The Effect of Gamification Elements on Engagement and Achievement in Calculus 1 and 2

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Abstract
Gamification is increasingly being used in educational contexts to attempt to increase student engagement and achievement. In this study, gamification elements were added to pilot course offerings of post-secondary Calculus 1 and Calculus 2. The content of these online courses was structured around a narrative of a pirate quest to retrieve sunken treasure. Gamification elements included badges, points, progression/scaffolding/levels, unlockable content, progress bars, immediate feedback, and replay/do-over options. Students responded positively to the gamification elements, particularly the ability to re-do assignments until a mastery level was achieved. Engagement was positively affected. The sample sizes were too small to show statistically significant improvements in achievement. This paper reviews the literature surrounding the use of gamification elements, analyzes the results of these pilot course offerings, and provides suggestions for next steps.

Keywords: Gamification, engagement, calculus

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Introduction

Throughout North America, the dropout/failure rate for first-year post-secondary level calculus is too high, despite the fact many of the enrolled students have excellent grades from their secondary studies and most have already passed a high school level calculus course. The Mathematics Association of America reports the national average of unsuccessful Calculus 1 students to be 25% (Bressoud, Mesa, 2015). It is not reasonable to conclude all these students are underprepared, although unpreparedness may be a factor for some. A more probable cause is the prevalence of the outdated lecture-based mode of instruction, where students have little chance to be active participants in learning the material. In addition, a large amount of content is presented at a fast pace, with few chances for students to check their understanding. No wonder there are many calls to teach this material a different way.

Gamification is an educational trend which is being used to attempt to increase student engagement. By carefully planning and adding elements of game strategy, students may stay interested in the material longer and become active rather than passive learners.

In this study, Calculus 1 and Calculus 2 were offered in an online, self-paced, gamified format. The course material was presented in the over-arching narrative form of two rival pirate groups on a quest to recover sunken emeralds. Students progressed through the material at their own pace with the exception of two set dates: the midterm and the final exams. A mastery level of eighty percent had to be achieved on all tasks in each topic before the student could 'level up' to the next topic. Gamification elements such as badges, completion marks, and progress bars were incorporated to help the students track their progress. As each topic was introduced, the story progressed and puzzles and questions related to the quest had to be solved by the students in order to move on.

This paper examines how students engaged with the material, how they reacted to and engaged with the gamification elements, and compares their grades with other offerings of these same courses in a non-gamified format. In addition, the design principles behind this offering are discussed, as well as recommendations for improvements.

Research Question

Can the incorporation of gamification elements in Calculus 1 and Calculus 2 improve student engagement and, subsequently, improve both student retention or student achievement in first-year calculus?

Review of the Literature

Gamification has been given a working definition of 'the use of game design elements in non-game contexts' (Deterding, et al, 2011) and has increasingly been used in education in the last decade. Children grow up having a positive relationship with games, more specifically with elements of competition, cooperation, and the belief that, with practice, one can get better at playing the game and proceed towards mastery. Video games are explicitly designed for entertainment rather than for utility.

These types of games demonstrably motivate users to remain actively engaged in an activity for long periods of time. Thus, it make sense to use game design elements on non-game activities to attempt to make those activities more engaging and motivating. (Deterding, et al, 2011).

Many children do not have a positive relationship with mathematics, especially in North America. Children are afraid of math, afraid of trying problems, and believe 'math brain' is innate, rather than learned (Baker, 2018). Even high school students who previously enjoyed and were good at math experience a statistically significant drop in confidence, enjoyment, and the desire to continue after experiencing first year calculus in North America (Bressoud, et al, 2015).

Enter the idea of gamification. Game design elements can make non-games more enjoyable, motivating and/or engaging students to pursue rewards, and encouraging students to spend more time doing a specific activity or performing that activity better (Goehle and Wagaman, 2016). While developing an actual computer-based game for learning math would be prohibitive in terms of both money and time, introducing game design elements into a calculus course can easily be done in most learning management systems. That being said, it is important to note simply randomly putting in gamification elements is not an effective plan.

The literature (Stott,A., & Neustaedter, C., 2013) shows the following concepts are consistently more successful than others in learning contexts:

- Freedom to Fail
- Rapid Feedback
- Progression
- Storytelling

If students are encouraged to take risks, to experiment and to repeat tasks until they are better at doing them, the focus is taken away from the final result and instead centered on the process of learning (Stott, A., & Neustaedter, C., 2013). Rapid feedback encourages students, gives them an instant 'reward,' and reduces the chance they will learn something incorrectly. "Feedback is a critical element in learning. The more frequent and targeted the feedback, the more effective the learning." (Kapp, 2012). The idea of progression is not a new pedagogical concept; it is also known as 'scaffolding' and has been in wide use since the 1990's. In a gamified context, it helps the student to restart if she gets stumped on a problem. Storytelling can give a seemingly unrelated set of facts context and can help students see the larger picture. Avatars can give some anonymity in an online setting. This is helpful for those students who lag behind but also for those students who previously did not want to identify themselves as academic leaders (Lee, J & Hammer, J.,2011).

It is important to distinguish between design elements and design principles. Design principles (Dicheva, et al, 2014) include goal setting, customizing the learning environment to allow personalized experience and adaptive difficulty, short feedback cycles, accrual grading, freedom of choice, and multiple routes to success. The 'elements' are simply things you can add to your course. Nah et al (2014) compiled a useful review of the literature on gamification and listed the most common elements. These include points, levels, challenges, badges, leaderboards, peer interaction,

replays, unlockable content, storytelling, and student customization. Many of these elements are standard in current Learning Management Systems, although some are available only as add-ons.

Much of the literature emphasized the principle of 'freedom to fail'. Games involve repeated experimentation so they involve repeated failure (Lee and Hammer, 2011). For many games, the only way to learn is to fail repeatedly, learning something each time (Gee, 2008). From their game playing experiences, students are used to 'failing' as a path to getting better. Student can markedly benefit from multiple attempts at an assignment, whether it is rewriting a paper or redoing a quiz. In principle, the 'reward' for success should be the opportunity to try something harder (Koster, 2004).

Method

In this study, I incorporated a variety of gamification design principles and design elements to see if more students would persevere in their study of calculus, rather than dropping out or simply giving up on the course. I was also interested to see if student attitudes or achievement would be affected.

During the fall of 2016, I prepared for a gamified offering of Calculus 1 to begin in January, 2017. The first step was to present the course in an online format so students could progress through the fourteen general topics of the course as they mastered each level. There were only two set dates in the course: a midterm exam after Topic 7, given at the halfway point in the semester; and a final exam, giving during the regular final examination period in April.

The design principles I incorporated were freedom to fail, rapid feedback, mastery learning for progression, and storytelling. An additional significant goal was to make the course fun. After all, enjoyment is a fundamental principle of playing a game.

I was systematic in my design of the course material and the progression. I separated course materials into 'skills' (algebraic skills, knowledge of trig and other functions, knowledge of geometry, etc.) and 'topics' (limits, derivatives, applications of derivatives, anti-derivatives, theorems, etc.). The skills became 'powers' in the story (for example, algebra knowledge was the ability to swim, geometry and graphing knowledge was the ability not to be sea sick), and the content became weapons, potions, and key pieces of knowledge needed to progress in the story. Badges were awarded for abilities and knowledge. I laid out the content along with the skills. I decided what was necessary for the next level. That helped me design the "restrictions" and the levels. Students were blocked from accessing certain activities or content modules until they had mastered particular skills or gained particular knowledge. For example, a student might have to have the badge for a certain potion to go to the next step. I mapped out the entire course, and made sure I was clear which skills and abilities should link to specific content blocks of the course. I ensured the content covered was the same as the content in a traditional face-to-face course, making sure successful students were prepared to progress to Calculus 2.

The quest story was written by a colleague and was designed to tie everything together. The story was about a ship carrying a chest of precious emeralds, which sunk on a reef. The location of the wreck is not exactly known. There are two

competing bands of pirates trying to find the jewels. The student has been recruited by one of these crews because of his or her problem solving ability. A map was central to the quest. Certain adventures took place at sea, some were on islands. Solving problems would tell the students where they were or, for example, would enable the student to find the jewels they needed to open a temple door. There were monsters, a wizard, as well as the other band of pirates to deal with. Questions had to be correctly solved for the student to know where they were on the map.

There were no fancy special effects and only very limited graphics (the map, badges, and the odd picture of a monster). Students needed to use their imaginations, similar to what players did in early role playing games such as Dungeons and Dragons. Each topic of the course within the learning management system had the same general format, starting with an audio file of me reading a chapter from the quest story. The story stopped at a point where there was a tricky situation where the student (as the hero) had to solve a problem. Next, there were links to content about the calculus material. These were video files of actual math lectures and pdf files of notes on the material.

Last in each topic section were the tasks. All topics contained a lab activity using a computer algebra system (mathematical software otherwise known as a CAS) called Maple, as learning to use a CAS is a learning outcome in the traditional course. I also utilized an educational software company called Lyryx, which pairs open educational resources with online homework assignments. Lyryx has the ability to generate the same type of problem, with different numbers, over and over again. It also gives the student immediate feedback on how the question should have been done. Each topic contained one of these online assignments. Lyryx assignments were gamified in that students could attempt these questions as often as they needed, to reach mastery (80%). Everything else was blocked until they achieved this goal.

Once students achieved 80%, they got a checkmark by that activity (which they loved), perhaps a badge or some points, and then they moved on to the Transition Quiz. The questions in the Transition quizzes were ones I wrote, and I like to think these questions were more difficult and comprehensive than the Lyryx ones. However, these questions were the same each time the student attempted the quiz. The last question of each Transition Quiz related the math topic and the quest story. Once mastery was achieved on that quiz, the level would be ‘complete’ (more checkmarks) and the next topic would unlock.

Students often would advance at the 80% level, but later go back and redo any incorrect questions, in order the raise their grades on these activities to 100%.

Data was collected in three ways. First, there was a questionnaire for the students to fill out to qualitatively measure their attitude towards math and how they approached difficult math problems. Next, there was the learning management system activity reports to quantitatively see how often students were interacting with the course materials. Lastly, there was the collection of the students’ final grades in the course.

Results

The two courses in the study (Calculus 1 in Winter, 2017, and Calculus 2 in Fall 2017) were pilot offerings and the class sizes ($n_1 = 14$ and $n_2 = 5$) were too small to be statistically significant. In addition, the people who do the support work for the learning management system at our College accidently erased all the user data for the Calculus 1 pilot course before I had a chance to download all of it, so the data I had to analyze for Calculus 1 was limited.

Based on their responses to the questionnaire, the students in the 2017 courses came in with a positive attitude towards mathematics and had a fair amount of confidence in their skills and abilities to handle the course material. This agrees with the Mathematical Association of America (MAA) study (Bressoud, Mesa,2015). We can't attribute the high dropout/failure rate in calculus to inadequate preparation at the high school level. The results of the math experiences questionnaire are summarized in the table below:

Question	Agree or Strongly Agree
Math problems can be fun or enjoyable	100%
I clearly see a use for the math I have already learned	82%
I prefer work that is challenging so I can learn new things	100%
Ideas from previous math classes are interesting to me	82%
If I do poorly on an assignment or test, I try to learn from my mistakes	100%
When math problems get difficult, I give up or only study the easy parts	9%
I feel it is important to do at least a little bit of math each day	91%
In the past, when I have enjoyed math, it is because of the instructor	90%
In the past, when I have enjoyed math, it is because of the content	73%
In the past, when I have enjoyed math, it is because of the learning environment	91%
I feel what is being taught in this math course is important	100%
I think I will be able to use what I learn in this course in other parts of my education	100%
I feel prepared to take on new math problems	100%
Compared with other math students, I think I am a good student	82%
I have an uneasy, upset feeling when I take a math test	45%
Compared to other math students, my study skills are excellent	55%
In my past math classes, I often did not understand what was being taught	18%
I try to connect the things I am learning to what I already know	91%
When I study, I put the important ideas in my own words	73%

Engagement with the course was dramatic. Students were accessing the course materials multiple times. The actual content for these courses was presented in two ways: a video of the material (each of these was at least an hour long), which simulated the experience a student would get sitting in a traditional lecture; and pdf files of the notes which would result from each lecture. The table below shows you how often students were accessing these resources:

Interaction with Learning Materials				
	Average Views per Student of Lecture Videos	Average Views per Student of Lecture Notes	Average Times per Student Transition Quiz was Accessed	Average Times per Student Transition Quiz was Submitted for Grading
Calculus 1	1.8	2.9	41.8	Not available
Calculus 2	2.4	1.8	55.7	9.8

In the Calculus 2 course, where I had access to all of the user data, every student watched every video at least once. The maximum any one video was viewed was 9 times. Contrary to what happened in Calculus 1, the notes were not looked at nearly as often. One student never looked at any them.

To me, the most dramatic data was how often students chose to access the Transition quizzes. On average, each and every student accessed those quizzes an average of 41.8 times in Calculus 1 and 55.7 times in Calculus 2. In Calculus 2, each quiz was submitted for grading an average of 9.8 times. No data was available on how often students tried the Lyryx assignments but students reported to me they were accessing those assignments in a similar manner.

The 'mastery learning' requirement appeared to work well. Students were able to move along at their own pace and not feel left behind. Although the course was designed to average completion of one topic per week, most students would complete several topics at a time, then pause, then complete another topic or two. One student (who ultimately was successful) did all 7 topics in the first half of the course in the week immediately before the midterm. Students appeared to appreciate having the flexibility to put calculus aside when other course or life demands were high and then catch up when they were able. This is important, as students who get behind in a traditional calculus course often just drop out.

Completion Rates for Assigned Work in Gamified Calculus Courses			
	Lyryx Assignments	Transition Quizzes	Maple Labs
Calculus 1	93%	88%	80%
Calculus 2	100%	100%	100%

It was disappointing to find the quest story did not seem to be important to the students. Despite the fact there were specific badges and questions relating to the story, only 5 of the 14 students in the first group created avatars, and only 11 of those students listened to most of the story. Strangely, only 6 listened to the final chapter to see what happened. This trend continued with the students in Calculus 2. Two

students listened to each chapter while the other 3 listened occasionally, and one student gave up completely after the midterm exam.

Quest Story Completion Rates														
	Avatar	Chp 1	Chp 2	Chp 3	Chp 4	Chp 5	Chp 6	Chp 7	Chp 8	Chp 9	Chp 10	Chp 11	Chp 12	Chp 13	Chap 14
Calculus 1	36%	21%	93%	86%	86%	79%	86%	71%	86%	86%	79%	79%	79%	64%	43%
Calculus 2	NA	100%	100%	100%	100%	80%	80%	80%	56%	60%	80%	20%	60%	NA	NA

Regarding achievement, as the charts below show, the overall results were not much different than with the traditional calculus course with one possible exception – it may have 'moved the bottom up'. The percentage of failures, withdrawals, and audits is lower in the gamified courses, and the percentage of C- s is higher. In Calculus 2, the lowest grade in the gamified course was a C. This fits with other research findings of gamification possibly being of more benefit to 'at risk' learners.

Grades in Calculus 1													
	A+	A	A-	B+	B	B-	C+	C	C-	D	F	AUD	W
Gamified	7%	7%	7%	20%	0%	7%	0%	0%	20%	13%	13%	0%	7%
Cumulative 2012 - 2017	7%	5%	12%	4%	6%	8%	5%	6%	6%	7%	18%	5%	14%
Grades in Calculus 2													
	A+	A	A-	B+	B	B-	C+	C	C-	D	F	AUD	W
Gamified	0%	0%	40%	20%	20%	0%	0%	20%	0%	0%	0%	0%	0%
Cumulative 2013-2018	3%	7%	6%	3%	6%	6%	5%	5%	3%	2%	8%	6%	6%

Discussion

Although this study did not yield statistically significant results, the data collected does agree with the findings of other studies – the addition of certain game elements can lead to increased engagement and may positively affect at-risk learners' achievement. Students took full advantage of the freedom to fail and the immediate feedback aspects as shown by the hundreds of times they accessed the assignments. As a teacher, I appreciated the progression aspect as I felt students had a deeper understanding of a topic's material before they moved to the next topic.

The storytelling did not work as I hoped but, upon reflection, it should have been structured better. The connection of the story and the course material was too superficial. In future offerings, I will create real choices for the students which will actually affect the outcome of the story.

I was surprised by how much students enjoyed the completion boxes and progress bars. These seemed to be more motivating for students than the quest story, a fact I will take advantage of in future course offerings.

Limitations

The sample sizes of the classes studied were small. These sections of Calculus 1 and Calculus 2 were offered in the 'off' semesters (Calculus 1 is usually offered in the fall, followed by Calculus 2 in the winter but, in this case, Calculus 1 was offered in the winter followed by Calculus 2 the following fall), so many of the students had already failed Calculus 1 previously. Additionally, calculus courses at our College have always been offered in a face-to-face format prior to this, so delivery in an online format may have had an effect on students' learning. The most unfortunate limitation was the accidental erasure by the IT Department of the actual usage data for the Calculus 1 course, leaving me with only the completion data, survey results, grades, and data I had recorded outside of the learning management system for that iteration.

Conclusion

Gamification is a useful tool for educators, one that is increasingly easy to incorporate. Learning management systems have created gamification plugins and blocks, so if you use a learning management system, the technical challenges have already been addressed. That being said, to be effective, educators need to carefully plan which gamification elements to add.

Gamification has the potential to add real flexibility and choice for learners. The desire to achieve check marks, badges, points, and unlock activities can help motivate students to complete more assignments and learning activities.

In British Columbia, Canada, the K to 12 Curriculum has recently been modernized with the goal of providing students with a rigorous education that is also flexible and innovative. We will see the first graduates of this new approach in the fall of 2020 and those students will be used to having choice in what they learn and how they demonstrate their learning. Gamification tools can help us bridge the gap between traditional teaching methods at post-secondary and the modern learning expectations the contemporary students have. As an added bonus, it might even be fun.

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