

A Study of Gamification Techniques in Mathematics Education

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Introduction and Overview of Literature

Mathematics is an extraordinarily broad field, and the creativity that is inherent in mathematical study is poorly conveyed by the often conventional educational methods used to teach it. The typical approach of being shown concepts and being expected to apply the learned concepts in problem-solving is often reported by students to be boring, dry, and repetitive; many students fail to understand the truly free and explorative nature of what mathematics study at the post-secondary level is like. Although effective for achieving standards for standardized testing, if educators do not make it a priority to otherwise convey the applications for mathematics, students often apply these same negative labels to math itself as well. Instead, throughout my math education experience I have found many of my classmates looking forward to the games that they will play during breaks.

Instead of this approach (which does not aim to discredit the repetitive drilling method of mathematics education, but aims to introduce nuance into it), the field of mathematics lends itself well to simulation, and creative game-like discovery. Hence, the practice of gamifying tasks or activities enables mathematics education to acquire some of the interesting qualities of the games that the students intend to play during their breaks. Indeed, it is reported that even in the workplace, games are pervasive: Erenli notes that 215 million hours are spent collectively by Americans playing games. This interest in games can be channeled also towards an educative objective.

Gamification is a very underdeveloped field; the practice of effectively using games to motivate and in fact assist learning is still at a very burgeoning stage. Recently, a literature review presented at a 2014 conference indicated the significant studies that have been performed about gamification. Although 400 papers were found that included the search term “gamification”, the review only identified 2 qualitative studies, 17 quantitative studies, and 5 mixed studies that targeted the application of technique and effectiveness of gamification

(Hamari et al). It is encouraging to note that all these studies provided only positive or neutral effects of gamification: in every experiment significant improvements in learning occurred in some aspect of the gamified program. Any method or general technique for education should not only serve an auxiliary role but in fact provide a new lens for approaching material that is not imitated by another method of teaching. Often, gamification attempts in the classroom are feeble, and lead to students' ire because additional work is assigned for them for which the objective is not clear. Often, from the students' perspective, the effort exceeds the educational benefit. Hence, this paper aims to investigate the techniques that can be used for mathematics gamification aiming towards making mathematics education more interesting, more nuanced, and more effective.

What led me to pursue this study was the summer experience I had as a Course Teaching Assistant at Bridge to Enter Advanced Mathematics (BEAM), a summer camp designed towards introducing talented low-income middle school students to the joys of mathematics. During weekdays, the students participated in six hours of mathematics instruction in topics usually only taught at the undergraduate level or in advanced competition mathematics, and the goal was to show students mathematics and thinking styles that they would not normally even encounter within their school setting. As these students were talented students that were specially selected for their interest in problem-solving, most of the students had expressed frustration and boredom within the mathematics curriculum at their local middle schools; BEAM aimed to re-energize their interest in math and introduce them to think about math not as methods of memorizing facts or problem-solving strategies but a more rigorous, creative, and artistic process of exploration. Many gamification techniques were employed in the BEAM program which will be discussed in this later.

Further, this paper also intends to present examples of effective gamification in education in literature and current use, and discuss the philosophies of gamification as reported therein. In order to explore some of the effects of putting these philosophies into practice, an experimental game, based on the matching game, was designed and distributed to Preceptor Oliver Knill's undergraduate Math 21A (Multivariable Calculus) course at Harvard University, and data from 375 completions of the game were collected. The paper also analyzes these results and provides discussion of the experiment's findings regarding gamification techniques.

Literature

Games have already been proven to have practical and observable results on education, from applications as varying as providing an environment for problem-solving drills in K-12 mathematics education, to applications requiring incredible precision such as triage training (the

rapid assessment and ordering of medical cases by their severity), or mapping and identifying neuronal images for neurobiology research. Currently, these applications have in general been applied at a smaller scale or for specialized purposes.

For example, in hospitals, a video game called Triage Trainer was designed to teach crisis management for use during Major Incident Medical Management and Support Courses. An excerpt from the abstract of this study performed by Knight et al. reads:

During Major Incident Medical Management and Support Courses, 91 learners were randomly distributed into one of two training groups: 44 participants practiced triage sieve protocol using a card-sort exercise, whilst the remaining 47 participants used a serious game. Following the training sessions, each participant undertook an evaluation exercise, whereby they were required to triage eight casualties in a simulated live exercise. Performance was assessed in terms of tagging accuracy (assigning the correct triage tag to the casualty), step accuracy (following correct procedure) and time taken to triage all casualties. Additionally, the usability of both the card-sort exercise and video game were measured using a questionnaire.

This is an example of a mixed experiment; in addition to quantitative data about the effectiveness of gamification (called a “serious game”) collected, a questionnaire was used to assess the feelings of the subjects towards the gamified experience. Overall, this experiment shows that even highly technical skills, such as triaging, can be taught effectively using gamification techniques.

In Ma et. al’s *Serious Games and Edutainment Applications*, the work of the anthropologist and education philosopher Gregory Bateson is discussed. Bateson defines the concept of learning levels to identify the different ways that a student needs to think about information and concepts before becoming proficient in its use.

An application of this multi-step approach to education is shown through discussion of the game *Global Conflicts: Sweatshops*. In this game, the player assumes the character of a tannery co-owner in Bangladesh, and learns about the state of child labor there. It is a complex game, requiring not only the basic acquisition of information but acquiring it, making Ma’s analysis of the game a useful model for discussion of concepts involving mathematical gamification in general.

As described by Ma et al., “on this first learning level the players receive information, memorize it and react to it without reflecting the context or reasons” (Ma et al., 48). In *Global Conflict: Sweatshops*, the player learns facts about the amount of child labor in Bangladesh (for example, in the game, the player learns that there are 5 million children that work and do not get an education in Bangladesh), but is required only to acquire rather than use or apply this information. No contextualization or evaluation is required at this phase. Interestingly, Bateson calls this first learning level “learning zero”; he does not believe true learning has occurred at this point.

At the second level, the player applies the information to repeatable contexts. The player judges what information is necessary or beneficial in a situation and is able to ignore or reject information that is not useful. For example, in *Global Conflicts: Sweatshops*, players are to interview various co-owners in branches of the company they are working for and in dialogue are given two or three choices as responses. The player is then able to apply the learning zero information acquired throughout the game and properly contextualize them into giving the correct responses that lead to desirable outcomes, such as reduction of the child labor policies in the company. Giving an improper answer, for example, can get the player fired, or otherwise dissuaded from continuing. Bateson terms this stage “learning one”, or “proto-learning”, in which players begin to understand how to play the game successfully through interpretation of acquired facts (learning zero) in given contexts.

Finally, many educators will stop at the second level of proto-learning, which is to teach students the necessary skills to properly know and make use of information they have learned. However, there is a further third level, as defined by Bateson, who also calls it “learning two” or “deutero-learning”). In deutero-learning, the student gains not only competency in utilization of the information but also the student learns how and why the information is relevant to their own life, and this learning begins to affect their overall life decision-making. In particular, Ma et al. state that, “in our example, *Global Conflicts: Sweatshops*, this serious level of learning would include a change of the player’s thinking about child labor, poverty, oppression, journalism, violence and pollution through experiences fostered in the game” (52). Ma et al. also notes that deutero-learning arises alongside proto-learning: “players may question why they can only talk to certain characters and not others, why they can only choose from two or three alternative answers during conversations, and why the characters’ accents are not Bangladeshi?” (50). This should be the end goal for educators, that students would consider the relevance of the material taught and how it should influence their life decisions.

This three-fold definition of different stages of acquisition in learning is important for background discussion of gamification because it provides a systematic framework for labelling the various levels of skill acquisition, terminology which is used throughout.

Summer Experience at Bridge to Enter Advanced Mathematics

During July 2017, I worked at the Bridge to Enter Advanced Mathematics program teaching eighth grade students more advanced mathematics and rigorous proof methods. From this experience, I was able to observe many practical applications of alternative education methods, which was the impetus for pursuing this study. Although not all methods presented in BEAM can be properly denoted as gamification techniques, nonetheless many important principles captured by gamification techniques can be observed from studying BEAM methodology.

During the three weeks, I acted as teaching assistants to three classes. The first class was called Solving Big Problems and led by Sarah Trebat-Leder. Using directed problem solving as a method of teaching, which is incentivized and presents learning as a form of game, the class aimed to lead students to be rigorous in defending their understanding. This demonstrated how gamification could be used not only to motivate the revision of simple skills, but problems were used as a teaching tool (PBL or problem-based learning) for illustrating proof methods, the importance and methods for clear communications, and general problem solving strategies. This ten-hour course ran for two hours each day for five consecutive days. The second course was Cryptography, taught by Siddhi Krishna. This course was eighteen hours in length. In the cryptography class, we explored using modular arithmetic to encrypt and decrypt information. The material itself was presented as a game-like challenge, but also even in presenting rigorous methods of proof, game techniques were used to engage the entire class in that concept. The third course was Graph Theory, taught by Prof. Reva Kasman. This course was eighteen hours in length. This class was inherently driven heavily by proof and PBL, but graph-tracing, an activity that is very different from the numerical understanding of math held by the middle school students, was able to encourage exploration and learning by virtue of its novelty.

A particular methodology was observed to have been used during the classes:

1. Open-ended problem exploration
2. Definition of basic terms and key concepts
3. Guided exploration using key concepts and terms
4. Presentation of theorems and lemmas, and Responsive interrogation

For example, firstly, on page 1 of the transcript document titled “BEAM SBP”, Theorems 1 and 2 were a result of open-ended problem exploration. The problem was trying to identify what

perimeter values were possible given a shape drawn on grid paper. Using specific cases and using trial-and-error methods on those simple examples, important results narrowing down the final result were obtained. For example, in Theorem 1, exploration showed that only even perimeters were possible; and in Theorem 2, through students' trial and error a method was generated for constructing any even perimeter greater than 2. This was followed by disconnected observations and questions. The impetus behind Observation 1 involved the proposition that removing squares from the center of a large figure could cause an increase in the perimeter. Filling in such squares could result in decreases in the perimeter despite the addition of area. However, some students objected to the definition of those as grid-shapes. Hence, as a class, a working definition was proposed and voted upon by the class, which voted to accept all such shapes as legal grid-shapes.

In this way, a valuable lesson was taught to these students by this method, that often problems solved with one definition may have a different answer when solved with any definition (or indeed have no solution). Students were also taught to be specific in asking mathematical questions, as well as rigorously defend their opinions and intuitions, useful skills that were otherwise very difficult to effectively teach except through such means of demonstration.

In another example, pencil-tracing problems (problems in which you attempt to trace a figure without lifting the pencil) were given to students in the Graph Theory course. Through trial-and-error, students solved 10 pencil-tracing problems in the first hour of the course. In the second hour, they were introduced to the concept of vertex degree, and the definition of Eulerian circuits and paths, and based on these terms asked to identify criteria for Eulerian graphs based on something they were shown. Using this, intuitively and quickly students found that the number of odd vertices dictated the type of graph, and by considering that every edge must have two ends (an "in" and an "out") they proved that only with even vertices can you have both an "in" and an "out", and thus continue to trace the graph.

In general, this problem-solving methodology produced many important results. Firstly, the purpose of the Problem Solving course was to teach proof skills to the students. For example, the students were challenged to explain why no other answers could be correct, or how the proposition they proposed in terms of n would apply even to cases such as $n=100000$. This guided, open-ended exploration at the beginning of this method allows for students to explore the concept of narrowing down key components for a proof.

An additional method was to use gamified, interactive activities as a means of deepening theoretical, foundational understanding regarding a subject. For example, in the Cryptography course one of the activities had all the students stand up and move to a certain location in the room, based on their opinion regarding a mathematical statement. One particular example is whether the minute hand of the clock operated on mod 59 or mod 60. The students were confused because it was taught to them that the hour hand was mod 12 yet times are given from 1 o'clock to 12 o'clock, whereas the minute hand ran from 0 to 59. Thus, the question posed was whether 60 or 59 was congruent to 0 when considering the mod with respect to the minute hand. The argument required them to truly understand what the meaning of a modular congruence was, and eventually a student arrived at the complex visualization that a modular congruence could be thought of as wrapping the number line around a circle of circumference equal to the length of the mod.

Gamification Application in Research: EyeWire

BEAM is a case study in which a large amount of time and careful individual attention was given to students to develop precise problem-solving and analysis skills. On the other hand, EyeWire is an example of a crowdsourced-based Internet game that manages to effectively teach players how to recognize and categorize components of neuronal images, a task that is currently too difficult for even artificial intelligence to do unaided.

The director of the EyeWire project, Dr. Amy Sterling, came to give a lecture about EyeWire in MCB 80, my introductory neuroscience class. Prior to the lecture, all the students were told to make an account and play 30 minutes on EyeWire. During the lecture, Dr. Sterling explained that the data collected by players while they are playing the game is used to assist real research by categorizing and interpreting portions of neuronal images, together with the game AI. A research project in neuroscience had produced an output of thousands of neuronal images that could not be interpreted by just a computer, and needed hours of personalized expert attention to interpret each image. Hence, EyeWire made use of crowd-sourcing and gamers to do this classification: throughout the introductory phase of the game, players were trained to identify which parts of the 3-D images were part of the axons, dendrites, and so categorize the information generated from the scans, etc. Then, the entirety of the gameplay (for entry-level players) is applying these skills to label the dendrites, axons, in a given part of the image. By scrolling up and down, players moved to a different 2-D cross-section in the 3-D image of a dendrite or axon and clicked on portions that the player deemed to belong to the same 3-D segment. This would result in the 3-D representation of the selected region being added to the current mapping (see Figures 1 and 2 below for images during gameplay).

At any given point in time, all the players in the game work together to label different parts of one particular image. The part of the AI that handles game coordination (the spawner) will automatically generate a segment of the image, called a cube. Multiple players will work on a cube and if they all agree, the AI will begin to give players new parts of the image and progress on from there to gradually map the entire neuron.

In order to train new players to correctly identify and recognize the different parts of the neuron in the image, there is a tutorial in which player are given cubes that have been solved numerous times by others.

In order to incentivize players to do well in the game as well as to play more often (and subsequently assist in more research), EyeWire gives more advanced players more sophisticated roles with higher privileges. For example, players that pass an initiation challenge can move on to process images of neurons that are known to have strange geometries, such as bipolar cells. By making this challenge require sustained accuracy over many difficult cubes, the EyeWire system simultaneously ensures that only skilled players can attempt these more difficult images but also incentivizes players to improve their accuracy. Even more experienced players (called scouts) are given the right to submit for review cubes that seem incorrectly done to administrators, who are themselves higher level players that can overrule or undo suspected mistakes made by other players. By providing hierarchical structure, EyeWire was able to provide largely non-substantive (non-material) incentives to play the game, using titles, ranks, and score to provide in-game rewards to skilled players. By setting specific targets challenges to unlock stages, this can also provide a quota for players interested in attaining to the next level, make all such players interested in the challenge attain to a certain standard. Furthermore, this player-run system allow the neuroscientists to continue their research while players would self-regulate and check the accuracy of their processing. This automatization and in-game structure provides specific goals for beginning players to aim for, legitimizes the game, improves overall player accuracy standards, and helps the researchers to focus on the actual research rather than the data analysis.

Figure 1. The initial starting screen when solving a cube, a segment of the neuronal image.

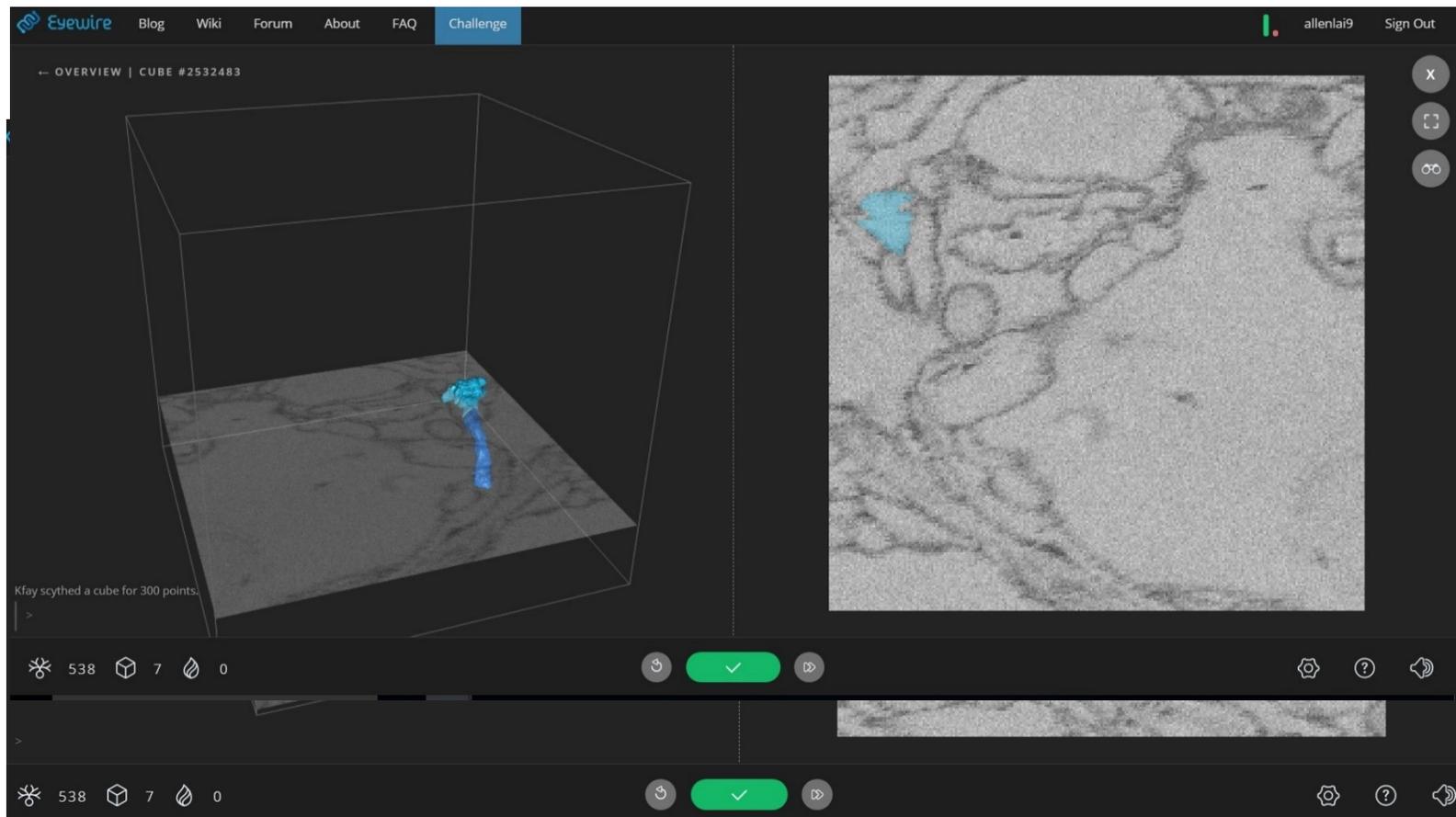


Figure 2. Clicking on the area on the right-hand side of the screen led to the generation of the light blue section on the left-hand mapping of the neuron.

Figure 3. EyeWire is very active, with players solving up to 293,000 cubes, spending hundreds of hours voluntarily assisting in the neuroscientific mapping research.

Profile Achievements Challenge

Nseraf

Mystic, Moderator, & Mentor

Joined November 16, 2013



Tutorial Annihilated
Earned 2014-04-25



blog.eyewire.org/stats



Points



Cubes



Trailblazes



Scythe



Completed

Today

44,132

59

17

129

748

Week

204,058

101

40

556

1,018

Month

241,843

108

44

665

1,951

Overall

70,163,224

293,760

105,227

163,909

445,660

Accuracy

Level 1



97.8%

Level 2



98.6%

Hence, EyeWire was able to get players to participate in this research without any compensation by making their game attractive and entertaining for players. EyeWire embodies many characteristics of a successful education game. Indeed, the current lead player, Nseraf, had solved over 293,000 cubes (Figure 3). Overall, EyeWire is able to enlist the help of players, without monetary compensation, to perform a complex task that assists in analyzing data in real neurobiological research. Further, it is able to have more skilled players check the accuracy of the work of others, and thus ensure not only accuracy but also automatization. EyeWire also represents a potential model for human learning: it is centered around the idea of refining an artificial intelligence by using large quantities of precise data regulated by humans. This use of data to affirm or deny predictions is an effective combination of both human and technological efforts in both research and education of a group of non-technical “students” to perform specialized tasks.

Discussion of Gamification Techniques and Philosophy

How can the techniques that have been just discussed, especially in the BEAM and EyeWire case studies, be applied more generally to math education? First, I would like to discuss several significant factors that should be considered in the design of a gamified task to incorporate into a system for mathematics education.

First, incentivization is very important to any gamified program or task, as the enjoyment or gain that can be derived from the game is a large part of what motivates students to attempt it. Different methods of incentivization include material rewards (a physical gift or extra credit), or benefits within the game, or simply enjoyment.

However, an important philosophical point to discuss is at which point students become involved in the game for the gain rather than the learning. Especially if the gain is material and goes beyond the constraints of the game, this is particularly dangerous as rather than recognizing the game as an opportunity to optimize learning in an entertaining way, the students may begin to play the game in ways that optimize score and performance rather than learning. This strategy is usually not directly correlated with the optimal learning strategy. Hence, in-game rewards are usually far superior to material rewards, as not only is this cost-effective for the educators, but also it is more likely that students, in their deuterio-learning process of identifying the relevance of the game and its context to the real world, will recognize that these rewards are less valuable and focus on the learning aspect. Even if the student begins to participate in the game for the sake of achieving in-game status (for example, in the EyeWire example, clearing the proficiency challenge so that the player can move on to map more complex neurons), this has the danger of addiction to the game and its mechanics rather than the learning that the educational game aims to provide. Hence, an important principle in administering gamified tasks is to ensure that students understand well the learning objectives and are continuously reminded of the place that task has within the course, for example.

Second, the balance of information conveyed versus the engagement level of the game needs to be considered. Students can easily identify feeble attempts to incorporate gamification in activities if it is unclear how the activity develops a learning objective. It is very difficult to simultaneously create a very engaging game and a game that teaches actually applicable skills. Further, if the game is very engaged but does not focus on the learning objectives, students can become addicted to the game and not focus on the learning objectives.

Further, rote memorization is a very limited form of learning, as noted by Bateson in his learning terminology, and any effectively gamified form of education should avoid being overly focused on memorization. In the ideal scenario, deuterio-learning is achieved in every gamified task: the practical implications of the game and its mindset is evident from the learning context.

Yet, there necessarily must be memorization, or learning zero, before contextualization of that “ground zero” framework knowledge can take place. Further, skills for which games are particularly skilled for developing are problem-solving skills, memorization (learning zero

applications), and inter-personal connections, as discussed in the Overview. Thus, there inherently is a tendency towards memorization games when developed games. Hence, it is necessary especially educators intending on incorporating gamification to be particularly careful in ensuring a balance between information acquisition and the level of engagement; a debate or role-playing game, such as found at BEAM, if properly used, can be effective at integrating these. Further examples, such as KhanAcademy, will be discussed later.

Also, an important aspect to consider in gamification is the effect which having a publicly displayed score and rank might have on a gamified task. As noted in Erenli's paper, scores, leaderboard, badges, and levels, and are the top four most studied aspects of gamified education, hence assessing their importance is crucial to any study of gamification. Indeed, these aspects will be further studied in the experiment performed using students from the Harvard undergraduate Math 21A class. Although scoring alone does not make an activity a game, if used correctly it can motivate students through competitiveness: in many countries around the world, a student's exam scores are publicly posted so that, it is thought, that students will be more motivated to out-compete their peers. This competitiveness, although useful in small amounts, has been shown to be overall detrimental to students' mental health (Blundy). Indeed, KhanAcademy uses this gamification tactic very effectively and appropriately: by giving a numerical value to watching educational videos and solving problems, it very effectively forms a structured environment for learning zero, as mentioned above. KhanAcademy permits people to register together and be able to view one another's progress, which is a multi-player approach that more greatly inspires one another to learn, not just to avoid losing.

On the other hand, there is a subset of the North American educational system that takes the other extreme: aiming to raise the self-esteem of its students, it tends towards creating activities with all participants being a winner in some way. This lax approach has created a sense of entitlement, and expectation of being achievers, part of which was observed in contrast to the BEAM students, who were used to competition and did not manifest such signs. Neither extreme is desirable.

Similarly, it is important to track the effect on performance as well qualitatively whether or not motivation is driven by obtaining a higher score or learning. This is why the students' recognition of gamification as a learning method, controlled by the student and not controlling the student, is key to a successful program.

Finally, an aspect often included in games is a time limit. This is often not considered important in the development of non-time sensitive specialized skills, in which accuracy is more

important than the rate. For example, although in triage trials it is absolutely necessary that one perform the diagnosis both quickly and accurately, in the writing of a mathematical proof, for example, time is usually not the most critical factor as being able to identify the key steps of the proof. Thus, although time pressure can be useful for certain scenarios, in general it leads to a desire to finish at a given speed rather than encouraging sustained accuracy. Surely, some games involving using time as an exercise or challenge can be used to great effect (as time is not a non-negligible element in application in general), but emphasizing time-based games often compromise and replace skill with speed. Except in time-constrained fields or applications, should avoid using heavy time constraint.

Gamification Experiment and Discussion

In conclusion, in order to test a simple example of gamification applied to mathematics, with the help of Preceptor Oliver Knill, I designed a simple memory game testing multivariable calculus concepts for use in Preceptor's Knill's Math 21A undergraduate Multivariable Calculus course at Harvard. In particular, I wanted to assess the effectiveness of having a visible score on performance, and if the time taken for the activity at all correlated with success.

The game was posted on <http://sites.fas.harvard.edu/~math21a/game1/> and involved the simple matching of definitions with their appropriate formulas, and the score, playing time, and accuracy of all completed games were recorded. 375 responses were recorded, with a mean score of 42361.2 (the formula for computing score will be described later), mean accuracy of 39.2%, and mean playing time of 31.5 minutes.

This game was designed to test both the ability of the player to recognize and match partial differential equation formulas and optimization formulas with their uses, but also in general test the ability of the player to memorize the positions they appeared in. In other words, the game provided a simple means to assess first-level retention skills (or "learning zero" under Bateson's model) under conditions in which the players were aware of their score being recorded, providing an environment for passive motivation. Some proto-learning skills were tested in the player's need to process and understand the uses of the formulas, but if the game was played on subsequent levels, the player could proceed via memorization and bypass this.

A harder version of the game was produced and released only to interested students: data was not recorded for this game. This game involved matching complex double integrals to their areas in addition to the formulas from the normal difficulty level. This version tested proto-learning skills significantly but was deemed too difficult for students and therefore not an effective trial for gamification. It was tested by students and Preceptor Knill and the amount of time it took to properly complete the game was considered to be too long to be of interest to students. The HTML/CSS code for both versions of the game are submitted along with this paper.

Score was computed additively: each successful match added a certain amount to the previous score. This made progress more easy to quantify overall, as a match that was the result of many failed attempts would not greatly increase the score while fast matches would be rewarded with a great increase in score. This scoring method in general was able to distinguish between players that thought about matches carefully and those who succeeded through random trial and error.

There was almost no correlation between the time taken and either score or accuracy, as shown in Figures 4 and 5; this is because the game was administered via the Internet, and no regulation was given that students needed to finish a game in one sitting. The mean playing time of 31.5 minutes for a simple memory game showed that many outliers needed to be removed when assessing the correlation between playing time and either score or accuracy. However, there was a notable correlation between accuracy and score (Figure 6), with an r^2 value of 0.8393.

This demonstrated an important aspect of gamification, as there was no time correlation between relative success at the task and time elapsed, regardless of how students allocated their time. For example, students could have left the computer, been distracted, and returned to focus on the task while other students patiently completed the game in one sitting. Nonetheless, there does not appear to be any particular correlation as such observed in the results.

Further, the results show a notable correlation between the two statistics that are visible to the player, whereas the absence of a marker recording time on the screen led to no correlation between it and the other variables. Although from the low level of specificity of the experiment it is not possible to identify a strong relationship, further experiments can be performed to identify whether or not revealing to students that a particular attribute is being assessed will increase performance; that is, whether or not students self-aware of their use and mindset towards gamification perform better.

For further steps, similar to the triage study mentioned from literature, a survey will be administered to the subjects of the experiment via the Harvard QGuide (class rating system), with some of the following questions:

- Were you ever encouraged to play the game again in order to get a higher score? Were score-related motives an important component for you in the game?
- Was the fast feedback time (short problems with little required input) useful or not for you in learning the Math 21A material? Do you think you would have been motivated by a point penalty for incorrect answers?
- Did you feel the player interaction was sufficient to be engaging?
- Do you think the game helped you in your understanding of the Math 21A material?

This will aim to provide both qualitative information about the success of the experiment in addition to the quantitative assessment of the information performed.

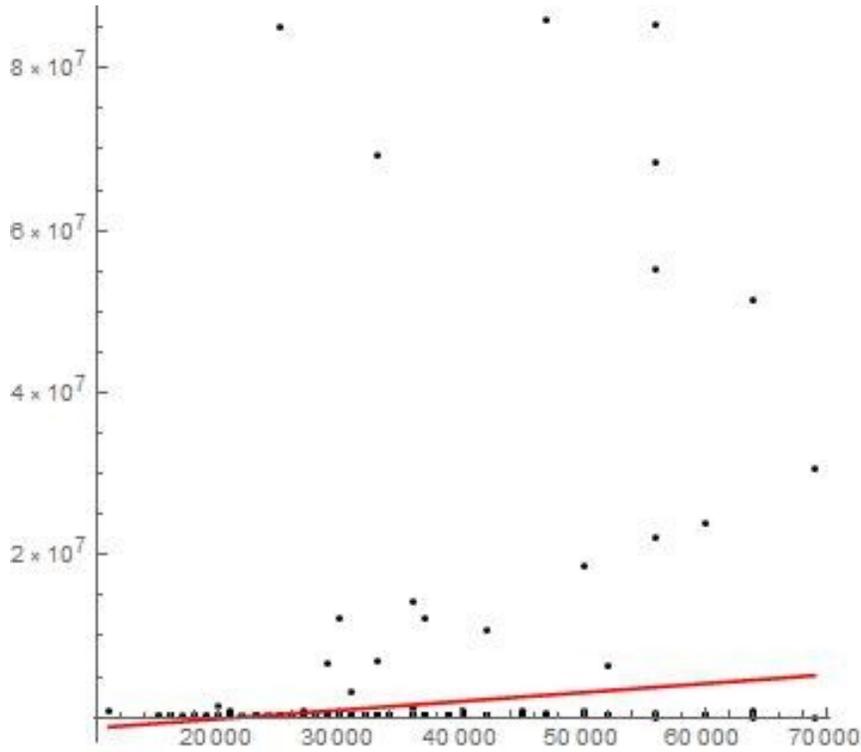


Figure 4. A scatter plot showing the lack of relationship between game time (y-axis) and score (x-axis)

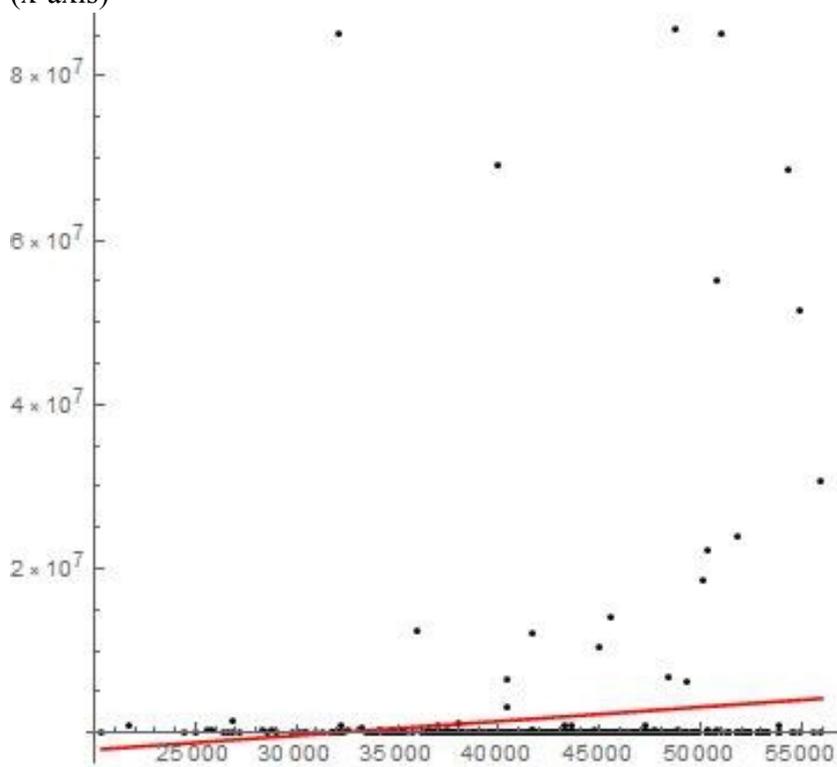


Figure 5. A scatter plot showing the lack of relationship between game time (y-axis) and accuracy (measured in %, or percentage of percent, on the x-axis)

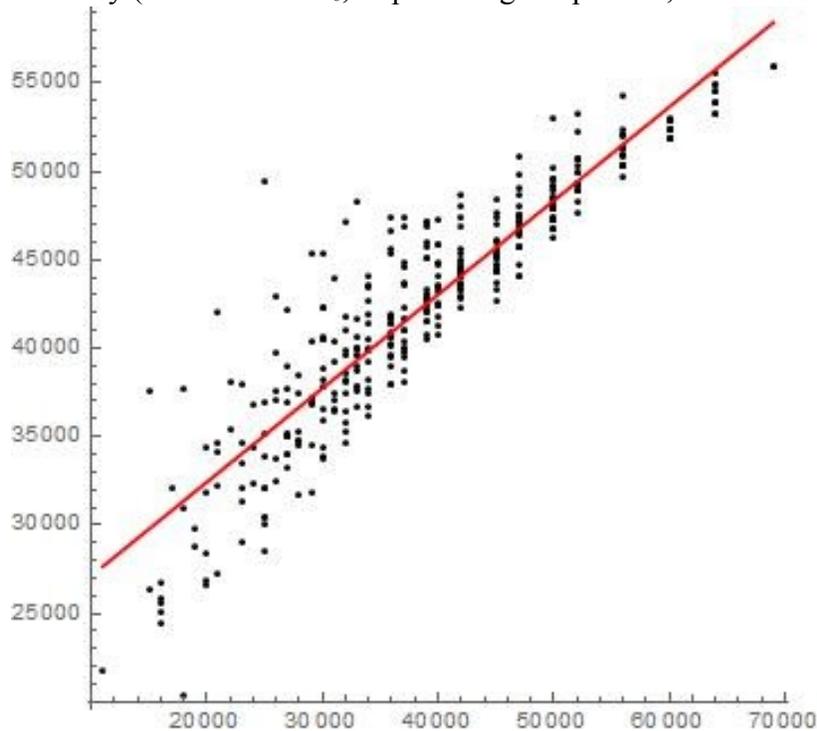


Figure 6. A scatter plot showing the relationship between score (y-axis) and accuracy (measured in %, or percentage of percent, on the x-axis)

Conclusion

In conclusion, here is a summary of the perceived advantages and disadvantages of using gamification as a teaching tool:

Perceived advantages of gamification as a teaching tool

- encourages learning beyond the book
- promotes learning on own initiative
- encourages creative conjecture making
- fosters and integrates students into collaborative environment of teamwork, if applicable
- recognizing the strengths of the team, understanding individual fits into the whole

Perceived drawbacks of gamification as a teaching tool

- creates focus on obtaining the individual achievements rather than understanding of the material
- addiction
- lack of understanding the applicability of the material learned

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