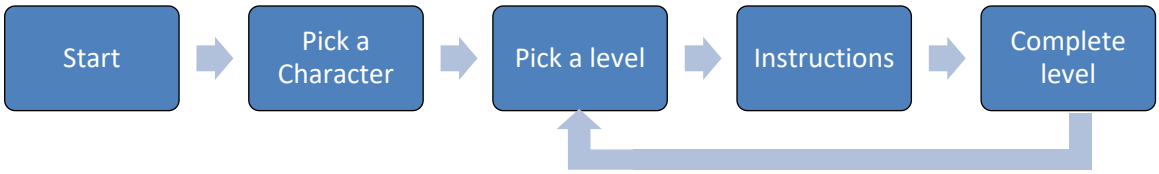

Figure 5: Flow of The Last Chip

At the beginning of the game, the player is given the option to select another X character, which allows for an engaging role-play experience [24, 25], and gives them control over the selection of the character. The player is then able to choose their starting level and choose a different level after the completion of a level, with increasing difficulty between each level. Similar to Dinner for Dogs, this feature was implemented to give the user control over the delivery of information [26]. The increasing difficulty of each level encourages deeper learning and helps to reinforce the math concepts learned in previous levels [27]. Before each level, the player is tasked with clear instructions on what needs to be accomplished. The table below lists the instructions for each level.

Table II: Instructions for each level of the game

Level	Instructions
Level 1	Take one chip on each turn
Level 2	Take one or two chips on each turn
Level 3	Take one, two, or three chips on each turn
Level 4	Take one chip OR turn Tails (ODU) to Heads (Sherlock) on each turn
Level 5	Take as many chips as you want, as long as they are either ALL Heads (Sherlock) or ALL Tails (ODU) on Each Turn
Level 6	Take As many Chips as you want, as long as it is LESS THAN - (Note: NOT equal to) HALF of the Chips between the Players.

As shown below the instructions are also written at the top of the screen for the player's convenience (Figure 6). A table in the center allows the player to track their progress after each round. The table displays the number of chips, the player who took the first turn, the number of chips each player received, and the winner of the round. This feature enables the player to identify patterns during gameplay.

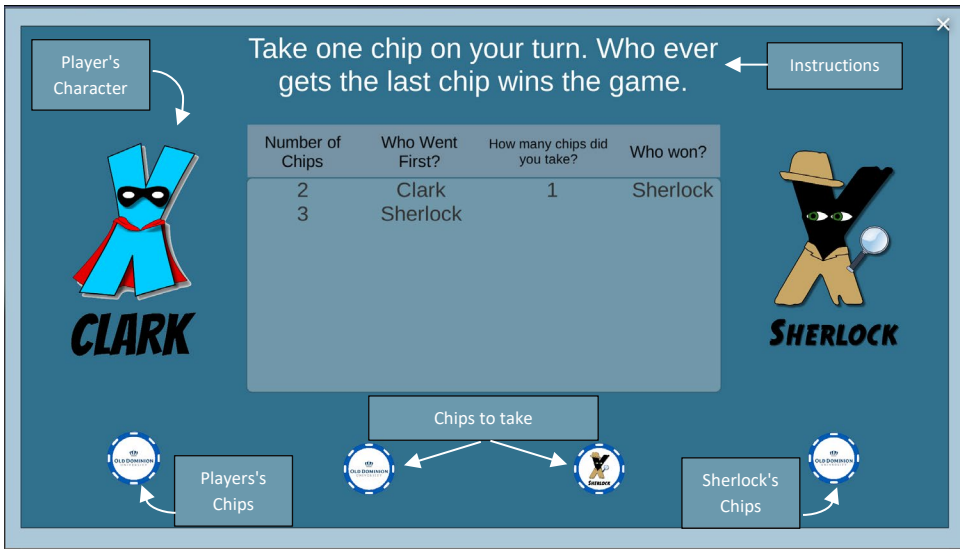

Figure 6: Play screen of The Last Chip

This game facilitates pattern recognition, helps students determine common multiples and factors, and recognize the characteristics of even and odd numbers. As the game is played the students will begin to recognize what moves and math skills will help them win the game by referencing the table or after playing a few rounds. For example, in the first level, the student may make the connection to take the first chip when there are an odd number of chips.

3.4 Mathemagical

Mathemagical is a number-sorting game that is played against an AI component named X-Caliber. The goal of this game is for the player to sort their cards before X-Caliber. Mathemagical aims to improve the student's mathematical problem-solving skills and mathematical reasoning skills. By sorting cards and strategically placing them at each turn, using number sense to determine their placement, and by evaluating their decision, students engage in mathematical problem-solving and reasoning skills.

Both players begin with ten cards each that are in random order. The player and X-Caliber take turns drawing a single card on each turn and strategically replacing one of the cards in their current hand until the cards are in order. The card that is replaced is placed in a discard pile. On each turn, the player can choose to use the last discarded card or draw a new card from the deck. The first player to sort their card wins the game. Below is a flow chart demonstrating the flow of the game:

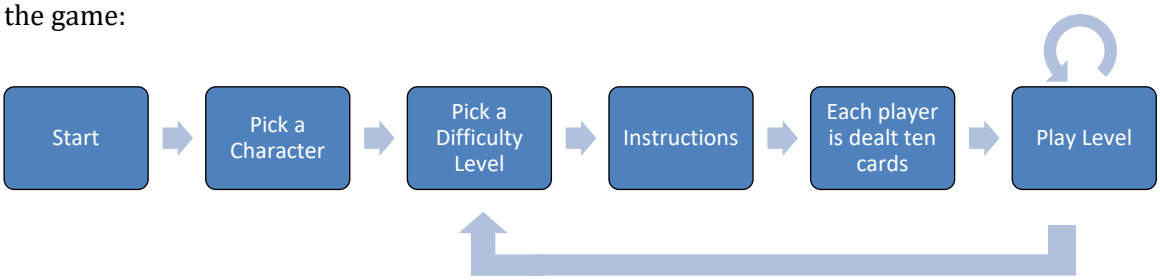

Figure 7: Flow of Mathemagical

The player begins by choosing a character to roleplay as. Then the player chooses a difficulty level from three difficulty levels: Easy, Medium, and Hard. Choosing their difficulty level allows them to choose a level that is challenging while not causing frustration, an essential requirement of a learning environment and a way to develop flow in a game [19, 20]. The player can choose to replay the current level/game after either player wins or choose a new difficulty level. The choice in difficulty and ability to change levels also provides the player more control

over their learning to better engage them [26]. Instructions are then provided to them before beginning the game to provide clear goals and guidance.

Below is an image of the game in play (Figure 8). The player's cards are on the left and X-Caliber's cards are on the right. The deck of cards is placed in the bottom center and the discarded cards are placed at the top-center. The player clicks and drags a card to move it to the appropriate spot. The card that is being replaced expands a bit so the player can accurately place a card. When either player sorts their cards, a screen appears telling them if they lost or won that game. They are then able to replay the same game or choose another difficulty level.

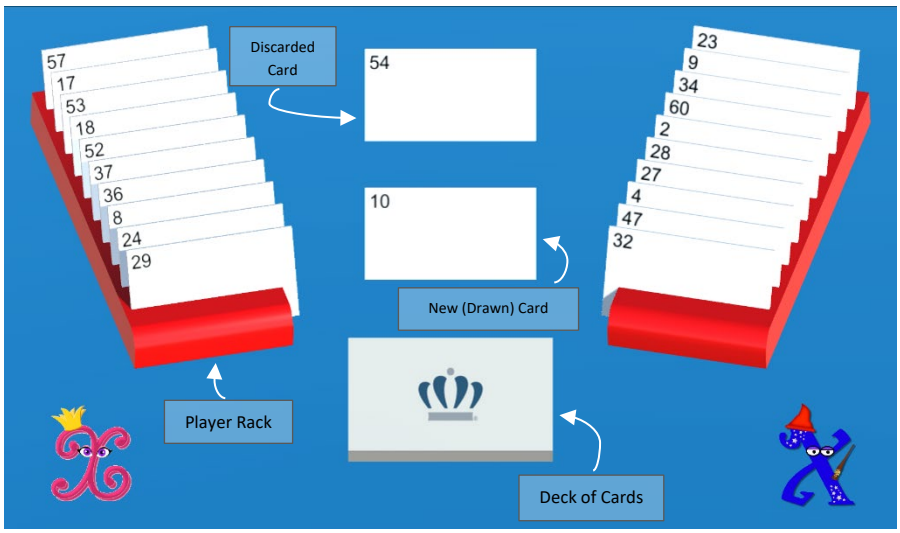

Figure 8: Mathemagical play screen

4. CONCLUSION

Comprehending math is crucial for students, as it is a fundamental subject that is used across many disciplines. However, the structure and complexity of math has made it difficult to both learn and teach. Pre-existing fears around the subject have also contributed to these difficulties. This paper presents a digital game-based learning solution to close gaps in mathematics learning. Three digital games were designed to supplement classroom teaching and learning by gamifying math concepts and creating interactive scenarios that promote critical thinking and problem-solving skills. These games have been prototyped to align with the Virginia Standards of Learning (SOL) for grade levels 3 through 8.

Incorporating game-based learning in the classroom can create a positive association with learning, gain the interest of students, and promote active learning. The design and methodology section presented the games and the design methodologies used to develop them. The designs of the games were tied back to creating flow for the player and achieving the seven basic requirements for learning.

Currently, two of the three games have been digitally sent out to teachers to use in the classroom. Future work includes gathering data on the impact of using the games in the classroom as well as further developing the games to include more challenges.

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