Impact of Narrative, Character Creation, and Game Mechanics on Student Engagement in a Game-Based Chemical Engineering Laboratory Course

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1. Introduction

As modern students have come of age in a time where video games, whether mobile, console, or social, have become ubiquitous, game-based learning (GBL) is gaining increased attention as a tool used in education[1-5]. In GBL, games are used as environments and contexts where students can learn via trial-and-error with no permanent consequences[6-8]. Note that GBL is not merely free-form activity, but one with rules that guide and dictate the experience, as well as offering a condition in which the game can be "won"[9,10].

One method of GBL that has come to the forefront recently is gamification, or the application of game elements to a non-game context[11]. The idea behind gamification suggests that if activities can be made to feel more game-like, participants will feel more engaged by them and will be more likely to participate[11,12]. The game elements also give participants additional ways to engage with a certain activity, either through the aesthetic of the game elements or through new problems to solve. Many of the common elements of games that gamified scenarios use in various capacities are shown in Figure 1. The specific game elements used in any given context can vary by application, as gamification is a tool that can be applied to multiple contexts; however, there is no one universal method for effective gamification[13].
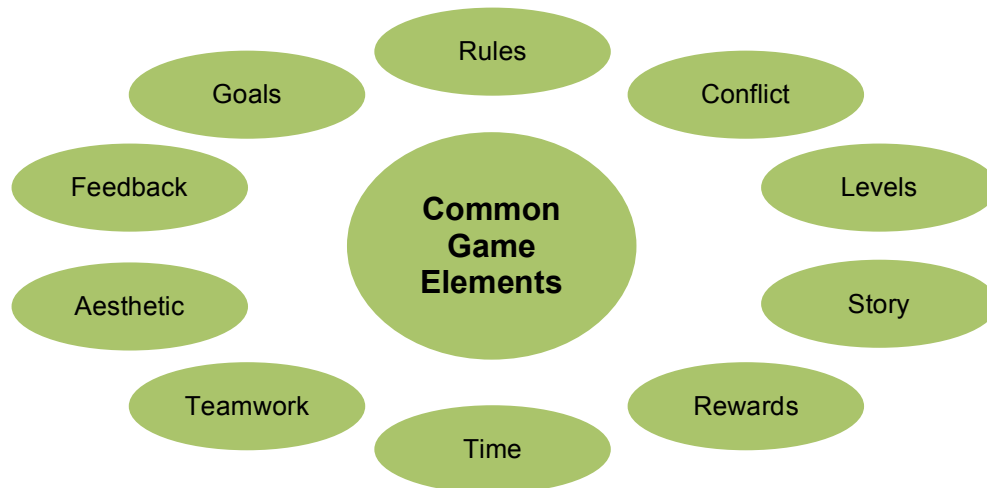

Figure 1. Common game elements used in gamified contexts[13]

While gamification of engineering courses has been garnering interest lately, the majority of gamified courses documented in open literature focus predominantly on badge, point, and leaderboard (BPL) gamification[3, 14-16]. In BPL gamification, students are rewarded for their actions by earning points, special badges to commemorate achievements, and progression up a leaderboard[13]. These implementations predominantly focus on rules (i.e. how to earn points), feedback (i.e. how many points you earned), and goals (i.e. you need to earn this many points). While these rewards can effectively motivate student action by providing a reward and an

incentive, they do not completely capitalize on all gamification can offer a classroom, such as narrative, conflict, and the game aesthetic[13]. The game elements used in BPL gamification can be made more meaningful to the game itself, which will provide a deeper engagement than the use of a points system alone[17]. Rather than simply awarding badges, the badges could grant students some special ability during the game. Rather than awarding points that help students win the game, the points could serve a function in the game itself before a winner is declared at the end of the semester. Furthermore, there is little to keep the student invested in the game over the course of the semester when just BPL methods are used. The novelty of game-based systems may wear off more quickly if these limited elements are used. This trend was observed previously by the authors when implementing a BPL game implementation in the capstone laboratory course at the University of Connecticut in Storrs[15], as students showed high interest in the game initially, but began to participate less in game activities as the semester progressed.

The intent of this study was to develop a more meaningful game-based system that would motivate students to participate more actively in the capstone chemical engineering laboratory course and improve their attitude toward the course for the full duration of the course. Students could participate in optional tasks in hopes of earning additional grade points at the end of the semester. This system would build off a previously implemented BPL system introduced to the laboratory curriculum with some success in the 2012-2013 academic year by introducing a game mechanic. This mechanic forced the students to defend their point totals from a game-specific force, designed to promote student participation throughout the semester, rather than primarily in the beginning when the concept is at its most novel. Further offerings of the game were enhanced through narrative elements and by allowing students to create their own in-game avatars. The system was designed to be no cost to implement and highly adaptable based on the needs of the individual instructor. Student attitudes toward the course and game elements, as well as student participation trends and some preliminary trends relating game participation to student grades, will be presented.

2. Course Structure

The capstone laboratory course at the University of Connecticut is a one-semester (3 credit) course taken in the fall or spring of the senior year. This course follows a one-credit fluid mechanics laboratory in the fall of the junior year and a two-credit transport and kinetics laboratory in the spring of the junior year. The capstone course meets for two, four-hour laboratory periods a week, and students complete three experiments (one that lasts two periods, one that lasts four, and one that lasts six). Each experiment has a different style of report; the first experiment is an individually written, 15-page laboratory report, the second experiment is a group oral presentation, and the final experiment is a group poster presentation. As the capstone laboratory fulfills a university writing requirement, students must submit a draft of their written report and have it reviewed by an instructor before turning in a final report.

In general, the course that used the systems described in the next section was graded out of a possible 3300-3500 grade points, in which 2700 were from the three reports, 300 were from student pre-laboratory reports, and 300 were from peer assessments. A few other assignments, such as graded presentation abstracts and a written report draft completeness score, were added to later offerings of the course.

The game structure originally implemented in this course was a straightforward use of BPL gamification. Students were split into three teams and were given optional tasks to complete. These tasks were designed to encourage students to collect higher quality experimental data and improve their laboratory reports, and the tasks were not activities that were traditionally graded. Completion of individual tasks awarded student teams with team points, which were independent from grade points. This structure is illustrated in Figure 2. At the end of the semester, the team with the highest team point total earned a reward, which was most likely a small boost to grade points.
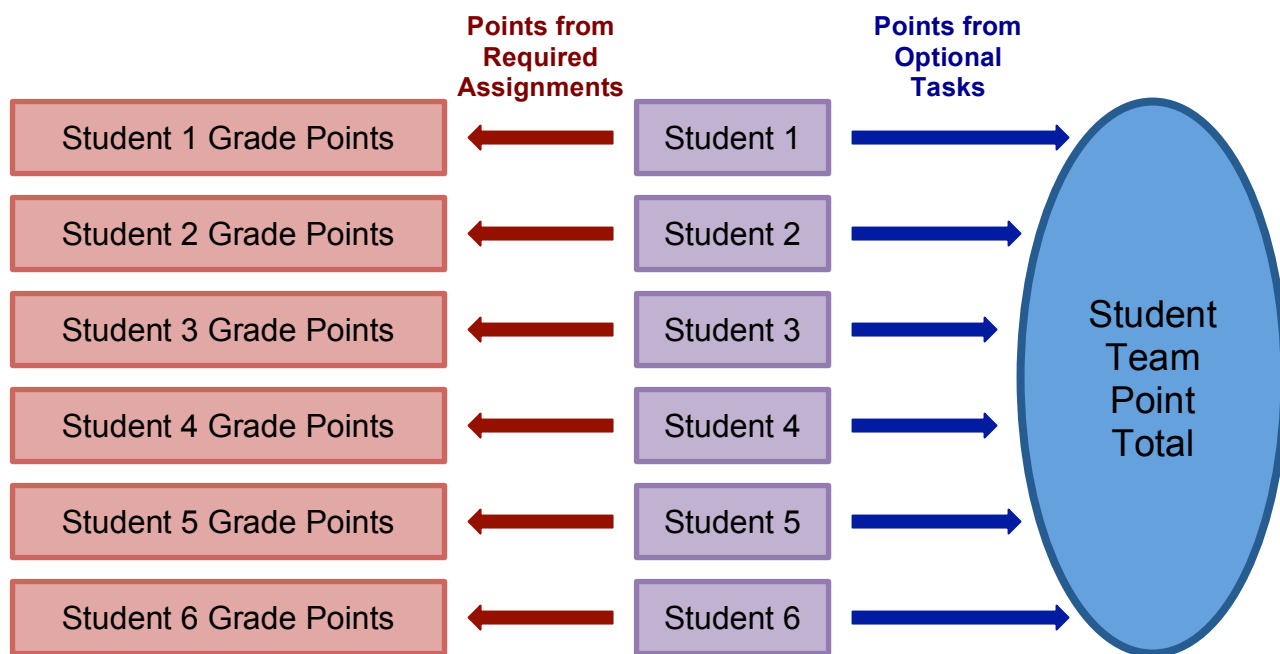

Figure 2. Diagram of previously implemented gamified course structure, where students completed required course material for grade points and optional course material for team points.

3. New Game Methodology

3.1 Game Mechanic

In an attempt to move beyond BPL gamification toward more meaningful gamification, the mechanics of the game were expanded. Rather than simply competing to maximize their team point totals, students collected three different kinds of team points (common points, uncommon points, and rare points), which were earned based on the relative ease or complexity of the tasks. During each experiment period, students collected common, uncommon, and rare points for their respective teams. After each experiment, the defense phase occurs. Student teams have their point totals reduced until a previously announced amount has been deducted. Teams first lose common points. If more points are needed, they are taken from the team's uncommon point total. If still more points are needed once uncommon points are depleted, student teams will lose rare points. After the defense phase, another collection phase occurs where students are

encouraged to continue collecting common, uncommon and rare points. This cycle continues until the end of the semester, shown in Figure 3.   At the end of the semester, the amount of rare points the student team has maintained will correlate to a bonus amount of grade points added to the grade point totals of each student on the team.
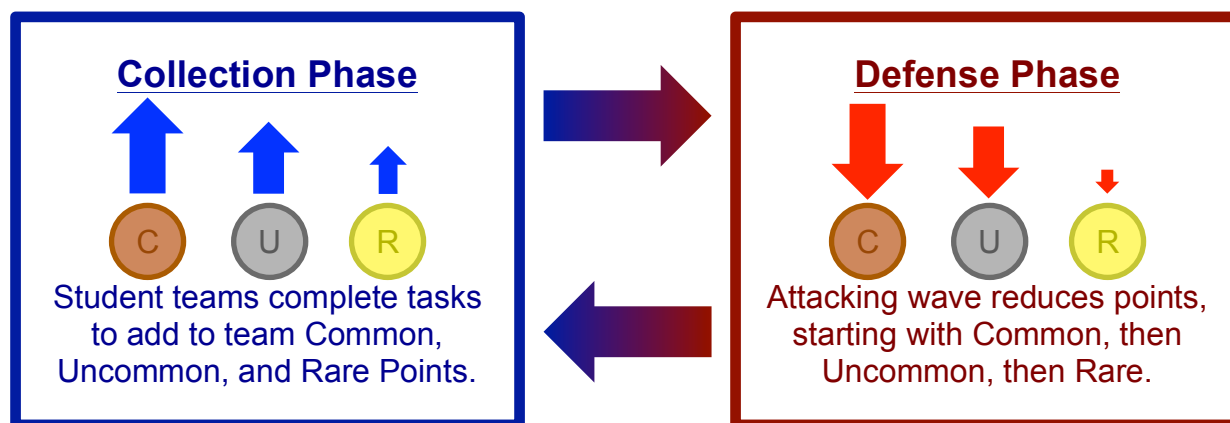

Figure 3. Diagram explaining the phases of the game. When implemented into the capstone laboratory course, the cycles repeat three times.

3.1.1 Collection Phase

The collection phase occurs while students are performing an experiment. Students are able to complete optional tasks that are designed to encourage them to improve their experimental data and analysis (relating to ABET objective B) and to promote their exploration of the broader impacts of the experiments they are performing (relating to ABET objectives H and I). Completing these tasks would increase a students' team's total of common, uncommon, and/or rare points, depending on the specific task completed. These points allow students to be rewarded for performing these extra tasks, but the rewards are not grade points, which does not diminish the importance of required coursework. A summary of these tasks and the points awarded is shown in Table 1. Note that some tasks award two types of points. This design choice was made thinking that it would discourage students from focusing on a handful of tasks, as there were multiple ways to earn rare points.

Table 1. Description of tasks and points that are awarded

Description of Task	Common Points Earned	Uncommon Points Earned	Rare Points Earned
Properly shut down equipment without help prior to experimental check-out	20	0	0
Began experiment data analysis between laboratory periods while experiment was still being done	10	2	0
Discussed data analysis with an instructor after experiment was completed	0	4	0
Cite a textbook not referenced in the experiment documentation in your laboratory report/presentation	10	0	10
Cite a peer-reviewed journal article not referenced in the experiment documentation in your final laboratory report/presentation	0	0	20
Score a 9 out of 10 or higher on the Broader Impacts section of your report	0	2	10

When selecting tasks to incentivize for a class, it is important that the tasks are not related to skills or performance in the class. For instance, there should not be a task that awards common, uncommon, or rare points for getting an A on a laboratory report or for making no mistakes in their experimental analysis. The tasks above were chosen because they are attainable by any member of the class, regardless of skill level, to attract the attention of the middle and lower ends of the class. While it may appear that the final task breaks this rule, students earn a 9 on Broader Impacts by listing multiple impacts beyond the most obvious one (i.e. the ones listed in the experiment documentation), making this a task that anyone can complete provided they have done the research.

The content of the tasks can vary based on the needs or desires of an instructor. Other possible tasks instructors may consider for classes include attendance at office hours or review sessions, collecting more data than is required for a certain experiment, or for handing in assignments before a deadline.

3.1.2 Defense Phase

After each experiment, and also generally after each lab report was graded, the collection phase would end and the defense phase of the game would begin. This phase was inspired by the mechanics of popular tower defense type video games, such as Plants vs. Zombies, Clash of Clans, and Desktop Tower Defense. In these kinds of games, the player is attacked by waves of enemies. The players of these games must erect obstacles to dispatch the attacking waves to protect their home base. In the game-based course structure proposed here, the obstacles are analogous to a team's common and uncommon point totals. The player's home base is analogous to a team's rare point total. Students are told at the beginning of the semester that rare points will correlate to a boost in their final grade, and they must use common and uncommon points to protect these points until the end of the semester. The idea behind this change is that it has the potential to motivate students both extrinsically and intrinsically[18]. Students are

motivated extrinsically by the game's systems; they want to collect points and defend the points they already have because it will result in a higher grade. However, the system can potentially motivate students intrinsically, as the system itself is designed to be more fun, engaging, and variable than the previous model of simply collecting points.

In each defense phase, student teams are "attacked" by a wave of enemies seeking to diminish their rare points. In essence, the attacking waves represent how many points are being deducted from students' point totals, starting with common points, then uncommon points, then finally rare points. If students can pay for the point deduction (or "dispatch all the enemies," in game parlance) using just common or uncommon points, then they will not lose any rare points. The defense phase ends and another collection phase begins, in which students will attempt to regain common, uncommon, and rare points to withstand the next defense phase.

In order to help students understand the defense phase and how certain points relate to one another, they are given a series of equations that show how many attackers they can ward off with their common and uncommon points, as well as how many rare points they lose if any of the attackers are able to reach that point total. These equations are shown in table 2. It is important to note that the three equations are slightly different from one another. For instance, common points may be easier to attain during the collection phase, but uncommon points can dispatch more attackers per point.

Table 2. Equations that dictate points lost during Defense Phase

Defense Phase Section	Governing Equation	Variable Definitions
Part 1: Common Point Losses	$A_1 = A_0 - 0.1[\eta_C(C_i - C_f)]$	A_1 = Attacking force size after Part 1 A_0 = Initial attacking force η_C = Common point efficiency C_i = Initial common point total C_f = Final common point total
Part 2: Uncommon Point Losses	$A_2 = A_1 - \eta_U(U_i - U_f)$	A_2 = Attacking force size after Part 2 A_1 = Attacking force size after Part 1 η_U = Uncommon point efficiency U_i = Initial uncommon point total U_f = Final uncommon point total
Part 3: Rare Point Losses	$R_f = R_i - A_2(11 - K_R)$	R_f = Final rare point total R_i = Initial rare point total A_2 = Attacking force size after Part 2 K_R = Rare point durability (or rare point "efficiency")

Each of these point efficiencies begins the game at a value of 1. Students are able to manipulate the efficiencies of their team's common, uncommon, and rare points throughout the semester as they earn grade points, which encourages them to work together as a team to develop a strategy to minimize point losses and allows them to practice critical thinking, collaboration, and communication. As each student reaches certain milestones in grade points, they earn a special ability that can increase one of the three point efficiencies. Early in the class, these abilities may boost an efficiency by 0.5, but later abilities may boost an efficiency by 2. Students selected

these abilities via online surveys. To promote diversity in strategy, and to prevent unbalancing the defense phase, each efficiency can reach a maximum of 10. Not only do these abilities allow students to influence the game, but it gives them a sense of ownership and a feeling of progress. Instructors should consider how many grade points an average student has accumulated by the beginning of each defense phase to determine when to award new abilities. If an instructor does not wish to keep track of individual student abilities, he or she can give each team a certain amount of points to distribute in whatever efficiency they wish prior to a defense phase. In either case, the game itself presents a new optimization problem to students, whether they realize it or not. Student teams must develop and execute a strategy to optimize the amount of points they maintain throughout the semester, promoting communication, collaboration, and critical thinking.

Each attacking wave should be larger than the previous one in order to increase challenge and encourage students to continue completing tasks. Again, it is important to consider how many points students should have earned before each defense phase and balance the size of the attacking wave appropriately. Generally, it can be assumed that 2/3 of the tasks will be completed by students for balancing purposes, although the exact number may vary. Using the point values and equations shown in Tables 1 and 2, the capstone laboratory course has the first attacking wave be twenty times the size of a student team, the second attacking wave is fifty times the size of a student team, and the final attacking save is one hundred times the size of a student team. In order to make the game more or less difficult, depending on student participation, narrative elements can be used, as discussed in section 3.2. Students are notified of the size of each attacking wave at the beginning of the semester so that teams may plan accordingly.

While this system was designed around a laboratory class with distinct breaking points between experiments, it is possible to adapt the system into other classroom settings as well. In a more lecture-based course, attacking waves may occur following a quiz or an exam, for example.

3.1.3 Endgame, Student Rewards, and Grading

After three rounds of collection and defense phases (as the laboratory class has three experiments and laboratory reports), the game ends. Students on a given team earn a certain amount of grade points based on the amount of rare points they were able to keep until the end of the semester. The assignment of grade points can be done directly, meaning the number of rare points can be divided up evenly among team members and converted into grade points. For example, if a student team has 8 students, and that team has 800 rare points at the end of the semester, each student will receive 100 grade points (the equivalent of one extra peer assessment or pre-laboratory report). Later uses of this structure used an alternative reward structure with tiers to dictate how many grade points students earn. This change to the system helps create a greater distinction between rare points and actual grade points, so the link between the two points appears less as a direct one-to-one conversion, while allowing instructors to set a maximum amount of points that could be possibly earned from the game elements. A sample of a tiered structure is shown in Table 3. Using this method, students now have to reach a set milestone to achieve more points, rather than assume that they would earn one more grade point if a teammate had done one more extra task. Using the numbers shown in Table 4, students will earn 100 extra

grade points whether they have earned 800 rare points or 900 rare points. As such, student teams are now encouraged to try new strategies as a group; losing a few rare points will not result in a loss of grade points, provided that the team did not lose enough points to shift them into a lower tier.

Table 3. Sample rare point to grade point conversion table for a 3400 grade point class where each student team has 8 members

Final Team Rare Point Total	Grade Points Awarded Per Student on Team
0 – 79	0
80 – 199	10
200 – 399	25
400 – 599	50
600 – 799	75
800 – 999	100
Greater than 1000	125

When implementing a game such as this, it is important to balance the amount of rare points earned as to not overwhelm the core course content. The instructor should calculate how many common, uncommon, and rare points a team of students could earn if they completed all tasks. These values should be checked at each of the major milestones, such as before an attacking wave and at the end of the semester. Doing this calculation can assist with determining the size of an attacking wave as well determining how many grade points students can earn. Using a tiered reward structure can help dictate the overall impact of game participation on a student's grade, as it allows the instructor to put a cap on the maximum possible points students can earn from the game. For instance, if an instructor only wants students to earn a maximum of 50 grade points from this system, the highest tier can be made 50 grade points regardless of the total number of possible rare points, and the rest of the tiers can be scaled down appropriately.

When using this system, it is important to also be cognizant of students who choose not to participate in the game and those who elect to participate to a small degree. This consideration is essential as the game, by definition, cannot be compulsory, as compulsory tasks can diminish the game aesthetic[19]. To avoid inadvertently lowering the grades of non-participants, grades should first be determined based on the required course materials (i.e. without factoring in any grade points earned from the game elements). Once this grade distribution is determined and the point differentiations between grades is set, the extra game points are added in to determine if that raises the grades of any of the students. Using this method assures that each student will earn at least the grade they deserve based on their coursework, which prevents students who choose not to participate in the game from receiving a lower grade due to others participating highly.

3.2 Game Theme & Narrative

Narrative elements are a key aspect of many popular games. Narrative often promotes an atmosphere of immersion and improves engagement in these games as students begin to interact with and influence the story[13,17]. It should be noted, however, that the narrative elements can function independently of the game mechanics described in section 3.1, and it is up to the instructor to decide what, if any, game elements should be used.

The system described in section 3.1 is designed to allow any desired theme to be easily applied over it, and anyone attempting to employ such a system is encouraged to use a theme that is interesting to them and their students. The theme will dictate what you call certain elements of the game (i.e. common, uncommon, and rare points, abilities, etc.). Some examples of themes are shown below in table 4. It is highly suggested that the theme for this narrative be a topic that is voted on by the students, as it will ensure that they will be interested in the topic selected. However, instructors should provide options they feel comfortable implementing.

Table 4. Sample game themes and thematic names for common game elements (starred themes have been successfully implemented by the authors)

Theme	Attacking Waves are called:	Student Abilities are called:	Common Points are called:	Uncommon Points are called:	Rare Points are called:
Zombie Survival*	Zombies	Equipment	Ammo	Traps	Supplies
Super Heroes*	Villains	Powers	Energy	Stamina	Approval Rating
Fantasy	Fantasy Creatures	Special Skills	Stamina	Magic	Gold
Business	Quarterly Losses	Company Benefits	Discretionary Funds	Reserve Funds	Company Net Worth

While a narrative may help students feel more invested in the game, the narrative does not need to be inherently complex or particularly profound. In order to add narrative elements to this system, a handful of non-player characters (NPCs) were created. Some of these NPCs served as allies to students, giving them additional tasks to earn more points, advance the story, and allowing them to overcome antagonistic NPCs. For instance, when a super hero theme was used, each of the three attacking waves was lead by an NPC super villain. Ally NPCs gave students "secret missions", such as finding a video related to their experiment on YouTube and writing a 1-page essay on how it relates and what they learned, allowing them to look for broader impacts while giving them a chance to practice writing. If half of the students in the class completed the secret mission, the villain NPC would be defeated and the size of his or her attacking wave would be reduced, meaning students would lose less points during the defense phase. These NPC "secret missions" also added spontaneity and uncertainty to the game, which may help motivate students to further participate in the course[20]. Finally, these extra missions presented yet another way that students could engage in and explore the potential broader impacts of their experiments.

A narrative also allows instructors an easy way to adjust the difficulty of the game in real time. For example, say students are participating in tasks at a higher rate than expected, and the size of the final attacking wave is too small. The narrative could then be used to justify increasing the size of the final attacking wave by saying the wave received reinforcements or an NPC has appeared to increase the size of the wave. This justification was successfully used several times during the implementations of the game discussed in later sections; students viewed the changing numbers as simply part of the game.

3.3 Character Creation & Progression Tracking

A final aspect of many popular games is an aspect of avatar or character creation and customization. These character creation elements can range from selecting specific skills of your player character to controlling their in-game name and appearance. These elements have become popular in social games, role-playing games such as Mass Effect and Dragon Age, simulation games such as The Sims and Minecraft, and Nintendo's Mii avatars. These aspects are popular in games as they better allow the player to identify himself or herself with the game, which potentially leads to deeper engagement[21]. Moreover, studies have shown that watching an avatar that resembles oneself changing in some way can positively impact one's future decisions and actions[13].

Character customization elements were added to the most recent implementation of this game structure (Fall 2014). As the theme for this game was super heroes, students were instructed to create a name for their heroic identity that would be known only to them. This name was used on the class leaderboard and all public class notifications. Using a selected alternate name allowed for the broadcast of student achievements and selected abilities without violating their confidentiality. While this implementation did not use a visual representation of avatars, it was hoped that students would feel motivated to do well on assignments and participate in tasks in order to unlock new abilities and powers for their hero persona.

Students are also given a personalized PDF that are updated weekly by the instructor. The sheet details their chosen in-game name, the abilities they have selected (referenced in section 3.1.2), their grades on required assignments, and what optional tasks they have personally completed. Furthermore, these PDFs have a list optional challenges that students can complete for minor grade point boosts (usually around 5 grade points per challenge, where there are usually between 10 and 15 challenges per semester). Some of these challenges reward students for meeting individual goals (such as performing a certain number of tasks) or for meeting goals as a team or as a class. Points earned from the challenges are considered extra credit, and they do not factor into the initial phase of grading discussed in section 3.1.3.

4. Assessment

This study's primary assessment methods were attitude-based and participation-based. Student attitudes were gauged by pre- and post-semester surveys administered through Survey Monkey. These surveys asked students about their interest in the various game elements. The post-semester survey also asked students to rate their attitudes toward several statements about how the game impacted their attitudes toward laboratory course as a whole on the Likert scale. Students were also asked to evaluate how much they felt they participated in the game and whether or not a system such as this one should continue in future semesters. Both surveys had an optional field for the general comments of students.

Participation in the game elements was assessed by quantifying how many tasks individual students completed. Evaluating how many tasks were completed during each collection phase is a strong indicator for student interest in the game as the semester progressed. Additionally,

student performance was related to student grades for the individually prepared written report. This report was chosen as the primary indicator of student performance since it is the only grade students do not prepare in a group.

Student attitude and participation data was collected during the Fall 2012, Spring 2013, Fall 2013, Spring 2014, Fall 2014, and Spring 2015 semesters. Detailed attitude and participation data was not collected prior to Fall 2012. The same group of students took the class in Fall 2012 and Spring 2013, as the capstone laboratory class was two semesters at the time, and the junior laboratory courses had not yet been introduced to the curriculum. For the cohort of students who took the capstone laboratory course in Fall 2014 and Spring 2015, the grades for the students' written laboratory reports were compared to the same students' average written report grades for the junior-level transport and kinetics laboratory course, which had no game-based elements, taken in Spring 2014. While the junior laboratory reports were not the same length or graded using the same rubrics as the capstone laboratory, they were graded for similar criteria (application of theory, quality graphical elements, appropriateness of conclusions, etc.). Moreover, the junior laboratory reports were graded by the same instructor who graded the majority of capstone laboratory reports. This instructor was not responsible for management of the game elements in the capstone laboratory course. A comparison of the grades will examine what impact, if any, the optional tasks have on student improvement between the junior and senior year.

5. Summary of Student Experiences and Discussion

5.1 Student Attitudes Toward the Game & Class

In order to assess student attitudes toward the game elements of the course, students were asked to express their opinion on post-semester surveys on the Likert scale, where a 1 indicated "Did not like at all," 2 indicated "Somewhat disliked," 3 indicated "Ambivalent," 4 indicated "Somewhat Liked," and 5 indicated "Liked a lot." The average student response on the Likert scale is shown as Figure 4. Cohort A, which consisted of the same 51 students both Fall 2012 and Spring 2013, used the simplified BPL gamification method. The tower defense game mechanic was used for Cohort B, which was comprised of 27 students in Fall 2013 and a different set of 22 students in Spring 2014. The additional narrative and character creation elements were added for Cohort C, where 22 students took the laboratory course in the Fall 2014 semester.
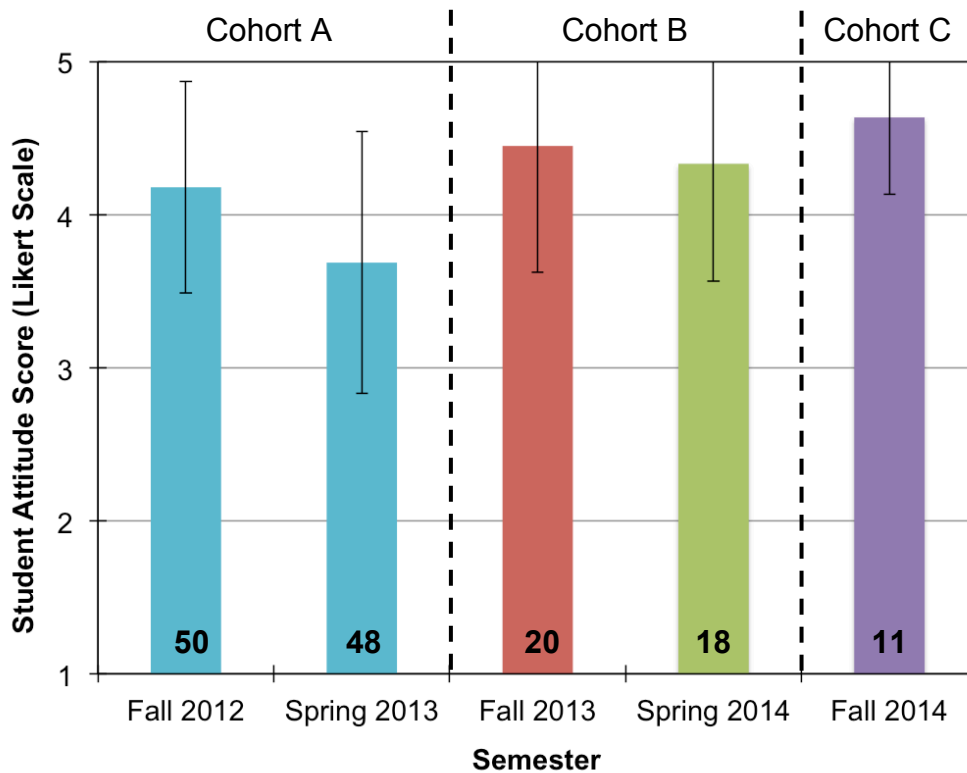
Figure 4. Average student opinion of overall gamified course per semester, based on Likert scale where 1 was "did not like at all," 3 was "ambivalent," and 5 was "liked a lot." Fall 2012 and Spring 2013 were the same group of students. The numbers in each bar represent the number of students who completed post-semester surveys. Error bars represent standard deviation.

Figure 4 indicates that the inclusion of the game mechanic (prior to Fall 2013) and increased emphasis on narrative and character creation (prior to Fall 2014) yield slight improvement in student attitudes toward the game elements of the course. The graph also illustrates the dangers of overusing game elements in classrooms. Cohort A participated in the game-based laboratory structure for two consecutive semesters (Fall 2012 and Spring 2013). These students felt more neutral to the game elements in the later semester. In post-semester surveys, students expressed that other obligations and classes of the spring semester impeded their ability to participate in the laboratory game. However, it is more likely that the novelty of the game had worn off for these students, as the attitudes of the Spring 2014 students more closely mirrored those of their Fall 2013 counterparts.

Starting in Fall 2013, students were also given post-semester survey questions asking them to consider how the inclusion of the game elements impacted their attitudes toward the laboratory class. The student responses from Fall 2013 through Fall 2014 to two of these questions are summarized in Figure 5 ("The game elements made me think about the laboratory more than I would have otherwise") and Figure 6 ("The inclusion of game elements made me feel like the instructors cared about teaching this course").
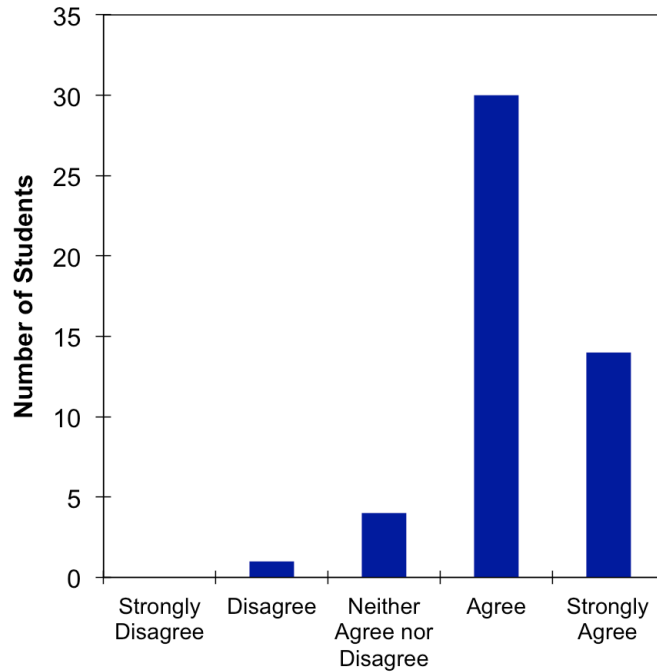
Figure 5. Student responses to "The game elements made me think about the laboratory course more than I would have otherwise" on post-semester survey (Likert scale), combined responses from Fall 2013, Spring 2014, and Fall 2014 semesters (n = 49).
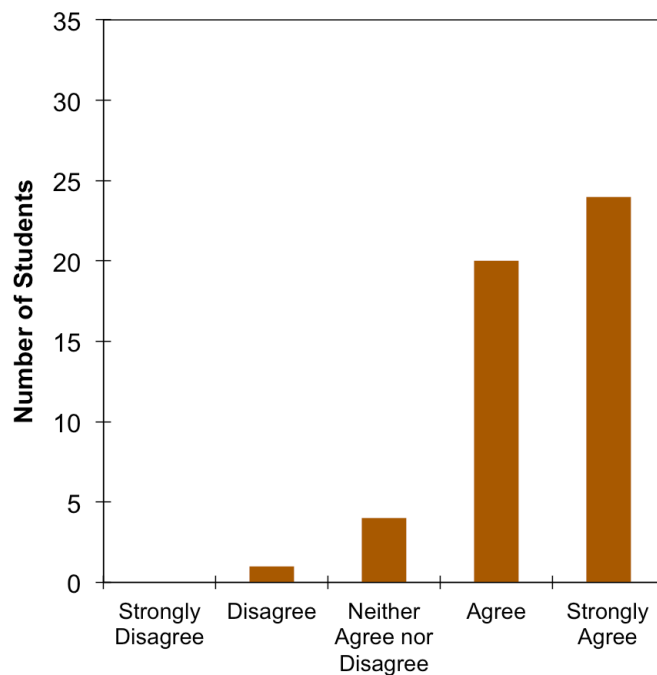

Figure 6. Student responses to "The inclusion of game elements made me feel like the instructors cared about teaching this course" on post-semester survey (Likert scale), combined responses from Fall 2013, Spring 2014, and Fall 2014 semesters (n = 49).

These student responses indicate that the game improves student engagement in the laboratory course, as the majority of students agree that they thought about the laboratory course more because of the game elements. Forty-four of the forty-nine students polled also agree to some extent that the presence of game elements made them feel like the instructors cared about teaching the course, with over half of those students strongly agreeing with the statement. These attitudes are especially encouraging since it demonstrates that students are more invested in the class and have more positive feelings associated with it. In the long-term, these attitudes may improve student knowledge retention, since the class is now more memorable to the students and they may have an easier time recalling information from it. However, currently a long-term study of the impact of this gamified system on student retention has yet to be completed.

In general, student anecdotal feedback is highly positive. Students who experienced the game with the defense mechanic and narrative focus commented that they enjoyed the game mechanic and the narrative element, saying that they "took the edge off" the laboratory course while not being distracting to their understanding of the course material. Some students admitted they did not understand all of the systems of the game, but they understood that performing optional tasks would be beneficial to their grade in the long run. Some students did not like that the game was team-based, as they felt that some of their teammates who did not contribute would be negatively impacting the amount of points students who were participating highly would earn. This feedback prompted the inclusion of the tiered grade point reward system discussed in section 3.1.3.

5.2 Student Participation in Optional Tasks

Student completion of optional tasks, summarized in Table 1, was tracked across each semester the game was run. Figure 7 shows class task completion for the Fall 2012, Fall 2013, and Fall 2014 semesters. Fall semesters were compared as to eliminate any biases that may occur in the spring semester of a student's senior year. As the amount of tasks varied between the semesters, task completion is presented as a percentage of possible tasks completed by the entire class. In the Fall 2012 semester (n = 51), the first experiment had six possible tasks (the first five tasks in Table 1 as well as a task to incentivize students to visit the university writing center) and the other experiments had five tasks each. For both the Fall 2013 semester (n = 26) and the Fall 2014 semester (n = 22), each experiment had eight possible tasks, including the six tasks listed in Table 1 and two bonus tasks that varied throughout the semester. Students typically only had a limited time (about two weeks) to complete the bonus tasks, which ranged from writing a summary of a news article that related to their experiment to proposing a new experiment that could be performed using the same experimental equipment.
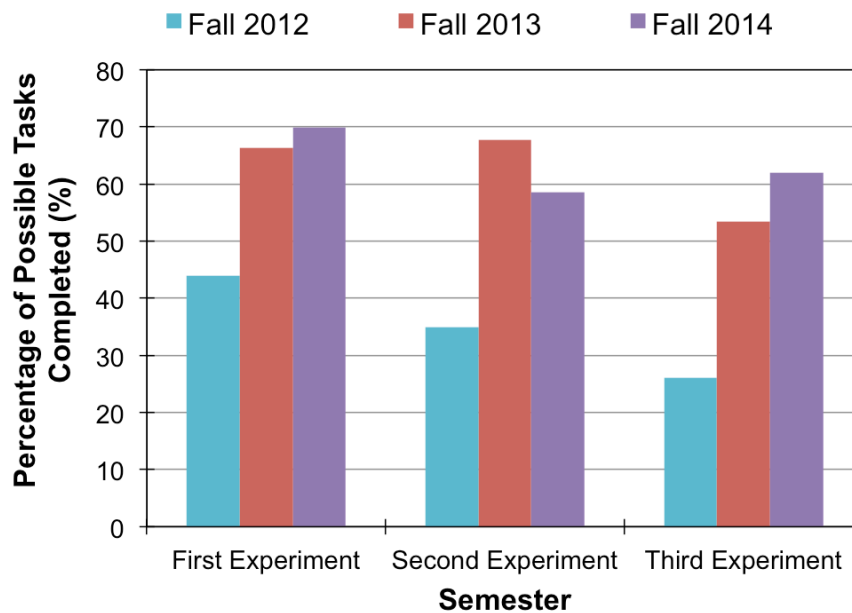
Figure 7. Completion percentage of optional tasks as the semester progressed in Fall 2012, Fall 2013, and Fall 2014. The defense mechanic was introduced in Fall 2013, and narrative and character creation elements were introduced in Fall 2014.

Students in Fall 2013 and Fall 2014, who experienced the gamified course with the defense mechanic, showed much higher task completion percentages the students in Fall 2012, who used the BPL gamification method. The lowest task completion percent for a given experiment for Fall 2013 and Fall 2014 (seen during the third experiment in Fall 2013) was still 10 percentage points higher than the highest completion percentage of Fall 2012. This suggests that the game structure highly motivated students to complete more tasks.

Furthermore, Fall 2012 students showed a steady decline in task completion as the semester progressed. While student participation may have fluctuated from experiment-to-experiment in Fall 2013 and Fall 2014, the steady decline seen in Fall 2012 is not present. In this respect, the defense-based game mechanic can be viewed as a success; students were motivated to continue to complete optional tasks throughout the semester, rather than predominantly in the beginning of the semester.

5.3 Impact on Student Grades

Evaluation of student learning in the presence of these systems has been somewhat difficult, as the laboratory courses had been restructured during this study. As a result, students did not share all graders between cohorts, and the presence of the junior-level laboratory course meant some cohorts had more experience in the laboratory and with technical writing. However, to assess how the game elements impacted the quality of student laboratory reports between the junior and senior years, the written report grades for the Fall 2014 capstone laboratory students were compared to the same students' grades on their written reports in the Spring 2014 junior laboratory. Spring 2014 was the first semester where the students had to write laboratory reports

as part of the junior laboratory curriculum (previously, students had completed short worksheets); thus, this cohort was the first where such a comparison could be made.

To further elucidate a connection between student improvement and the game elements, the students were grouped by the number of tasks they had completed by the time they had turned in their written capstone laboratory report (up to 8 maximum). The written report grades of students in each task group were averaged for both the junior year and the senior year. The average junior lab written report and senior lab written report grades for the students in each group are shown in Figure 8.
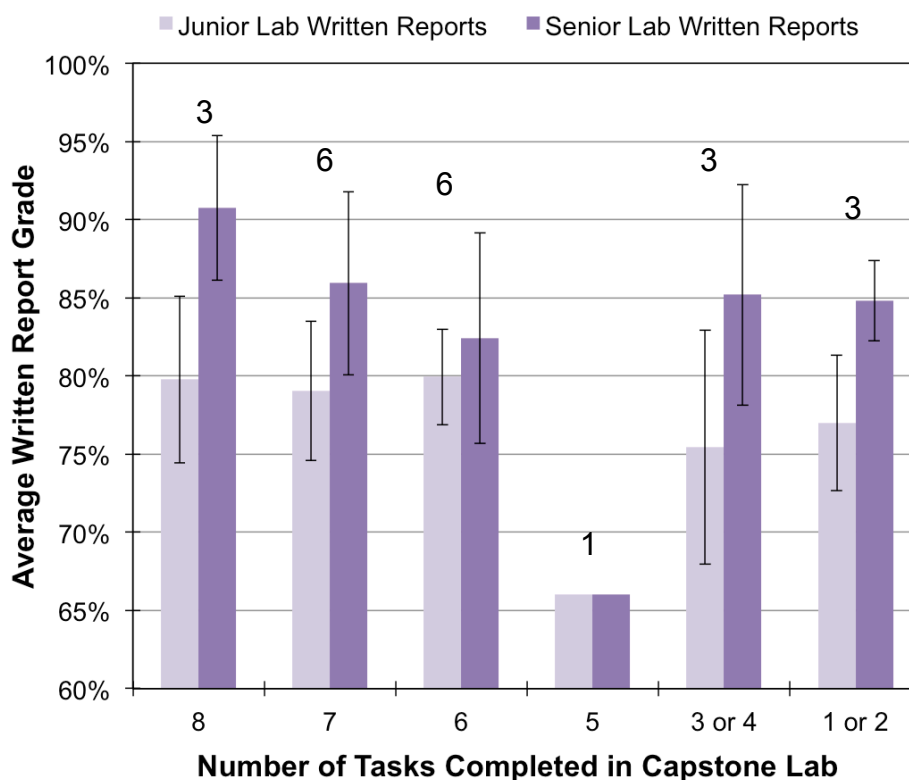

Figure 8. Comparison of grades between junior and capstone lab, based on groups divided based on the amount of optional tasks they had completed in capstone laboratory (shown on the x-axis) prior to the first written report submission (up to 8). The number above each column represents the number of students in each group. Error bars represent standard deviation.

Although the small sample size leads to large standard deviation error bars, Figure 8 shows a trend can be seen in the students who completed six, seven, or eight tasks. These students generally performed similarly in the junior-level laboratory. However, the students who completed eight tasks performed significantly better on their capstone written report compared to their junior laboratory reports. The amount of improvement above the junior level reports decreases with the amount of tasks until students complete less than five tasks. These students show improvement roughly similar to the students who completed seven tasks. Again, the limitations of the small data set make distinguishing trends, if there are any, difficult, and more

data will be collected as the game is run in the Spring 2015 semester with a group of students new to capstone laboratory from the same cohort.

It is also notable that all nine of the female students in the class are represented within the group of sixteen students who completed over 50% of the eight optional tasks available before the completion of the first laboratory report. This fact may seem surprising, as many assume games are a hobby for young males and additionally assume that game-based learning must be alienating to female students. However, according to a study conducted by the Entertainment Software Association, 48% of all game players are female. Moreover, women over the age of 18 make up a larger percentage of people who play games (36%) than boys under 18 (17%)[22]. As such, one should not shy away from game-based learning for fear of alienating a demographic; it is essential to make the game experience itself interesting and engaging to encourage students to participate.

6. Conclusions & Future Work

The game-based system described in this paper has been shown to be incredibly popular with senior-level chemical engineering students in the capstone laboratory course. The game mechanic based on popular tower defense games serves multiple purposes. First, it provides a unique classroom environment that students feel positively about. Second, it gives students multiple ways to engage in the classroom and contribute while promoting their critical thinking and collaboration skills. Finally, it encourages consistent student participation throughout the semester. In the authors' experience, this system has proven to be much more popular with students and more successful at promoting student involvement in class than a similar gamified course structure that relies only on badges, points, and leaderboards. The use of narrative elements and character creation may enhance the experience further, making students feel like they are part of a unique system that their personal actions can influence. As stated previously, however, this system is designed to be modifiable and customizable, and elements can be taken in whole or in parts to suit an instructor's needs or desired level of game integration.

The next stage of implementation of this structure involves the development of computer software to track student progress and to keep students informed as to what tasks they have completed. Currently, these parameters are tracked using Microsoft Excel and Microsoft Word. It can be cumbersome for an instructor to manually input completed tasks, and sometimes mistakes can be made and tasks can be missed. Learning management systems like Blackboard often have tools to allow student groups, optional assignments, and non-grade point awards. However, a customized software or smartphone app that allows students to log in, customize a virtual avatar, submit tasks, and check their in-game status would be a desirable alternative. Other future work includes a more thorough study of the impact of the game and the optional tasks on student performance, both in terms of performance in the class and in terms of improvement of laboratory skills. It would also be interesting to examine how student attitudes toward the course and the game elements were linked to their overall performance in the course, but the anonymous nature of the attitude surveys make it difficult to draw any direct conclusions. In the future, a third party may need to conduct exit interviews with students to assess this connection.

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