Developing a Framework to Better Engage students in STEM via Game Design: Findings from Year 1

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Dr. Landis joined Clemson in June 2015 as the Thomas F. Hash '69 Endowed Chair in Sustainable Development. Previously, she was an Associate Professor at Arizona State University in the School of Sustainable Engineering and the Built Environment. She began her career as an Assistant Professor at the University of Pittsburgh, after having obtained her PhD in 2007 from the University of Illinois at Chicago under the supervision of Dr. Thomas L. Theis. She has developed a research program in sustainable engineering of bioproducts. Her research ranges from design of systems based on industrial ecology and byproduct synergies, life cycle and sustainability assessments of biopolymers and biofuels, and design and analysis of sustainable solutions for healthcare. Since 2007, she has lead seven federal research projects and collaborated on many more, totaling over $7M in research, with over $12M in collaborative research. At ASU, Dr. Landis continues to grow her research activities and collaborations to include multidisciplinary approaches to sustainable systems with over 60 peer-reviewed publications. Dr. Landis is dedicated to sustainability engineering education and outreach; she works with local high schools, after school programs, local nonprofit organizations, and museums to integrate sustainability and engineering into K-12 and undergraduate curricula.

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Kristen Parrish is an Assistant Professor in the School of Sustainable Engineering and the Built Environment at Arizona State University (ASU). Kristen's work focuses on integrating energy efficiency measures into building design, construction, and operations processes. Specifically, she is interested in novel design processes that financially and technically facilitate energy-efficient buildings. Her work also explores how principles of lean manufacturing facilitate energy-efficiency in the commercial building industry. Another research interest of Kristen's is engineering education, where she explores how project- and

experience-based learning foster better understanding of engineering and management principles. Prior to joining ASU, Kristen was at the Lawrence Berkeley National Laboratory (LBNL) as a Postdoctoral Fellow (2009-11) and then a Scientific Engineering Associate (2011-2012) in the Building Technologies and Urban Systems Department. She worked in the Commercial Buildings group, developing energy efficiency programs and researching technical and non-technical barriers to energy efficiency in the buildings industry. She has a background in collaborative design and integrated project delivery. She holds a BS and MS in Civil Engineering from the University of Michigan and a PhD in Civil Engineering Systems from University of California Berkeley.

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I. Abstract

Science, Technology, Engineering, and Math (STEM) teaching strategies that engage students and create an atmosphere of community are desperately needed to recruit, retain, and best prepare students in STEM fields to address challenges facing the 21st Century. Research shows that student performance and persistence in a STEM degree is associated primarily with three aspects of their experience: *intellectual engagement and achievement, motivation (e.g., having role models), and identification with a STEM field (e.g., developing meaningful relationships, being part of the community)*. While there is a large body of work about pedagogies and strategies that address these needs (e.g., active learning, experiential learning, service learning, flipped classrooms, etc.), the majority of university instructors are slow to adopt new teaching strategies. Most STEM faculty were never trained to be teachers, and there are many well documented reasons that faculty are slow to change teaching habits (e.g., (Frederick 1986). According to Sarason and Banbury (2004), "many faculty accept the premises of active learning but do not have adequate tools to bring active learning techniques into the classroom."

Games and game-based learning have been used in many classrooms as an active learning strategy. Game-based learning is a well-documented method to engage and motivate students with course material in order to improve student-learning outcomes. One very successful and popular game is Clarkson University's Energy Choices board game. This award-winning board game teaches concepts of energy; research shows that when game play was integrated into the curriculum, this game was shown to increase desired cognitive (e.g., documented improvements to math and science achievement scores) and affective (e.g., student interest and confidence in STEM) outcomes. In addition, the Energy Choices board game is widespread. Using Energy Choices as inspiration, we are developing a framework for integrating game design into civil engineering and construction management curriculum that makes it easier to develop and publish games like Energy Choices.

We are developing a set of **game design** approaches for use in the classroom that promote high levels of student engagement, create a sense of community, improve student metacognition, increase student retention in STEM, all the while being easily transferable and scalable. By involving students in game play *and* game design, we not only better engage students, we also create community and drive students to higher levels of metacognition. We have also found that following game play with game design easily moves students up the cognitive dimension of Bloom's taxonomy, from merely understanding, to reflection, creation, and evaluation. Board games and role-playing games are formats that create community; students interact with one another over intellectual, enjoyable, and memorable shared experiences. When the co-authors play board games in their classrooms, they note 100% of students in class that day engage in game play – anecdotally, this activity seems to engage more students than other types of active learning strategies. And finally, board games and role-playing games are an ideal format because any faculty or student can easily modify them. This poster presents our project results to date and provides recommendations and resources to adopt game design in civil engineering and construction courses nationwide.

II. Introduction

Undergraduate construction and engineering curricula is faced with several challenges including, but not limited to, providing contextualized classroom and field experiences, teaching students with diverse capabilities, refining students' professional competence, improving students' communication skills, and improving assessments of student learning outcomes (Auchey et al. 2000; Chan et al. 2002). As such, instructors seeking to better engage students in their learning may engage in a variety of pedagogies that support active learning, experiential learning, and problem-based learning. The authors adopt various elements of active, experiential, and problem-based learning in their game design approaches. Namely, the authors leverage team-based projects, which enhance student learning in STEM fields as they promote active and collaborative learning while simultaneously promoting individual accountability, personal responsibility, and communication skills (Allen et al. 2006; Savage et al. 2007).
Further, the authors leverage hands-on learning, which contributes to the development of students' verbal and written communication skills in addition to their interpersonal and teamwork skills (Savage et al. 2007). In addition, hands-on learning can address issues with students who struggle with traditional learning and testing methods (Dewoolkar et al. 2009).

Williamson et al. report that students learn by acting as part of a community and practicing the application of knowledge to situations where there exists shared values and goals (Williamson et al. 2005). Games afford instructors the ability to simulate a virtual community where students can operate as a resident within constraints defined by the game creators (Williamson et al. 2005). Game-based learning (GBL) is a recognized pedagogy for teaching students a defined learning outcome. Games used in GBL have been classified many different ways however tend to fall into one or more of the following genres: action, adventure, fighting, role-playing, simulations, sports, and strategy (Gros 2007). Games that promote education in addition to providing entertainment value are described as serious games (Chen and Michael 2005). Digital games predominate serious games in the GBL literature and have been instrumental in the creation of new social and cultural worlds (Prensky 2003; Williamson et al. 2005). The use of non-digital games, such as board games, offer many of the same community interactions as digital games without requiring the use of computers, making them accessible to a wide variety of classrooms (Berland and Lee 2012).

While GBL with the use of serious games and their ability to help students learn is explicit in the literature, little research has been conducted on student-developed games to assess student learning. The closest example is in computer science courses that allow students to modify an existing computer game by program changes into the game to receive immediate feedback on effective code execution (Eagle and Barnes 2009). When compared to writing code in a traditional programming assignment, the students that practiced the learning objectives within a game environment outperformed students who participated in the traditional assignment (Eagle and Barnes 2009).

There are several ways to assess student progress towards learning goals. Traditional methods include, but are not limited to, quizzes, papers, projects, reports, portfolios, exams, attitude surveys, journal entries, and capstone design projects. However, entirely student-designed games as a method for assessing student learning is absent from the literature.

This paper explores the use of student-developed board games as a method to assess student mastery of construction and engineering concepts. Specifically, this research addresses the questions, (1) "can student-developed games demonstrate mastery of student learning?" and (2) "does student performance improve when engaged in game design as compared to a more passive assignment?" This paper describes the development of three game design approaches and their effectiveness as assessment methods. Each game design approach utilizes active and experiential learning; students apply the concepts learned throughout the semester in the design of a board game that their peers will play at the end of the class. Student-developed games enable the instructor to assess student mastery of course content through games designed entirely by students. The balance of this paper presents game design approaches and their implementation at Arizona State University (ASU), the University of Pittsburgh (UPitt), and Clemson University (Clemson)..

III. Game Design Approaches:

GD Classics- In the GD Classics approach, students create games based on classic known board games. Students are already familiar with the game structure and rules, and are then asked to integrate course concepts into the game, thus actively engaging in critical thinking about their course content.
GD Modifications- In the GD Modifications approach, students play a game with existing learning objectives, and then modify the game to incorporate their course content.
GD Culmination- The GD Culmination approach allows the students to integrate course concepts from the entire semester into the design of a new game using any game mechanism they choose.

IV. Implementation of Game Design Approaches

This section presents the Game Design approaches and where they were implemented in the first year of this project. Our goal was to design, test, and evaluate each game design approach for enabling engineering curricular change by integrating game design and game play into the classroom, with the aim of creating a framework that can be easily adopted by **any** STEM instructor. In the first year of this project, GD Classics was implemented at University of Pittsburgh in the Green Building's class, as well as at Arizona State University in the CON 252: Building Construction Methods, Materials, and Equipment class; while GD Modifications was implemented at Clemson in the Sustainability and Business course. GD Culmination was not implemented at any of the schools during the first year.

V. Methods

The authors conducted student surveys and focus groups/interviews to evaluate the effectiveness of the use of games in the classroom and the students' engagement, sense of community, intention to remain in the major, unintended bias based on prior use of games or cultural differences, and perceived cognitive and academic gains.

V.1. Student Surveys

The provided students with both a pre-game and a post-game survey electronically to assess their perceptions related to the use of games and measure any differences. The students completed the

surveys anonymously. We connected their pre- and post-game responses using a student-selected code that was entered for both surveys.
The pre-game survey contained a series of questions to determine each student's experience with games in the past and whether he/she felt the use of games would make the course more difficult or negatively impact performance, thereby leading to unintended bias. Each student was also asked about intentions to remain in his/her current major. ASU, UPitt, and Clemson all implemented pre- and post-game surveys.

V.2. Student Focus Groups and Interviews

Another assessment technique used to gage how students felt about the games in the class was through the use of focus groups and interviews. The project evaluator conducted two focus groups or interviews at ASU and UPitt – one with the students who were identified as engaged and another with those identified as not engaged. The authors asked questions about the students' prior use of games, intention to remain in the major, impact of the games on engagement, motivation and learning, and other benefits and drawbacks to the use of games.

VI. Results

VI.1. Student Survey Results

Students were asked to complete both a pre- and post-games survey electronically. Based on our pre-games survey, the large majority of students had experience with playing games. Thus, any unintended bias based on not having played games previously was not a factor for the large majority of our students. In addition, on the pre-games survey, 83% did not anticipate that the use of games would make the course more difficult or negatively impact their performance, with only 17% answering "yes" or "possibly" to this question. Reasons cited for this included a lack of seriousness of games, subpar learning opportunities, and teaming or creativity issues. Therefore, the large majority of our students did not exhibit an unintended bias based upon anticipating difficulties with games.

In evaluating the post-games responses, the large majority of respondents (85%) across the three schools told us that games had (indeed) not made the course more difficult or negatively impacted their performance. For those who indicated that games had made (or possibly made) the course more difficult, the reasons cited included the need for group work, time spent on game design versus learning course content, lack of seriousness, time issues, and a high difficulty level.

On the post-survey, we also asked students about their intentions to remain in their current majors and whether the games had impacted this desire, with 94% of students being architecture, construction management, engineering, science, or math majors. Only two students were uncertain about their intentions to stay in the current major per the post-survey, with one of these students also having been unsure at the time of the pre-survey (and the other not having responded to the pre-survey). All other students on the post-survey intended to remain in the current major. Eighty-two percent (82%) of respondents further indicated that the games had no impact on their desire to remain, although 17% indicated that the games had increased their desire to remain in the current major. Only one student (2%), who was a STEM student, said the games had decreased his/her desire to remain in the major.

Interestingly, 17% of the respondents indicated that the games had increased their desire to remain in the current major. Upon contenting-analyzing their responses as to why, two main categories emerged, which were mentioned with equal frequency – 1) games inspired self-confidence and/or were more interesting or fun, and 2) real-life experiences, perspectives, or solutions were gained or realized through designing or playing games.

VI.2. Student Focus Groups and Interview Results

Focus groups and interviews were conducted at both ASU and Pitt with the students identified as engaged vs. non-engaged during the classroom observation. The three most frequent categories for each group are highlighted in Table 1. From Table 1, the engaged students at both ASU and Pitt most frequently noted 1) application and active learning via games, 2) an actual positive impact of games on technical learning and performance, 3) the motivating and fun nature of games, and 4) an overall desirableness of games for learning. Although the non-engaged students most frequently noted positive benefits such as engagement and motivation also, the non-engaged students at ASU noted a lack of challenge with their games, including already being familiar with the material. The non-engaged students at both schools also most-frequently indicated that the games "changed things up" in terms of the instruction, and the non-engaged students at Pitt frequently cautioned about appropriate group sizes with games. Note that the non-engaged students mentioned application/active learning less frequently than the engaged students at both schools.

Table 1: Focus Group/Interview Coding Categories (Top 3 occurrences per group highlighted)

Occurrences of Categories (participants in parentheses)		**ASU**		**Pitt**	
Description/Examples	**Code/ Category**	**En-gaged (4)**	**Non-Engaged (6)**	**Engaged (1)**	**Non-Engaged (2)**
Games promote/provide application or practice, active learning or activities; example problems for repetition/reinforcement; and real world problems or perspectives	APPL ACTIVE	16	2	3	
Games *actually* positively impacted (were good for) performance or learning of the technical course content, including deeper learning; games were *actually* thought or idea-provoking.	POS IMPACT	14	2	3	2
Good idea to use games; I like game-based learning; I encourage its use, including in other courses; benefits exist with games	GOOD	5			
Games provide more interesting, engaging, or motivating way to learn or do homework; they are more appealing or fun	ENGAGING	3	6	3	1
Game or game content not challenging or was easy; already familiar with the game content; game not motivating, incentivizing, impactful, or beneficial	NOT CHALLENGING OR MOTIVATING		5	1	
Games change it up (i.e., games provide alt. teaching method or type of assn..)	CHANGE	4	3	1	5

Occurrences of Categories (participants in parentheses)		ASU		Pitt	
Description/Examples	Code/ Category	En-gaged (4)	Non-Engaged (6)	Engaged (1)	Non-Engaged (2)
Game was hard or difficult to do	HARD		3		1
Games did not impact desire to be in major (i.e., no impact on retention or transfer)	NO IMPACT RETENTION	4	3	1	1
Ensure group size for playing/designing games is optimal or not too large	SIZE				3

VII. Conclusion

This paper presents our project results to date. Game design approaches introduced students to the concepts of active and experiential learning through board game adaptations. The approaches were assessed using a mixed-methods approach of surveys, and interviews. Thus far, it seems that the **game design** promote high levels of student engagement, foster students' sense of community, improve student metacognition, and increase student retention in STEM. Moreover, game design approaches are transferable and scalable. To date, we find that the engaged students involved in this study noted 1) application and active learning via games, 2) an actual positive impact of games on technical learning and performance, 3) the motivating and fun nature of games, and 4) an overall desirableness of games for learning. Further, instructors at ASU, Pitt, and Clemson report that students can demonstrate mastery of concepts through board game design. The authors, therefore, assert that games can be used as an effective tool for instructors to evaluate student learning in lieu of traditional reports or exams.

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