Play to Learn: Exploring Student Motivation Through Gamified Math Instruction

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1 ABSTRACT

The average attention span of students has been rapidly decreasing, making it more difficult for educators to engage students when introducing new concepts. With the growing integration of technology in education, supported by expanding access initiatives and subsidies, this project explores the development of an educational video game designed to improve engagement among students in mathematical concepts. This game leverages the engaging aspects of video games to encourage students to obtain a deeper understanding of educational topics. More specifically, applying the intrinsic motivations of gameplay to educational contexts. Fractions were targeted as the main math topic of the game, as they are widely recognized by educators as one of the more difficult concepts to teach at the primary level [12]. This paper outlines the motivations, goals and challenges in creating an educational game to address these issues along with a detailed explanation of the design choices made, before finally evaluating the finished product under a game design and educational lens. The evaluation will discuss whether or not the integration of technology in the product either elevated or limited its effectiveness to support teaching mathematical concepts.

2 INTRODUCTION

Majority of public schools have reported struggling to fill educator roles, the sentiment only increasing year by year. Exacerbating this issue, educators may also find it more difficult to maintain prolonged attention with their students. With unlimited information at our fingertips, AI chatbots delivering instantaneous answers, and companies constantly competing for attention, the average human attention span has reportedly to be below that of a goldfish [2]. With less than eight seconds to capture a student's attention, educators must look beyond traditional teaching methods to effectively engage students.

The introduction of technology into the educational sector has allowed educators to better manage larger groups. For example, LMS (Learning Management Tools) are commonly used by educators as an online platforms to host and track access to digitized versions of homework/lectures/textbooks. While the tool is helpful in extending access to educational content to students outside of the classroom, does not actively transform or enrich the learning experience for students. Gamified educational products have the potential to use the more "fun" parts of gaming to engage students in long, focused/driven gaming sessions. While not all students may view themselves as high achievers in every math concept, majority do consider themselves gamers. With an upwards of 90% of students playing games (including physical playground and digital forms), there are clearly qualities of gaming that have the ability to captivate every student [10].

Methods of maintaining deep-focused thought have been identified by both educational psychology and game design principles as a balance between frustrating challenges and boringly easy tasks.

Common gamer terms such as *farming, grinding, sweat, and no-lifing*, describe the process of losing track of time due to being so focused and engaged in a game. More formally, in psychology this phenomenon is referred to as the flow state or Optimal Challenge in Flow Theory. The Flow Theory, first presented by psychologist Mihály Csíkszentmihályi, posits that the delicate *flow state* is cultivated in an environment with balanced levels of anxiety and stress with boredom [17]. This is similarly described by the Developmental psychologist Vygotsky as the Zone of Proximal Development (ZPD). This zone includes the gap between what a learner is capable of learning with the help of others [16]. The introduction of gamified learning content attempts to take advantage of the addictive nature of flow state by recreating the environment in an educational context. Although this can increase engagement for students, this does not necessarily guarantee that the student obtains a deeper understanding of the material [3]. This project aims to harness the intrinsic motivation of games to result in conceptual mastery of the content. This project takes advantage of the intrinsic motivation found in video games to motivate players to master mathematical concepts. The project was implemented as a 3-D game *Arctic Flip*. The game incorporates an arctic theme throughout its 3D assets, all of which were independently created using Blender for integration into a Unity-based project.

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3 RELATED WORK

3.1 General Games

Games often employ a variety of methods to add voluntary additional stress to the playing experience. A compelling example is bullet chess, a variation of chess that restricts the time a player is permitted to spend on deciding †heir next move. With about one minute to decide the next move, the game constantly pressures players to make rapid decisions. Players that previously found the pace of chess to be boring can be enticed by the added frustration to enter the flow state. The intense and fast-paced environment pushes the player to rely on intuition and pattern finding behavior. The time turn mechanics prevents players from dwelling on past mistakes, instead focusing on applying what they learned in subsequent moves, thus accelerating skill development through rapid iteration. Failure, typically a strong discouraging factor in academic settings, especially for students who have historically struggled with topics. However, many popular games actually use frustration and large skill gaps as method of captivating players.

A great example is Super Monkey Ball, a 2001 game developed by SEGA. Players are tasked with navigating a monkey through an obstacle course with a time limit to collect as many bananas as possible before reaching their goal destination. The game has a unique feedback style of sending a player character (the monkey) falling off of the platform if the player fails to stay on the obstacle path [18]. Researchers at the Helsinki School of Economics found that the failure feedback was not actually received negatively by players. While making and correcting minor mistakes contributed to a focused loop of frustration and satisfaction, during stupendous failures, players exhibited decreased central theta activation and increased fronto-central beta activation [15]. Additionally in a publication from Advances in Physiology Education, researchers found that humor can reduce anxiety and promote a positive classroom environment by making the learning process more memorable and enjoyable [11]. From these two examples of popular games that increase motivation of players to voluntarily engage in challenging tasks, this shows games are a promising teaching delivery method.

3.2 Educational Games

Beginning in the early 2000s, the growth of game-based educational content has exploded. Most notably in math-related games like IXL, a software platform that provides students with math practice questions and aggregates their performance data for educators [9]. IXL has introduced a new method of instruction with its usage of quantifiable points accumulation, also dubbed the SmartScore system, which simultaneously motivates students to 'master' math topics while providing educators with detailed, performance data from students [9]. The main pitfall with this system is its measurement of "mastery" and penalty system for making mistakes. While a points system can quickly report student practice statistics for educators, it can form unhealthy goals in students to value scores over learning. Point deductions can enforce negative beliefs in students when attempting new topics, difficult questions, and recovering from mistakes.

In contrast, ST Math offers an alternative model by removing the numerical scoring system and traditional instructions. By shifting the focus from quantitative performance metrics to long-term conceptual learning, ST Math's instructional approach will serve as the model for our educational game. Without textual instructions and penalties, ST Math encourages students to explore mathematical concepts through trial and error, promoting curiosity in learning rather than anxiety [7]. This also mitigates the issues of linking negative connotations to incorrect answers and attempting new or difficult questions. By making design choices around the choices of the student and exploring math, games can spark confidence and an intuitive understanding of mathematical concepts before formal instruction begins.

4 DESIGN, GOALS AND CHALLENGES

4.1 Learning Objectives

The following learning objectives were identified to help guide the design of the gamified product. Through interacting with the game, students should:

- Exhibit self-motivation by completing levels beyond the first tutorial level.
- Understand basic integer arithmetic operations.
- Recognize and compare fraction numerical values
- Connect numerical values to in-game 3-D assets with minimal assistance and/or hints

These four main learning objectives were used to highlight three main criteria to consider when adding an additional feature to the game. Additional features and design decisions must have some value that supports at least one of the following desired player responses:

- Maintaining prolonged focus
- Grasping new ideas without explicit help (english text may not be used to give problem answers or point to a correct decision)

4.2 MDA framework

The MDA framework, a popular tool for game design and analysis, was used to design a game that engaged students more effectively in challenging math problems than traditional teaching methods. It is composed of three main parts: mechanics, dynamics and aesthetics. Each component works together to create an enjoyable and voluntary experience for the player. The mechanics include the rules and action options. The primary mechanic involves object manipulation, restricted to only picking and placing ice blocks. The secondary mechanic is jumping and walking to aim the character to select the correct ice objects. All actions to construct an answer must be completed within a 30-second time limit before it is evaluated. Points can be earned by submitting correct answers and there are no quantitative penalties. The mechanics influence the player behavior to create the dynamics of strategy and decision making. The time-limited challenges force the player to focus on rapid hypothesis testing and critical thinking to creatively come up with new solutions. The game also encourages competitive engagement by challenging players to compete against a computer-controlled wizard character. Increasingly panicked and frustrated responses from the opposing wizard character can bring satisfaction, feeling that they have outsmarted a character despite not having the upper hand in terms of time and knowledge on fractions. The ability to allow players to form hypotheses and rules surrounding the game mechanics on their own gives them a sense of competence. Within the framework of Self-Determination Theory (SDT), researchers Richard M. Ryan and Andrew Przybylski view autonomous actions through a game lens, "When games offer meaningful choices, freedom to act, and flexible paths to success, players feel more autonomous — which enhances intrinsic motivation" [14].

The main aesthetics of the game were sensation and challenge. Emotional responses of sensation were elicited through gentle colors with low opacity and cohesive asset design. A polar winter theme was used to evoke calm and focused emotions in players, using slow-tempo background music with bells and reverb effects, and low opacity colored 3-D penguin and ice assets to match. The winter themed assets also assisted in supporting the aesthetic of challenge in level designs like using ice to decrease motor function and snow to obscure vision. Blue, the main color scheme of the game, was chosen for its calming and soothing effects, which are commonly associated with supporting the heathy focus needed for studying [4]. Penguins were chosen as the anthropomorphized animal for the player character due to their simplicity and match to existing in-game themes.

4.3 Implementation

The identified game and education tool design choices were implemented in a desktop game labeled Arctic Flip. Upon launching the game, the player is greeted with the antagonist wizard penguin character, selected to foster a competitive environment for players. A 2-D UI system locked on the right side of the screen includes a representation of the wizard (in Figure 1 below) with humorous feedback text to further support a competitive setting to motivate the player to successfully defeat level challenges. The player may choose to provide an in-game name (shown in Figure 1 in red text), although not required to play.

Figure 1: Figure 1: Arctic Flip during an active challenge including feedback UI, timer and highlighted interactable objects

After the player clicks the start challenge button, the timer starts counting down from 30 seconds and a randomized question set within the user's player level is selected. The timer encourages players to focus on experimenting with different approaches rather than fixating on finding the one perfect solution. To help players understand what items can be used to form solutions, a Unity Raycast, a mathematical ray from the pengiun's head in the direction of movement was cast to highlight interactable blocks. If the player selects a block, it is placed on top of the player's head to simulate the action of picking it up to enhance the sense of autonomy, which is a key motivational factor idnetified by Przybylski et al in studies on video game motivation [13]. Additionally, the numerical value of each block was shown in the UI feedback in the player's speech bubble to help player connect in game items to mathematical concepts. The ice block items are placed on the wizard's side of the iceberg platform to represent the selected question set. By matching the question id, a SQL query will select the equivalent problem set to place possible ice blocks players can manipulate to form the correct answer. Successful completion of a level challenge will earn players one point. When enough points are accumulated, players will level up, receiving a different badge for each level (shown as a star for reaching level 2 in Figure 2 below) accompanied by a playful leveling up sound effect to celebrate the student's accomplishment. The wizard's speech bubble will also express wry frustration over the player's intelligent response.

Figure 2: Figure 2: Arctic Flip during an an failed challenge with visual feedback through the platform flipping over

If a player fails to construct the correct answer to a challenge, the iceberg platform will be flipped over (the animation shown in Figure 2 above). The wizard's speech bubble will express satisfaction over their carefully constructed problem. Both of these design choices help the game use humor to recover from wrong answers and competition to motivate players to try again.

4.4 Challenges

The main challenge associated with the implementation of the described design choices was balancing question difficulty. Exploration and challenge were the main aesthetics when designing the game to mitigate issues of surface level understanding of targeted math topics. In order to guarantee that a student was not simply memorizing answers from previous questions or applying recognized patterns without understanding the logic behind them, answers and textual instructions were purposefully omitted from the game. Similar to ST Math's approach, players are then forced to engage in trial and error style problem solving methods in order to achieve mastery in a math topic [7]. While this method can be effective, the steeper learning curve can discourage many students already struggling with the topic or frustrate others who feel lost without a direction to start with. Hints in english text were provided in order to mitigate the learning curve issue, but due to the diversity of skill-set students can posses, it was difficult to ensure that the learning curve was correctly adjusted for every player for both gaming and mathematical knowledge.

5 EVALUATION

In order to wholistically assess the level of effectiveness of the game *Arctic Flip*, both the depth of learning and its use of technology must both be evaluated. Bloom's taxonomy will be used to evaluate the level of comprehension player can expect to achieve from playing the game ad PICRAT will be used to access the effectiveness of incorporating technology as a teaching mode.

5.1 Bloom's Taxonomy + PICRAT

The Bloom's Technology framework is represented as a pyramid, with each level representing of cognitive demand building off the mastery of its lower counterpart. With this variation of Bloom's taxonomy the technical report will be assessed by traversing through the taxonomy from foundational to complex cognitive load [5]. The *remember* level is satisfied by requiring students to recall fractional values when viewing the fractional values in the UI feedback panel. Using their memory of the fractional values, they must *understand* them well enough to connect the numerical value to in game ice block objects (example: the half circle represents 1/2 fractional value). Then they must *apply* this understanding to solve new problems (for example, matching fractional values to balance the iceberg so it is not flipped over). As the problem type difficulty increases from whole values to partial fraction values, students must analyze relationships between fractions with differing denominators. Upon receiving feedback from the game, students must *evaluate* their solutions(for example, if a submitted solution is incorrect, the player sprite is flipped over and the student must investigate why their solution was wrong), thus the game achieves the *evaluate* level in Bloom's Taxonomy [8]. To fully assess the impact of technology in this educational tool, the PICRAT model was applied [8]. PICRAT evaluates the level of interaction expected from both the student and the teacher when engaging with a digital tool. It categorizes student interaction as Passive, Interactive, or Creative, and instructional use as Replace, Amplify, or Transform. The students' relationship to this tool was analyzed and found to be the interactive by responding to game content rather than simply viewing/reading text. The tool transforms traditional practice through interactive 3-D models for real time feedback, therefore classifying the game as an amplification of traditional teaching methods [3].

6 DISCUSSION

Classified as an interactive amplification tool, this tool can be a great way to enhance student motivation and depth of learning without completely replacing human instructor roles in the classroom. As a supplemental tool to traditional brick and mortar instruction, this can be a great way to scale teacher instruction by distributing traditional math practice activities in a game setting and logging student performance statistics.

6.1 Extensions

The game can be expanded to allow students to play as the antagonist wizard penguin character. After passing the the introductory levels of the game, the player will be offered the opportunity to create their own math problems and add additional operations to the game. Doing so can provide a completely transformative tool for educators to promote creativity and social interaction among students.

Additionally, to visually represent fraction understanding and help students deduce the rules of the game, the iceberg can flip in the direction of higher numerical value. This can incentivize students to flip the iceberg in a particular direction. As mentioned in the dynamics portion of the MDA analysis in section 4.1, players can be motivated by autonomy by having control over game outcomes. In order to fully enjoy the added flipping feature, students must learn to compare fractions with differing denominators in order to strategically flip the penguins in their desired direction. Through this added feature, students can be motivated to achieve a higher-order cognitive processes, strengthening the *analyze* level of Bloom's Taxonomy.

6.2 Future Steps

The next steps for the lifespan of this projects involves eventual deployment into a classroom. In order for the product to be introduced into a classroom, it must be aligned with the Common Core State Standards (CCSS). The CCSS that applies to our game, a product for teaching 4th graders fraction fundamentals is 4.NF.A.1. The game can be proven to be aligned with CCSS 4.NF.A.1 because it allows students to manipulate visuals to match fraction values. In Arctic Flip, in levels 2 and beyond, CCSS 4.NF.B.3 is also applicable by requiring students to compare fractions to whole numbers and sum smaller fractional values [1].

To ensure that the software is accessible to all students, compliance with WCAG 2.1 and cross-platform functionality standards is necessary. Accessibility considerations include, among others, adherence to a 4.5:1 color contrast ratio and screen reader compatibility to accommodate students with disabilities. Adaptation of the software to accommodate diverse hardware setups and network limitations is essential for students with limited connectivity and depend exclusively on mobile devices for at home access [6]. Proper OAuth and compliance with FERPA (Family Educational Rights and Privacy Act) will be necessary as the last step before releasing the software for public school to ensure the security of student private data. Students must learn to compare fractions with differing denominators in order to strategically flip the penguins in their desired direction. The game should still remain open to public use without payment or school affiliation to allow students in under-resourced math programs have access to alternative math learning tools. Once intrinsic motivation to learn has been established. the fundamental objective for an online learning tool like *Arctic Flip*, is to maintain a free and open source learning resource to cultivate a culture of self-driven learning.

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