Student Perspectives on Application of Game-Based Learning within a Graduate-Level Engineering Course

Cheryl Bodnar
Rowan University
Glassboro, NJ, United States
bodnar@rowan.edu

Renee Clark, Jesse Davis, Tom Congedo and Daniel Cole
University of Pittsburgh
Pittsburgh, PA, United States

***Abstract*—** In recent years, game-based learning has been increasing in popularity as a tool for providing students with experiential learning opportunities. Although there have been a few implementations at the graduate level, there is still the need for a greater number of studies documenting the effectiveness of game-based practices in graduate-level environments.

In our study, we developed and implemented a digital game with technical content in a graduate-level, distance-enabled nuclear engineering course. As part of assessing this implementation, we gathered the perspectives of the students using a learning environment survey, a focus group, and individual interviews. The results of these methods demonstrated positive student viewpoints towards the learning environment and the use of the game in this course. Based on a double-coded content analysis of the focus group and interview data, the students found the game engaging and noted the possibility of points and "winning" associated with playing the game. They further indicated that the use of the game was a good approach with potential that "changed things up." Although we received positive feedback, the students also provided constructive feedback on this initial implementation and how it could be improved, including increased gaming elements and challenge level as well as providing more performance feedback to students as they participate in the game.

***Keywords*—**Games, Graduate education, Nuclear engineering, Student perception

I. INTRODUCTION

Game-based learning offers much potential as an educational tool for students in higher education. Elements of games such as a distinct goal, rules that need to be followed, and immediate feedback on whether the individual is attaining the desired end goal are all key components that can help individuals identify, practice and eventually master difficult concepts [1, 2, 3]. In addition, game-based learning provides the opportunity for individuals to gradually build their skillset by scaffolding their learning experience so they always experience just the right amount of challenge without feeling overwhelmed [3]. An additional pedagogical benefit of games is that they don't necessarily need to be incorporated as part of the class experience but can be provided to students outside of class time as a method to reinforce instruction [4].

Recently, a systematic literature review was performed that examined the application of game-based learning within engineering undergraduate programs over the past fifteen years. It was found that publications on the integration of games within these contexts have steadily increased with 23 papers published from 2000 to 2004 - increasing to a total of 109 papers between the years of 2010 to 2014 [5]. This clearly demonstrates increased interest in applying game-based learning within higher education settings and more specifically in the engineering context.

There have also been studies that have documented the application of game-based learning at the graduate education level, although notably fewer than those observed at the undergraduate level. Examples of game-based studies performed with engineering graduate populations include those related to building skillsets ranging from innovative thinking to technical based competencies such as artificial intelligence and production ramp-up. Raviv discusses how he integrated games and puzzles as activities within his graduate level course to encourage students to get to know one another better and learn to be more open minded in their thinking [6]. Salcedo-Sanz et al. describe how they used software to create a digital bubble breaker puzzle game that could be used to teach students concepts associated with artificial intelligence such as hyper-heuristics [7]. In their study, they provided students with the software and gave them a series of assignments that related to applying artificial intelligence concepts to the puzzle in question. At the end of the course, students were given a questionnaire to assess how they liked this pedagogical approach. They found that all the students believed they understood the concepts better than with traditional methods that have been used to teach these concepts. They were also more willing than they would have been in a traditional classroom to take on additional assignments. In the study by Bassetto et al., students were exposed to a production ramp-up situation based on a manufacturing game, called SIM-FAB. They provided their students with a pre and post-test as a means of identifying changes in student performance through their game participation and found that students' learning was improved but that the increase in performance wasn't uniform across the entire student population in question [8].

Nuclear Regulatory Commission (NRC) grant # NRC-HQ-84-14-G-0065.

These examples highlight how games can be applied as a means for improving student engagement, motivation, and learning within a graduate engineering context. This work examined how a game-based learning platform could be used as a homework tool outside of the classroom to encourage students to master course material and review concepts that were introduced as part of the in-class lectures. To assess students' interest in and experiences with this form of pedagogy, we evaluated the classroom environment via survey and performed a focus group and individual interviews.

II. Methods

This study investigated how nuclear engineering graduate students participating in a distance learning course entitled "Fundamentals of Nuclear Engineering" in the fall of 2015 responded to the implementation of a game-based learning activity as a portion of their homework component for the course. The class had a total of 17 students and consisted of a mixture of full time graduate students and individuals from industry that were in a part-time graduate program. The course was offered as a distance-enabled learning course where students could either attend class in person or participate through an online portal. As part of the study, students were assigned to complete a portion of their homework assignments using the game and were then asked to complete an online learning environment survey and participate in a focus group or individual interview to assess and provide feedback on their experiences. Appropriate human subjects approval was obtained prior to conducting the study.

A. Desert Island Reactor

The game entitled "Desert Island Reactor" immerses the students in the role of nuclear engineers on a desert island who need to demonstrate to a nuclear expert that they have sufficient understanding of core nuclear engineering principles, such as neutronics, transport, and heat transfer, to be able to get their grass roots nuclear reactor certified for use. As part of the game environment, students were directed through a main map to four areas of the desert island that focus on the key content areas identified (see top panel of Figure 1). As students solved problems, which consisted of a mixture of multiple choice and short answer questions, they acquired points and letter badges which were specific to the desert island region they were working on (see bottom panel of Figure 1; different color letter tiles refer to different regions of the game). The points provided students with a real time view of how well they were progressing and what they had accomplished up until that point in the game. Each question allowed the student unlimited attempts at solving the problem in a manner that allowed him/her to have the opportunity to master the content before moving forward. When they mastered a specific region, the students then needed to unscramble the letter badges collected to solve the word puzzle for that area and get one step closer to getting their Desert Island Reactor certified. Only once students had mastered each region and solved the 4 word puzzles were they considered to have won the game, receiving an official certificate from their course instructor. Two screen shots of the game software are shown in Fig. 1.

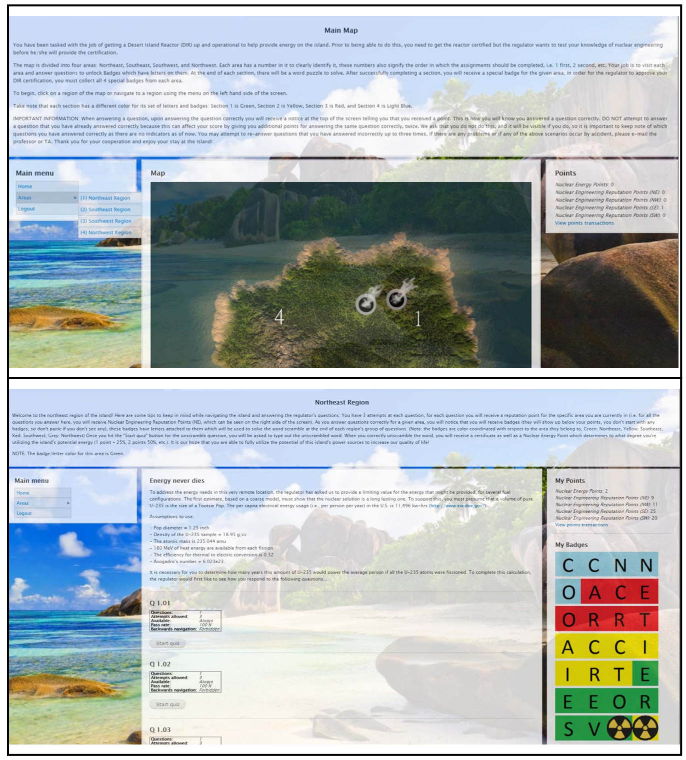

Fig. 1. Desert Island Reactor Main Title Screen (top) and Region Activity Screen (bottom)

The game was designed over the course of the summer of 2015 and consisted of a joint effort between course instructors, the first author on this study and the game designer. The first author on the study first met with the game designer to learn more about potential game designs and then brought this information to the course instructors to decide which approach would be best for the targeted student population. The game design and development was then a joint effort between the three parties to ensure that the content provided was accurate and representative of the skillsets that the instructors were seeking the students to master while the appearance and design of the platform maintained the key characteristics of a game.

B. Distance Education Learning Environments Survey (DELES)

We employed the Distance Education Learning Environments Survey (DELES) to assess the psychosocial learning environment in this course [9]. This reliable and validated instrument, which has been tested with both undergraduate and graduate students, evaluates perceptions of six psychosocial dimensions of the post-secondary distance education classroom, as described in Table I. Each of its 34 questions, which encompass the six dimensions in Table I, has a scale of 1 to 5, with 5 being most desirable. Several of these dimensions were relevant to and had a relationship to the use of the game in the course.

TABLE I. DELES Dimensions

1.	Instructor Support
2.	Student Interaction and Collaboration
3.	Personal Relevance
4.	Authentic Learning
5.	Active Learning
6.	Student Autonomy

C. Focus Groups and Interviews

We also evaluated student perspectives using focus groups and interviews. Focus groups provide a means to obtain information from a group of students, which can be used with other student data, such as surveys, for triangulation purposes [10]. Given the work schedules and physical locations of the students, we also conducted semi-structured interviews with individual students who could not participate in the focus group, using the same set of questions [11]. These questions are shown in Table II and were developed by the first author and the assessment analyst, with input from the instructor (fourth author). The questions encompassed the following outcomes and aspects regarding use of the game: levels of student engagement and motivation, learning effectiveness, and benefits and drawbacks within graduate education.

TABLE II. Focus Group/Interview Questions

1.	Did the game enhance or lessen your level of engagement or motivation with the associated technical material? Were certain "regions of the island" particularly engaging or not engaging?
2.	Was playing of the game an effective way to receive nuclear content material?
3.	Did the gaming process provide you with any new perspectives on how you do or view your work in industry?
4.	Which approach was better for your learning of nuclear content in this course – the traditional instruction or the game-based instruction?
5.	Did the game impact your level of achievement related to the content?
6.	Did the "word scramble activity" in each region motivate you to complete the technical content and questions in the region?
7.	Please comment on your level of engagement or interest in this course compared to your other graduate courses.
8.	Within graduate nuclear education, what are the benefits of game-based instruction?
9.	Within graduate nuclear education, what are the negative implications or disadvantages of game-based instruction?
10.	Do you have any additional comments or suggestions relative to this course and its use of the game?

After collection of the focus group and interview data, we used a coding scheme to analyze the focus group responses in a structured fashion [12]. The coding scheme was developed using a grounded, emergent qualitative analysis by the assessment analyst, with support from the literature [13]. Thus, the focus group and interview data were used to construct the coding scheme, and the literature was used to support the construction. Two coders (i.e., the first author and the assessment analyst) then applied the coding scheme to content-analyze all of the data; thus, the students' responses were double-coded. The most prominent codes or themes uncovered by this double-coding are presented in Tables IV and V in the results. Their first time inter-rater reliability was $\kappa = 0.80$, showing strong agreement beyond chance [14].

As discussed above, the literature provided support for our coding scheme, which included codes related to motivation and engagement, learning and pedagogy; game design and execution; and student feedback. In particular, in recent data gathered from students taking online courses, many of whom had work experience, several themes emerged regarding their definitions of engagement in a course [15]. These students identified interaction and timely feedback as required for engagement, including participation in team and individual projects and questioning. Also discussed was a desire to relate course and job content and actively participate so as to understand and learn the material beyond simply passing the exam [15]. These particular students also defined engagement as application of course concepts to real world, relevant scenarios and being truly motivated by and interested in the material [15]. The author suggested that faculty should provide opportunities for hands-on work in such cases, using a variety of tools and methods to present and motivate the content [15]. Adult learners often prefer active approaches to learning, including integrating their academic and work experiences [16, 17].

Graduate scientific education has also recognized the advantages of "learning by doing" and exposing students to real-life, problematic scenarios that (ideally) have aspects of excitement, investigation, and even play, followed by formative feedback to students [18]. These authors further believe that teaching science from a know-how, skills-based perspective drives the development of autonomy and self-learning. Interestingly, these themes coincide with the dimensions of the DELES.

III. Results and Discussion

The following section summarizes the results obtained from both the DELES survey and qualitative analysis of the focus group and semi-structured interview data. Additionally, it will make connections between the results obtained and the game implementation within this graduate class environment, leading to suggestions for other instructors who may be interested in applying this form of pedagogy within their classes.

A. *Distance Education Learning Environments Survey (DELES)*

We distributed the DELES at approximately the ¾ point in the semester to enable a comprehensive viewpoint of how students perceived their involvement with this graduate level nuclear course. An average score for each dimension of the DELES based on the entire sample was calculated, as shown in Table III.

As shown in Table III, all dimensions scored above the expected or median value of a 3.00 for the scale, except for the student interaction and collaboration dimension. We used the expected value of 3.00 to run a one-sample Wilcoxon Signed Rank test to determine if the true median of each of the course's dimensions was significantly higher than 3.00 [19]. This non-parametric version of the one-sample *t*-test was used given the small sample size. For the five dimensions with scores above the value of 3.00, the true median of each dimension was determined to be significantly higher than 3.00 ($p<=0.007$). These observed *p* values would remain significant even after correcting for multiple comparisons using Bonferroni's adjustment, which reduces the α-level required for statistical significance by dividing by the number of dimensions tested ($\alpha_{new}=0.05/6=0.008$) [20, 21]. Although the assumptions of the one-sample *t*-test may not hold given the small sample size, its significance levels for these five dimensions were in agreement with those of the Wilcoxon test.

The results in Table III reflect a positive learning environment in this course. The active learning, authentic learning, personal relevance, and student autonomy dimensions contained questions that were related to the use of the game in the course. The game may have contributed to providing students with a sense of control over their learning process (student autonomy), as the game was available online at any time to them. It may also have contributed to students' perception of authentic learning and personal relevance since it provided a story based narrative that allowed them to connect elements and theories that were introduced as part of class to nuclear engineering problems. Additionally, as the game encouraged mastery of course content through continual active practice, it may have empowered students to feel confident in their understanding of the course material by providing opportunities for sufficient repetition of difficult course content.

Table III. DELES Dimensions and Scores

Dimension	Mean	s
Instructor Support	4.15	0.70
Student Interaction and Collaboration	1.95	1.06
Personal Relevance	3.95	0.66
Authentic Learning	3.93	0.67
Active Learning	4.24	0.65
Student Autonomy	4.45	0.67
sample size	11	

For the interaction and collaboration dimension, which assess interaction with other students, the observed significance level was $p=0.016$, which would *not* be significant after correction for multiple comparisons. The distance-enabled nature of the course likely contributed to the lower score for this dimension. The game also would not have contributed to increasing students' perception of interaction with other students, as it was designed for individual student versus collaborative play.

B. *Focus Group/Interview Results*

The top five positive themes uncovered in the focus group/interview data are given in Table IV along with their frequencies of occurrence, based on a content analysis of the data. These themes centered on enhanced student learning and motivation. As shown in Table IV, the game was frequently mentioned as an additional resource or tool for learning or understanding the course content, including the basics; it was also recognized as a study guide or refresher tool. Also frequently mentioned was the application or practice of course material, including providing a real world problem with which students could "interact." This coincides with the literature we discussed previously about application and real-life scenarios. The students also frequently mentioned the game to be a more interesting, engaging, or fun way to learn, including the ability to accumulate points (including extra credit). They indicated that it was overall a good idea to use the game within the course.

The top five themes uncovered in the focus group/interview data related to drawbacks or suggestions with the game are shown in Table V, based on the content analysis. They centered on game design and execution, feedback to students, and motivational issues. Since this was the first time the game had been used in the classroom, many of the students' suggestions or issues were related to initial design and execution of the game, including bugs in the software. However, many of the technical bugs could be (and were) fixed upon notification. The students also suggested enhancing or adding gaming features to the product, such as competition, interaction, animation, time limits, and ranks. Also related to the design of the game, the students felt the use of multiple-choice questions may not have been optimal for content achievement, as it allowed for guessing. In line with online students' interest in interaction (previously discussed), the students frequently mentioned the desire for additional feedback from the game, including errors made and the correct answers. Some students felt the game was not motivating, or even de-motivating, or they did not take it seriously. However, the frequency associated with this theme (i.e., 5) was less than the frequency associated with the theme of a "more interesting or engaging" way to learn (i.e., 10) in Table IV.

Thus, although our game did not perform or execute optimally during its first-time use in the classroom, the interesting outcome is that the students still valued the game relative to their learning and motivation.

Table IV. Top 5 Themes about the Game: Positive

	Theme	Frequency
1.	Additional resource for learning or understanding; review or refresher tool	16
2.	Enables application or practice of content; provides real world problems; promotes interaction with and repetition of content	13
3.	More interesting or engaging way to learn or do homework; more appealing or fun	10
4.	Overall good idea to use a game; should encourage its use	7
5.	Points or extra credit points can be earned	6

Table V. Top 5 Themes about the Game: Drawbacks or Suggestions

	Theme	Frequency
1.	Increase or add game-like features or qualities	12
2.	Provide additional feedback to students during game	11
3.	Software bugs	11
4.	Multiple choice questions not optimal for achievement	5
5.	Not motivating or taken seriously by students	5

IV. Conclusions

Game-based learning is growing in popularity within higher education and more specifically in the engineering field. However, very few studies have investigated whether this form of pedagogy provides equal or greater benefits to graduate level students. This study demonstrated how a nuclear engineering digital game could be integrated within the homework component of a graduate level course to provide students with the opportunity to actively engage and apply course concepts outside of the classroom. The digital game was created with a storyline to draw students into the scenario and encourage their engagement with the platform as they were asked to apply course concepts to real-life nuclear engineering problems. Students in the course were asked to provide feedback on the implementation of the game through completion of a course environment survey and participation in a focus group or semi-structured interview. Results from this assessment demonstrated that students felt there was a positive learning environment in the course and that the game provided them with opportunities to review and apply course concepts to real problems in an engaging and interesting manner. Although our game was associated with initial software or implementation issues, mostly associated with its stage of development, the students nonetheless felt that it was a worthwhile addition to this course and wanted to see it provided to students as a tool in future course offerings.

Acknowledgment

The authors would like to thank both Dan Gill and Mike Meholic, the other two instructors for the nuclear engineering course where the game was implemented, for their time and help with the design of the game.

References

[1] K. Squire, Video Games and Learning: Teaching and Participatory Culture in the Digital Age. New York: Teachers College, 19-39, 2011.

[2] J. McGonigal, Reality is Broken: Why Games Make Us Better and How They Can Change the World. New York: Penguin Group, 19-34, 2011.

[3] N. Whitton, and A., Moseley, Using Games to Enhance Learning and Teaching: A Beginner's Guide. New York: Routledge, 9-18, 2012.

[4] D. Oblinger, "The Next Generation of Educational Engagement," Journal of Interactive Media in Education, vol. 8, pp. 1-18, 2004.

[5] C.A. Bodnar, D., Anastasio, J., Enszer, D., Burkey, "Engineers at Play: Utilization of Games as Teaching Tools for Undergraduate Engineering Students," Journal of Engineering Education, vol. 105, issue 1, pp. 147-200, 2016.

[6] D. Raviv, "Innovative Thinking: Desired Skills and Related Activities," ASEE 2008 Annual Conference & Exposition, June 22-25, 2008. Pittsburgh, PA.

[7] S., Salcedo-Sanz, S., Jimenez-Fernandez, J.M., Matias-Roman, J.A., Portilla-Figueras, "An Educational Software Tool to Teach Hyper-Heuristics to Engineering Students Based on the Bubble Breaker Puzzle," Computer Applications in Engineering Education, vol. 23, issue 2, pp. 277-285, 2014.

[8] S. Bassetto, V., Fiegenwald, C., Cholez, F., Mangione, "Experiencing production ramp-up education for engineers," European Journal of Engineering Education, vol. 36, issue 4, pp. 313-326, 2011.

[9] S., Walker, and B., Fraser, "Development and Validation of an Instrument for Assessing Distance Education Learning Environments in Higher Education: The Distance Education Learning Environments Survey (DELES)," Learning Environments Research, vol. 8, issue 3, pp. 289-308, 2005.

[10] J., Fitzpatrick, J., Sanders, B., Worthen, Program Evaluation: Alternative Approaches and Practical Guidelines. Upper Saddle River, NJ: Pearson Education, Inc., pp. 385-386, pp. 437-438, 2011.

[11] J., Boulmetis, and P., Dutwin, The ABCs of Evaluation: Timeless Techniques for Program and Project Managers. San Francisco, CA: John Wiley & Sons, Inc., pp. 131, 2011.

[12] R., Krueger, Focus Groups A Practical Guide for Applied Research. Thousand Oaks, CA: SAGE Publications, pp. 128, 1994.

[13] K., Neuendorf, The Content Analysis Guidebook. Thousand Oaks, CA: Sage Publications, 2002.

[14] M., Norusis, SPSS 14.0 Statistical Procedures Companion. Upper Saddle River, NJ: Prentice Hall, pp. 152, pp. 183, 2005.

[15] P., Bigatel, "Student Engagement Strategies for the Online Learning Environment," Retrieved from < http://www.facultyfocus.com/articles/online-education/student-engagement-how-to-help-students-succeed-in-the-online-environment/> on March 14, 2016.

[16] J., Benshoff, and H., Lewis, "Nontraditional College Students," ERIC Digest, No. ED347483. Retrieved from < http://www.ericdigests.org/1992-3/college.htm> on March 18, 2016, 1992.

[17] L., Wyatt, "Nontraditional Student Engagement: Increasing Adult Student Success and Retention," The Journal of Continuing Higher Education, vol. 59, issue 1, pp. 10-20, 2011.

[18] L., Bot, P., Gossiaux, C., Rauch, S., Tabiou, "'Learning by Doing': A Teaching Method for Active Learning in Scientific Graduate Education," European Journal of Engineering Education, vol. 30, issue 1, pp. 105-119, 2005.

[19] J., Devore, Probability and Statistics for Engineering and the Sciences. Boston, MA: Brooks/Cole Cengage Learning, pp. 625-629, 2012.

[20] T. Perneger, "What's Wrong with Bonferroni Adjustments," BMJ, vol. 316, pp. 1236-1238, 1998.

[21] J., Bland, and D., Altman, "Multiple Significance Tests: The Bonferroni Method," *BMJ, vol. 310, pp*. 170, 1995.