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Evaluating the Effectiveness of Game-Based Learning on Improvement of Student Learning Outcomes within a Sophomore Level Chemical Product Design Class*

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Recently, several studies have been published that have shown the need for greater student engagement within engineering education. These studies indicate that when students are exposed to pedagogies that stimulate student engagement, such as active learning, student performance is better than with more traditional forms of instruction. One form of active learning that is starting to grow within engineering education is the use of games and gamification. In the spring of 2014, we were able to compare two sections of a sophomore Introduction to Chemical Product Design class to determine the effectiveness of game-based learning on student learning outcomes. The first section received content delivered utilizing active learning techniques. The second section received content utilizing the same form of delivery but included classroom based games and a game-based portal for homework assignments. Each section was evaluated in the same manner, and the instruction in each section was provided by the same two faculty members. Throughout the course, students completed clicker questions on class content, and at the end, they reviewed content in a class session administered using the clickers. Students were also responsible for completing a semester design project that included both a written and oral component. Analysis of the clicker responses demonstrated that the students in the game-based class performed statistically similar to or better than those in the control group throughout the semester. In the last class review session, retention of material appears to have been better in the game-based class, where several learning objectives demonstrated a significantly higher outcome. Student performance on the semester design project also exhibited similar trends. As the sample sizes are relatively small in this study, the results are preliminary but do demonstrate a trend towards enhanced learning outcomes when content is delivered utilizing game-based pedagogy.

Keywords: game-based learning; student learning outcomes; games; engineering education

1. Introduction

Traditional lecturing has been the primary method of instruction at universities for over 900 years. However, a recently published study showed that in Science, Engineering, and Mathematics classes, the use of active learning instead of traditional lecturing increased the students' examination scores by an average of 6%. Furthermore, the study showed that students taking a lecture-based class were 1.5 times more likely to fail the class than were students in active learning classes [1]. For this reason, it is important that instructors, particularly those in STEM related fields, strive to make the classroom environment engaging to students, which will contribute to their ultimate success within these fields of study.

The purpose of this study is to examine the impact of game-based learning methodologies on the performance of students within a sophomore level Introduction to Chemical Product Design class. Game-based learning techniques were selected due to their growing recognition as a medium that can contribute to student engagement [2], although more research is still required to ascertain the benefits of this form of pedagogy on student learning outcomes. Two class sections of the Introduction to Chemical Product Design class were taught using active learning strategies, with one of the sections including live classroom games and completion of homework assignments through a game portal.

This paper provides an overview of the types of instructional strategies that were used in both sections, the assessment measures employed, and the impact of game-based learning strategies on student learning outcomes. We will also discuss faculty perspectives of the use of game-based learning

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within the classroom and opportunities for future development. We found through our analysis that students in the game-based class performed statistically similar if not better than those in the active learning class throughout the semester. We also found that students in the game-based class demonstrated higher retention of course material with significantly better performance in three out of the seven learning objectives in the summative clicker assessment. In addition, interviews with the course instructors revealed that both felt game-based learning was an effective pedagogy for this type of class content and would continue to use this method of instruction in the future.

1.1 Game-based learning

Game-based learning has the potential to increase the learning ability of students, due to its capacity to engage students in course material. This is due to the many properties of game designs, including the provision of a goal with specific rules, immediate feedback on performance, a gradually-increasing difficulty level based on user performance, and the ability to encourage users to work to the edge of their capabilities to achieve the winning condition [2–4]. These characteristics allow for games to be used for more than just fun by providing a foundation that will encourage meaningful learning to take place. However, it has been cited that one of the main challenges of using games within an educational setting is to balance the motivational aspects for playing games with student learning [5]. For this reason, some researchers have tailored the design of their games to meet the motivational needs of the student population and help ensure they facilitate learning [6].

Perhaps the best way to envision how these properties work together within an educational environment is through example. One such example is an adaptation of a trivia game, such as Jeopardy, which can work well in higher education classes. In this type of game, students can either work in teams or as individuals (depending on class size). The goal of the game is for students to select questions they would like to answer in a given category when provided with a game board that outlines five questions per category, with each question assigned a different point value. The higher the point value of the question, the more difficult the problem is to solve. Students are told that they can only select a specific number of questions and will lose the points assigned to the question if they answer it incorrectly. These rules encourage students to be strategic by choosing the questions they feel they can answer while working towards the winning condition of obtaining the greatest number of points. When students respond to a question, they are told immediately whether they are correct or not, which provides the feedback necessary to iterate on their solution to the problem. This type of game can serve as a great review tool for students by encouraging them to actively engage with course material prior to an exam.

Although games can lay the framework for meaningful learning to take place, it is crucial to their broader adaptation that proper assessment of student performance with the games is performed [7]. There are many ways that students can be assessed, but in order to obtain the most conclusive results regarding the effectiveness of game-based learning, the assessment must be in-depth and leave little room for error [8]. The next section will provide an overview of studies that have been performed, specifically within engineering education, to determine the impact game-based learning has had on student learning outcomes.

1.2 Game-based learning within engineering education

Only a limited number of studies have been published which provide an argument for the benefits of games on student learning outcomes. In a recent literature review performed on the implementation of games within undergraduate engineering classes, it was found that only 40% of publications over the past five years have performed some measure of student learning assessment as part of their implementation whether through qualitative or quantitative measures [9]. Examples of different methods for assessing the impact of games within undergraduate engineering classes have been included below for reference of the existing work in the field. It is important to note that the examples provided do not capture all of the work that has been done in this field, and readers are encouraged to reference the literature review cited previously for the complete listing of references in this area.

One common approach to quantitatively assess the impact that games can have on student learning is through the utilization of a pre- and post-test. In these instances, the pre-test is used as a measure of the students' baseline performance and then the post-test allows for comparisons to be made on student learning after the intervention. An example of a study that utilized this approach was done by Chang et al. in 2011 when they implemented a game-based version of a virtual laboratory [10]. In their implementation, students were given a pre-test to assess their preparedness for the laboratory and also determine areas where they showed conceptual weaknesses. After completion of the pre-test, students participated in the game-based laboratory and then completed the post-experiment test. The authors utilized tests that were similar in nature although not identical to avoid the possibility of short-term memorization impacting the results. They found that students showed increases in their performance on the post-test in comparison to the pre-test measure. In this particular implementation, there was no control group that was used and benefit from the implementation of the game was characterized solely on the basis of the change in student performance between the start and end of the intervention.

In other implementations, tests can be used in conjunction with control groups to allow for a more detailed understanding of whether the learning observed may be associated with game-based intervention. Ebner and Holzinger took this approach in their assessment of whether a computer-based game was helpful in teaching civil engineering students [11]. In their implementation students selected whether they wanted to voluntarily participate in playing the game, with the remaining students in the class becoming the control for the implementation. This approach involves a concurrent cohort comparison. They also had an additional experimental group that was outside of the classroom (i.e., online) during the entire study. Similar to the approach described earlier, students in this study were given both a pre- and a post-test as a measure of learning gains associated with the intervention. Their results demonstrated that there was an increase in the average number of problems that students answered correctly from the pre- to the post-test. However, there were no statistical differences in the results between the control and experimental group.

There are also studies performed which don't use specific instruments or tests to assess the students but rather focus their analysis on student performance on course-embedded materials such as homework assignments and midterm and final exams. This was the approach that was taken by Sancho et al. in 2009 when they were determining the ability of their "Nucleo" framework for computer programming, built around the principles of virtual collaborative blended learning, to improve student learning outcomes [12]. In the three case studies that they performed they examined not only performance on traditional student assignments, such as classwork and the final exam, but also determined if there were any changes in the dropout rate of students. Their results showed that there were a significantly lower number of students that withdrew from the course in the experimental group and that on average their exam scores were also higher in comparison to the control group.

Another method for assessing the impact of games on student learning outcomes is a qualitative-based approach. This was utilized by Hauge and Riedel in their evaluation of two serious games, COSIGA and BEWARE, for teaching engineering and manufacturing [13]. In their study, they analyzed a combination of student communication chat logs, student responses to cognitive formulated questionnaires administered prior to and after exposure to the simulation, and student work that was produced after interaction with the simulation. The COSIGA game, which was evaluated using student communication chat logs and cognitive maps, extended learning benefits for students; however, this was impacted by the student's role within the simulation. The BEWARE game demonstrated that students could identify risk better after interaction with this simulation. In addition, performance was improved when students were exposed to a learning cycle that involved playing the game, debriefing their experience, and playing the game a second time. Results were also impacted by students' past experiences, and it was found that taking this background into account during the debriefing period could positively impact the learning.

Our study focuses on the assessment of two concurrent cohorts of students taking an Introduction to Chemical Product Design class, with one of the sections receiving in-class games and completing homework through a game-based portal and the other receiving only active-learning based instruction. The direct assessment of student performance and learning outcomes was performed through the analysis of clicker (i.e., audience response system) questions during the semester as well as in a final review session. Additional comparisons are made based on student performance on a semester design project. Finally, faculty perspectives and observations regarding the two class cohorts provide a qualitative assessment of the differences in these two forms of instructional pedagogy.

2. Research question

In an effort to investigate the use of games in a chemical engineering course and contribute to the evidence-based body of knowledge about the impact of game-based instruction, we asked the following research question: *Does implementation of a game-based learning pedagogy within an Introduction to Chemical Product Design course result in any difference in learning outcomes when compared to a class taught using active learning pedagogy?* To investigate this question, we compared student performance both during and at the end of the course on clicker questions as well as their performance on a term design project. Additional insight on differences between the two classes was provided through a semi-structured interview with the two instructors who co-taught the course.

3. Methods

3.1 Study design

Two sections of the chemical engineering design course, each having 57 students, were taught during the spring of 2014 semester. One of the primary goals of this course was to provide the skills necessary to develop an appreciation for the role of customers within product design. In addition, students worked on professional skills development. Topics covered included brainstorming techniques, identifying customer needs, market analysis, and finance. In addition to those topics, the course also covered communication, teamwork, decision making, leadership, and project management. Student enrollment in each section was done randomly. A comparison of the average start-of-the-semester cumulative grade point averages (GPAs) of the game-based versus control group was done to ensure that the groups were similar in terms of previous achievement. It was found that there was no significant difference between the two class sections in terms of the pre-course average GPA ($p = 0.912$).

The control section was taught using a combination of different active learning techniques and traditional lecture. The active learning strategies included think-pair-share, group discussion, case studies, and role-play assignments. The students in this section did not participate in any games in class and were given regular weekly written homework assignments. The experimental group was taught utilizing these same strategies but also through game-based learning elements, such as live in-class games. Students in this section also completed homework through a third party platform known as 3D Game Lab [14].

The games played in class were relatively simple games that varied in structure. Each of the games was selected after consultation with a live game designer who helped the instructor in selecting games that showcased the principles relevant to the course. Some of the games lasted roughly 5 minutes, while others took almost 30 minutes. Additionally, some games were played with the entire class, while others were played within a group of students. At times, teams were randomly selected, and at other times, they were selected based on where the students were seated in the classroom. In a few instances, each student comprised his/her own team. An example of one type of in-class game was the hula hoop race. In this particular game, five students were grouped together and told to link arms in a circle. A hula hoop was then placed on one of the set of linked arms. The goal of the game was for the students to get the hula hoop around the circle in the shortest period of time. This game was selected on the basis that it was a means to visually demonstrate to students that the first solution to the problem might not always be the best approach. As elaborated on later within this paper, this game can lead to further illustration of pre-conceived constraints that students place on problems without necessarily realizing it.

Students in both classes also completed semester long design projects and were encouraged to respond to the College and University Classroom Environment Inventory (CUCEI) in the second-to-last week of the semester. Appropriate human subjects clearance was obtained prior to the commencement of the study.

3.2 3D game lab

The 3D Game Lab platform, which was invented by educational technologists and is currently available through GoGo Labs, Inc., allows for students to complete assignments using a computer and submit them online [14]. The assignments covered all topics that were relevant to course material. Often, they involved reading an online article or watching a video and providing a reflection on what was observed. Later assignments in the course built upon material that students had already worked on, providing a scaffold for the students to expand their knowledge in these topic areas.

Once an assignment was submitted, the instructor reviewed the student's work and either approved or rejected it. If the student's work was approved, he/she was given a set number of points determined before the start of the semester. If the student's work was rejected, the assignment was returned with comments indicating which aspects of the student's work could be improved. The student then had the opportunity to make the proper adjustments and re-submit the assignment. The student's work was again examined in the same manner, and if approved, received the same number of points associated with a first-time acceptance of the work.

During the semester, the students were required to accrue 1750 points in 3D Game Lab in order to receive a homework grade of 100% for the course. Homework assignments accounted for 25% of the final grade in the course. Students needed to take responsibility for completing assignments on 3D Game Lab, as assignments were not collected on a weekly basis.

3.3 Learning outcomes measurement

Students in both sections utilized audience response systems, or clickers, during in-class lecture. Whenever the instructor asked a question, students answered using the clicker. All of the questions were multiple choice with no more than five options to choose from. During most lectures, a few questions were asked, and the timing of these questions varied throughout the lecture period. The last lecture of the course served as a review of course material, in which approximately 40 questions were asked. The questions were selected from previous lectures as a method to determine how much material the students had retained. This approach allowed for the collection of data related to student learning outcomes from both sections without any instructor bias.

Comparison of student performance on semester long design projects was also done. Student teams were required to develop a two minute infomercial as well as a written report on a sunscreen product they were to develop. Performance on each of these individual components of the assignment along with overall performance on the design project was assessed by the instructor using an instructor-developed rubric. In addition, there was a peer-review component. The infomercial represented 15% of the design project grade, and the written report comprised 85% of the project grade.

3.4 Statistical analysis of learning outcomes

To analyze the results from the clicker questions, all of the questions that were asked during the semester were categorized based on the learning objectives for the course. All of the questions that were not included as part of the review session as well as any questions that were opinion-based were removed from the analysis. This left only questions that were fact-based and used during the semester as well as in the final review session, enabling the most objective comparison of learning outcomes. The percent of questions answered correctly by all respondents within a particular learning objective was calculated. This was done for all seven learning objectives in both sections. A z-test of proportions was used to compare the percentage of correct answers obtained by each section using a significance level of $\alpha = 0.05$. To determine the impact of the game-based learning on the students' design project performance, final scores for the written, infomercial/oral, and overall design project performance were compared between the groups using both a t-test and the Mann Whitney test, given the small sample size.

4. Results and discussion

4.1 Impact on learning outcomes

All students were evaluated using a combination of their responses to clicker questions during the semester (formative) as well as in the final review session (summative) and their performance on a semester long design project. These results are described in the following sections.

4.1.1 Formative clicker questions

This course had the following seven primary learning objectives or topic areas: brainstorming, customer information, market analysis, communication, teamwork, leadership, and decision making. In the assessment of formative student responses, students in the game-based class performed just as well or better than students in the non-game class from a statistical standpoint on all seven topic areas, as shown in Table 1.

In particular, for the topic areas of brainstorming techniques, market analysis, teamwork, leadership, and decision making, the percentages correct in the game-based class were higher than in the non-game class. In addition, the two-proportion z tests for each topic area showed that students in the game-based class performed significantly better in the area of market analysis. These enhanced performances by the game-based students in several of the topic areas may have occurred because students were allowed to move at their own pace with 3D game Lab—potentially ahead of the instruction in the classroom. With this self-paced method of instruction, it is quite possible that students in the game-based class had already covered the material on these topics before being exposed to them during class

In addition, the increase in performance for the topics of brainstorming, teamwork, and leadership may have been due to the live classroom games that students had the opportunity to participate in. For

Table 1. Student Performance on Formative Clicker Questions

Learning Objective	Number of Questions	Percent Correct		p
		Non Game	Game	
Brainstorming Techniques	4	56.65%	61.36%	0.32218
Customer Information	6	82.90%	81.40%	0.67748
Market Analysis	11	77.28%	84.04%	0.00456
Communication	5	76.69%	75.87%	0.82588
Teamwork	4	58.20%	64.05%	0.29372
Leadership	4	83.83%	88.34%	0.22246
Decision Making	3	61.55%	62.70%	0.87288

instance, just prior to instruction on brainstorming, students took part in two to three classroom games that related to pre-conceived constraints that impact the ability to generate ideas when brainstorming. One of these live classroom games was the Hula Hoop Race mentioned earlier. In this particular game, many of the students felt that it was necessary to have each student step through the hula hoop, effectively moving it from student to student in order to move it around the circle in the shortest period of time. However, during debriefing of this activity in class, it was discussed that this was a limitation the students had imposed on the problem, since it was not stated in the instructions that the hoop had to travel from one student to another. In fact, the fastest way for the hula hoop to go around the circle is for the group of students to make one complete circle. This experience can be related back to brainstorming because in many instances we impose limitations on design problems that aren't prescribed in the problem statement. These perceived limitations then lead to the generation of fewer ideas or difficulties getting beyond the initial solution to a problem. For this reason, it is important for students to recognize the types of limitations they might impose when trying to generate more diverse and creative solutions to the problems they are presented with.

An example of a game that targeted teamwork was "Star Wars," in which a number of hula hoops was scattered around the classroom floor, and students were told they had to have a foot within one of the hoops when time was called. This game then required students positioned within the same hula hoop to learn about each other and find interesting similarities. At each subsequent round of the game, a few hula hoops were removed. By playing subsequent rounds of the game, the students began to know each other better, and they had to work as a team to solve the final problem of fitting a significant number of students into a small number of hula hoops. After completion of the game, a debrief session helped students to connect the experiences they had during the game with the teamwork skills that were being covered in class.

4.1.2 Summative clicker questions

The results from the review questions presented at the end of the semester showed a considerably larger difference between the game-based and the non-game-based classes. In this review session, the game-based class correctly answered more questions in six of the seven topic areas, as shown in Table 2. The z test of proportions showed that the game-based class performed significantly better on the market analysis questions ($p = 0.002$). Although differences in brainstorming techniques and teamwork were significant at $p = 0.02$, they would not be significant after correcting for multiple comparisons using Bonferroni's adjustment. The formative analysis also showed better performance in these three topic areas as noted previously. The use of both live classroom games and a game-based portal likely helped students to reinforce these topic areas. For example, with the brainstorming assignments in Game Lab, students had to provide an example of a new brainstorming technique and compare it to the techniques covered in class. By asking students to make this additional comparison, they had to revisit the techniques covered in class, which helped in making connections to the course material. There were also several live games used to develop teamwork skills, including "Star Wars," as discussed earlier.

4.1.3 Design project performance

A major contributor to the final grade within the course was a semester long design project, which was worth 40% of the grade. There were two components to the project—an infomercial and a written report for a new chemical product the team was proposing to develop. For the infomercial, there was both a peer and an instructor evaluation component. The peer evaluation component, which had a possible score of 20, contributed to one third of the final infomercial score. The instructor component also had a possible score of 20 and contributed to two thirds of the infomercial score. The written portion of the design project was graded by the instructor and had a possible score of 100. As

Table 2. Student Performance on Summative Clicker Questions

Learning Objective	Number of Questions	Percent Correct: Non Game	Percent Correct: Game	p
Brainstorming Techniques	4	37.87%	49.15%	0.02382
Customer Information	6	74.43%	73.25%	0.74896
Market Analysis	11	71.92%	79.82%	0.00188
Communication	5	70.99%	71.84%	0.79486
Teamwork	4	58.86%	69.74%	0.02144
Leadership	4	88.32%	92.02%	0.22246
Decision Making	3	67.88%	72.95%	0.30302

Table 3. Student Performance on Term Design Project

	Game		Non-Game		*p*-value	
Project Component	**Average Score**	***n***	**Average Score**	***n***	***t*-test**	**Mann Whitney**
Peer Review Infomercial (/20)	19.1	14	18.8	15	0.13	0.11
Instructor Infomercial (/20)	15.5	14	16.2	15	0.09	0.10
Written Design Project (/100)	82.7	14	78.0	15	0.08	0.09
Total Design Project (/100)	82.8	14	79.1	15	0.10	0.10

shown in Table 3, the written portion and the total design project showed promising trends with the game-based students, although the significance level did not quite reach $\alpha = 0.05$. Given the small sample sizes, we performed both a *t*-test and the non-parametric Mann-Whitney test and observed that the results from the two tests were generally in agreement.

The promising difference in the written design project performance between the two groups may have been due to the nature of the homework assignments in the two classes. As discussed previously, students in the game-based class were continually tasked with working on individual assignments in the 3D Game Lab portal pertaining to different areas of the course according to their own interests in the pursuit of the 1,750 point goal. This required them to use information they had seen in previous assignments as well as during class in order to successfully complete the new assignments. This differed from the other section, in which the homework assignments only corresponded to material that was covered in class the week immediately prior to the assignment. In addition, the feedback element of 3D Game Lab required the games-based students to iterate on their technical writing assignments and likely promoted better mastery of the material. In this project based course with no examinations, the non-games students didn't necessarily have the need to review and reinforce material.

The results obtained in the learning outcomes analysis, although preliminary, show similarities to other work that has been done in the game-based learning field. Our results from both the clicker questions and the student design projects demonstrated that the games-based students performed statistically similar to or better than students in the non-games based class. This coincides with other work that has shown positive increases in the performance of students exposed to game-based learning [10–13, 15–19].

4.2 Classroom environment

As described in a previous article, we found that students in the game-based class rated the classroom environment better on all seven dimensions of the College and University Classroom Environment Inventory (CUCEI), although not significantly so when corrected for multiple comparisons using Bonferroni's adjustment [20, 21]. In particular, students in the game-based class rated their involvement in the classroom as characterized by participating actively and attentively in class at 3.39 on a 5 point scale, in comparison to only 3.17 in the non-game based class ($p = 0.12$) [20]. It has been discussed previously that learners need to be actively engaged to promote meaningful connections with their prior knowledge [22], which the live classroom games would have helped to do. The personalization dimension of the classroom, which measures the interaction between the students and instructor, was among the classroom characteristics of interest to the instructor. This dimension was rated as significantly better by the games-based section based on a *t*-test ($p = 0.039$) as well as a Mann-Whitney test ($p = 0.015$). However, these would not be significant at $\alpha = 0.05$ if adjusted for multiple comparisons. The effect size for personalization, as measured by Cohen's *d*, was 0.48, which is in the medium range. We achieved a 71% response rate with the CUCEI.

4.3 Interview of course instructors

The assessment analyst for the study conducted a semi-structured interview after the course with the two chemical engineering faculty members who served as co-instructors. In the joint interview, several issues pertaining to student behavior within the course were discussed, including the instructors' perspectives on student engagement, confidence, and attitudes. Both instructors agreed that students in the game-based class were more engaged. This was observed through higher attendance in the games-based class (i.e., estimated 30-50% higher) and greater involvement in class activities. This greater involvement entailed more students actively taking part in group discussions and responding to the instructors' questions as well as comfortably participating in impromptu presentations during class. We believe this increase in engagement may have resulted from the continual change in classroom practices, with no two class periods being alike. The instructors also observed that students in the game-based class appeared livelier and more alert during class. In the games section, the students were participants in all the activities, and the instructors noted a progression from hesitancy at the beginning of the semester to participation without hesitation (for the most part) towards the end of the semester. This change may have occurred due to gains in student self-confidence, with the students in the games section appearing more confident based on instructor observations.

The instructors were also asked about their views on which teaching method was the most effective instructional practice for this content area. Both instructors agreed that game-based learning was the better method from both a student engagement and performance perspective. When asked to elaborate, one of the instructors indicated that the games-based class provided a more realistic (i.e., authentic) experience for the students. Specifically, the students had to get organized, and time management was a large component. In short, the games helped by "providing a more realistic situation for students, similar to what they will encounter later in their professional lives." When asked whether they would use this instructional strategy in the future, both instructors felt they would continue to use game-based learning in this course.

4.4 Limitations of study

Although these results are very encouraging and show that game-based learning may help students in gaining and retaining knowledge, there are some limitations to this study, including the small sample sizes. Each class section had just fifty-seven students. When the students were placed in groups to work on their semester design projects, the sample size was reduced to just 14 teams in the game-based section and 15 in the other section. Although it would be beneficial to repeat this exact study in future semesters and expand upon the dataset for statistical testing, the instructor decided to move forward with only game-based learning in the course based upon review of teaching evaluations.

An opportunity that was missed with this study was the gathering of student perspectives on the two types of pedagogies. A focus group with students in both game and non-game sections would have been helpful for obtaining a broader understanding of the differences in performance and engagement observed. For instance, was it the live games in class or the 3D Game Lab portal that was most useful to the students in understanding the course material? Did students feel that they were more involved in their own learning when challenged to take part in the game-based activities during class? Future studies could work on gaining a better understanding of the type of cognitive theory that supports the changes that are being observed in student performance with games-based instruction.

Additionally, there is a potential limitation due to the method utilized for selecting the games that were employed as part of this classroom study. As described earlier, classroom games were chosen based on their alignment with concepts that were important components of this course and not necessarily on their alignment with the backgrounds and characteristics of the students in the course. This may have led to the games having less of an impact on student performance than if they had been selected based upon their ability to meet the needs of the student population within the game-based class.

5. Conclusions

The application of game-based learning appears to be increasing within engineering education, as evidenced by increases in the number of publications on this subject. This study represents the first implementation of game-based learning within a sophomore level Chemical Product Design course.

The results of this study show that inclusion of live classroom games alongside a game-based portal for completion of homework assignments may have a positive impact on student learning outcomes. In particular, students in the game-based class performed at a statistically similar or higher level than students in the non-game class. Achievement in particular topic areas, including brainstorming, market analysis, and teamwork, showed evidence of being greater in the game-based class. The use of games that particularly reinforced these areas and the iterative homework assignments in the 3D Game Lab portal, which often included technical writing assignments, may have contributed to better understanding of these specific content areas and enhanced writing skills. An interview with the faculty members who taught the two sections further supports the advantages of games-based instruction. Students in the game-based class appeared to be more engaged and enlivened during class and possessed greater self-confidence, including with impromptu classroom presentations. Both faculty members felt that this instructional methodology had a positive impact on students, and they planned to use it in future course offerings.

It is of critical importance to engage students in the learning process to help them achieve better learning outcomes and retain their knowledge as they progress through their technical courses and beyond. Game-based learning is a pedagogy that holds great promise for enhancing learning outcomes through increased student engagement and participation in the learning process. In addition, it may lead to a more positive classroom environment and student experiences. Thus, one of the research questions to be further investigated is the impact of this pedagogy on students' perception of the classroom learning environment and their professional skills development.

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