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Opportunities for Innovation: Game-based Learning in an Engineering Senior Design Course

Erica B. Walker

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Opportunities for Innovation: Game-based Learning in an Engineering Senior Design Course

Erica B. Walker

Clemson University
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Introduction

Game-based learning is a novel approach for teaching a studio design course, especially within the domain of engineering. As a field, engineering is innovative by nature but is often highly focused on a certain type of learning with a strong emphasis on how to think in a logical, analytical, factual, organized, and structured way. One of the priorities of engineering education, in general, is to prepare students for future success within a chosen field, and this way of thinking will serve future engineers well, but professional engineers also need to be able to think creatively, problem solve, and work well with a team (ABET, 2014; Felder, 1996; Herrmann, 1995; Lumsdaine & Lumsdaine, 1995; Shuman, Besterfield-Sacre, & McGourty, 2005; Welsh, 2012). Classroom learning can be passive, but true preparation for a career requires self-activation and development of an ability to take intentional action (Apelian, 1994). Many programs look to studio design classes to provide students with this type of application-based learning opportunity. Studio design courses focus on teaching a diverse set of engineering and professional skills by mimicking the design process that students will perform after graduation as professional engineers. This type of course is developed to give students real-world experience and a chance to practice innovative design while still in the protected environment of the university setting.

In recent years, many involved in education have indicated that 21st Century Skills and epistemic frames are vital ingredients for successful, next-generation graduates. Design courses are ripe with opportunity to embed these important skills into the curriculum (Brouwer, Sykes, & Vander Leest, 2011; Lee & Wong, 2014; Matthew, Monroe-White, Turrentine, Shartrand, & Jariwala, n.d.; S. Zappe, Hochstedt, Kisenwether, & Shartrand, 2013). In this study, I present an investigation using game-based learning as a vehicle for embedding 21st Century Skills and epistemic frames.
within the domain content (subject-based, factual knowledge) of a Senior Design course in Bioengineering. The resulting narrative provides an examination into the process of converting a lecture-based bioengineering Senior Design course into a game-based course, but the story really began well before the first day of that course.

Background

In my first class as a doctoral student, I was given an assignment to design a mini-proposal for a qualitative research project. Having recently been accepted into the program, I did not know yet which direction my research was likely to take; however, I had a keen interest in entrepreneurial education, a term that later I felt was best defined as the transference of 21st Century Skills to students in a classroom setting. In my experience as an entrepreneur, a student, a parent of a student, and more recently, as an educator, I observed that the education system was very good at teaching and assessing factual knowledge, but that students were not necessarily grasping how those separate facts would later become relevant to the diverse demands of their lives and careers after graduation. From what I saw, there were plenty of intelligent students enrolled in college, but many of them did not seem to be equipped with the 21st Century Skills (such as working well in groups, communication skills, creative problem solving, etc.) necessary to excel in leadership roles within today’s competitive job market.

That early assignment was the first time I delved into the research literature to look for a way to understand what I was observing in undergraduate students. Up until that point, since I had just begun formal training in education, I had been relying on personal observations and casual conversations with other faculty with which to decipher what I was seeing in my classroom and, more broadly, in formal education as a whole. The instructors with whom I spoke recognized that current educational practices necessitate that students prior to college be taught with a focus on
standards-driven curriculum (Nodoushan & Ali, 2009). In order to ensure success on the required exams, teachers were forced to spend large amounts of time each school year preparing students for required tests and were therefore not able to spend as much time focused on exploratory, student-driven learning. When encouraged to respond with the “correct answer” to a question, students were more likely to carry a dualistic mindset further into their college careers. People with a dualistic mindset believe that there is only one right answer, that information comes directly from authorities, and that knowledge is either right or wrong, suggesting that all answers are black or white (Perry, 1968). Admittedly, there is a natural maturation process, normally during the college years, by which students move from a dualistic mindset to relativism, but the increased emphasis on students knowing the “right” answer over a “best answer based on context” could deter this growth. The disadvantage of measuring school achievement in this way was that we found ourselves encouraging students all to have the same “right” answers rather than producing individuals that had unique and innovative thoughts and became active participants in the creative problem-solving process (Perry, 1968, 1999; Woods, Felder, Rugarcia, & Stice, 2000). Yet, in recent years, the demand for a workforce that can produce innovative solutions had steadily increased. Companies needed employees who were able to transform their products and processes to meet the demands of a new, differentiated audience; they were not looking to hire college graduates who could simply answer questions correctly (Arastoopour, Golnaz, Chesler, & Shaffer, 2014; Coalition, 2014; Ernst, 1996; Shuman et al., 2005).

From my perspective, it seemed that a vital part of education is to prepare students for success after graduation; therefore, aligning what we should be teaching students with what they need to know to succeed after school is always an important educational question to consider (United States Department of Education, 2010). Through conversations with other faculty around
campus, many instructors were observing similar situations in their own classrooms. Again, I returned to the research literature and found that over a decade before, researchers had argued that the United States and other first-world nations were facing an educational crisis, one that closely aligned with what my colleagues and I were observing in classrooms across the university. This literature pointed out that young children were being prepared in the same way as they had been in previous generations (Ernst, 1996; Friedman, 2005). As a result, when they completed school, graduates would be prepared for commodity jobs … but those jobs would no longer exist. “Commodity jobs” refers to careers that focus on the manufacturing of commodities, goods that are mass produced and sold to households at a reasonable price: e.g. manufacturing positions where employees repeat specific tasks within the overall production process (Friedman, 2005). Yet, in many sectors, the modern economy was now looking to hire people who could do innovative, creative work as opposed to repetitive, task-based work. In order to better prepare students for this shift in demand within the current market, education needed to move towards teaching students to do the type of work that requires creativity and innovation rather than focusing on reproduction of standards and standardized skills (Ernst, 1996; Nodoushan & Ali, 2009; Saavedra & Opfer, 2012). This was a call to action for myself and other educators; in order to prepare students for this shift in the workforce, we needed to reevaluate how students were taught and how assessments were collected and measured.

As I dug deeper into the research literature, I focused on bringing 21st Century Skills, which have significant overlap with the development of the entrepreneurial mindset, into the classroom as a way to address these changing needs (Boyles, 2012). Therefore, I actively sought out faculty on campus and across the nation who were increasing 21st Century Skills as a vital and under-represented aspect of modern curriculum, or academic content, within their courses. I
asked them how this shift was impacting their classrooms, students, and curriculum. This search for other instructors with similar goals led me across campus and sparked conversations with faculty in many different disciplines. I even found myself venturing into buildings that I had not heard of before and speaking with members of departments far outside of my own discipline and college. As an instructor from a creative business major, I was in foreign territory when I first sat down to talk with a professor and a graduate student from Bioengineering. None of us knew it at the time, but that meeting between Dr. John DesJardins (an Associate Professor in BioEngineering), Ms. Bre Przestrzelski (a Ph.D. student in Bioengineering and a University Innovation Fellow), and me (a Lecturer in Graphic Communications and a Ph.D. student in Curriculum and Instruction) was the start of an unlikely partnership that would work together to transform the Bioengineering Senior Design curriculum at our university.

During our first meeting, I learned that Dr. DesJardins taught the Senior Design course for the Bioengineering Department. This two-semester-long capstone course began with fifteen weeks that focused on the foundational information necessary to engage in the design process during the second fifteen weeks of the course. The goal of the first semester coursework was to teach the domain content knowledge necessary for the second semester, which was experiential and hands-on in nature. During the second semester, students worked in small groups directly with an advisory team composed of clinicians, faculty, and staff to identify, develop, prototype, and test a new biomedical device. With the guidance of their advisory team, second semester students went through the bioengineering design process from beginning to end, starting with needs identification and progressing through to the final phases of the design process: participation in design competitions for development funding and submission of a patent application. During the second fifteen weeks of the course, students had the opportunity to “do” biomedical engineering
in a meaningful way that mimicked how a professional within the industry would engage with the process (Itabashi-Campbell, Gluesing, & Perelli, 2012; Shaffer, 2006). The overall goal of Senior Design was to provide opportunities for immersion in a real world experience and meaningful participation in the bioengineering epistemic frame with the important addition of the scaffolding and guidance afforded in the classroom. But the experiential learning aspect of Senior Design happened primarily during the second semester of the two-part series, which followed the foundational first semester of domain content.

As the lead instructor for the course, Dr. DesJardins had been delivering the first semester content using traditional pedagogy and domain content delivery methods, by employing a combination of lectures and guest lectures. This method of delivering the course content was initially implemented by the bioengineering department to standardize delivery across multiple instructors and sections of the course. Upon hearing Dr. DesJardins and Ms. Przestrzelski speak about the current course content and the desired learning outcomes, my mind began churning out dozens of “what ifs” and “could we” questions, due to the recent conversations and research articles with which I had been engaging. I envisioned an opportunity to embed entrepreneurial learning and 21st Century Skills within the context of practicing an industry-standard biomedical engineering process through a game-based learning approach to the first-semester curriculum. The course was supported by an NIH National Institute of Biomedical Imaging and Bioengineering Grant and a Venturewell Program Grant. Both grants encouraged classroom innovation and experimental curriculum development which would further support this approach for redeveloping the classroom experience. Based on guidance from curriculum experts, advisors, engineering education organizations, and the current research, we began to envision an opportunity to form a multi-disciplinary team, combine our different backgrounds
and skillsets, and rework the delivery methods of the first semester of this course. Through a partnership with Dr. DesJardins and Ms. Przestrzelski, we could infuse the course domain content (i.e. subject-based, factual knowledge) with opportunities for students to identify, practice, and develop the 21st Century Skills so important to success in an innovative, design-based field like bioengineering. We proposed that game-based learning techniques could be the ideal pedagogical tool to employ for this change.

It would be impractical to think that every type of course content or every teacher would be a fit for the implementation of game-based learning. However, both Dr. DesJardins and Ms. Przestrzelski were already involved in the promotion of design thinking and innovative learning techniques in various programs across campus and nationwide. Ms. Przestrzelski was a University Innovation Fellow (UIF), a member of a program sponsored by Venturewell and Stanford University that focused on campus innovation at the student level. As a UIF, she attended nation-wide conferences and events centered on bringing student-driven, ground-breaking programs to college campuses across the country. For her campus initiative, she and Dr. DesJardins co-founded a successful multi-disciplinary Creative Inquiry course called The Design and Entrepreneurship Network (The DEN). The DEN included students from many different majors and focused on entrepreneurship, ideation, networking with mentors, and providing the tools students needed to launch innovative ideas and businesses.

As a team, the three of us—Dr. DeJardins, Ms. Przestrzelski, and I—combined diverse, and perhaps even unlikely, backgrounds and skills, but together we were centered on common ground regarding the potential for the Senior Design course to increase student application of 21st Century Skills as they drew near to graduation and entry into the workforce. Before we
began the process of re-working the course materials for the first semester of Senior Design, we still needed to determine how best to disseminate the domain content (subject-based, factual knowledge) in an engaging and meaningful way. So the next step in the process was to delve into the current research regarding engineering education, design-based courses, flipped classrooms, and innovative pedagogy.

Soon after we met, an opportunity arose to be fully immersed in current engineering educational research by joining Dr. DesJardins and Ms. Przestrzelski at the “Open Conference” in Washington DC. Open is hosted by VentureWell, an organization dedicated “to fostering an emerging generation of young inventors and entrepreneurs driven to improve life for people and the planet” (“VentureWell Website,” n.d.). Conference presentations focused on design and innovation in the classroom and encouraged faculty and students to undertake solving some of the biggest wicked problems (i.e. problems that have no clear-cut, single correct answer) the modern world faces (Buchanan, 1992; Rittel & Webber, 1973; Walesh, 2012). Although the conference claimed to be multi-disciplinary, attendees and workshops focused on engineering education. Throughout the conference, there was a heavy emphasis on students developing 21st Century Skills and an entrepreneurial mindset through engineering coursework.

While attending the conference, I heard a definite call for change in how future engineers should be taught. Dozens of workshops focused on current classroom research where faculty employed pedagogical techniques such as game-based learning, improvisation, flipped classrooms, problem-based learning, and interactive classroom activities. The researchers noted a shift in their students, noticing increased active participation, domain knowledge mastery, and student development of 21st Century Skills. Faculty from engineering programs across the United States
shared evidence of classroom successes and failures. Although educators were calling for adjustments in engineering education and wanted to increase classroom research, many engineering faculty did not have training in curriculum development or access to the expertise and resources necessary to undergo this type of transition. Perhaps by partnering across departments, Dr. DesJardins, Ms. Przestrzelski, and I could leverage the diverse expertise and resources available from the School of Engineering, the School of Education, and the College of Business and add a different perspective to the current classroom research. By attending the Open Conference workshops, engaging in conversations with faculty from across the nation, and reading the available research, we began to lay the foundational ideas for re-working the Senior Design course. Engineering education was attempting to make strides towards adjusting both the content and the pedagogy, but the progress so far was limited because curricular resources were not available, and our research team could help fill that gap.

With the needs of our students at the forefront and by leveraging our team’s unique perspective and resources, we transitioned the Bioengineering Senior Design course. Utilizing a game-based learning approach, the domain content (subject-based, factual knowledge) was wrapped with opportunities for students to develop 21st Century Skills and an entrepreneurial mindset. The purpose of this mixed methods research was to examine the difference in self-reported 21st Century Skills between two groups of senior Bioengineering students enrolled in the design capstone course: students exposed to the course material through game-based learning techniques compared with students enrolled in the course section taught with traditional lecture pedagogy. An additional intent of this research was to detail the process a faculty team undergoes as they develop, deliver, and assess the effectiveness of a Biomedical Engineering design course using a game-based approach. Answering these questions would address a gap in current
classroom-based research regarding the development of 21st Century Skills and an entrepreneurial mindset in tomorrow’s engineers.

Review of the Literature

This literature review examines several areas of research that are key to this study. First, the history and current standards for engineering education in the United States will be explored in order to determine what content integral for engineering education and the preparation of future engineers. A broader look at education, as a whole, is needed to understand the drive for incorporating the 21st Century Skills across many disciplines, including engineering. Much research has been conducted on how to effectively teach the entrepreneurial mindset in a classroom setting and this literature needs to be considered as well. The literature defining games and game-based learning as a potential pedagogy for this study are reviewed next followed by literature on epistemic frames. Finally, the literature regarding cognitive apprenticeship as an overarching framework for the development and delivery of the intervention will be explored.

Standards for Engineering Education

The United States’ British and French roots influenced the early engineering industry in the country. In Britain, engineering had entrepreneurial roots where young men interested in the career learned by taking apprenticeships and working directly with master practitioners. On the contrary, in France, the first Civil Engineering Corps was designated by King Louis XV. An engineering career with the French Corps required higher education and as a result placed young men at the forefront of society. The historical influence from these two very different paths to a career in engineering deeply influenced the field and the direction of American engineering...
education as it is practiced today (Apelian, 1994; Emmerson, 1973; McGivern, 1960). When today’s engineering programs attempt to wrap both the apprenticeship experience and the classroom knowledge into a four-year program, the difficulty of these varied influences can be clearly seen. Engineering programs have discovered that four years is not enough time to incorporate both styles of education. As a result, either the domain-based, theoretical knowledge or the apprentice-based, practical knowledge is sacrificed within the program curriculum to meet the standard four-year degree cycle.

In modern engineering education, national organizations such as the Accreditation Board for Engineering and Technology (ABET) and the American Society for Engineering Education (ASEE) develop annual reports detailing the current state of and national recommendations for engineering education programs. Both organizations have long recognized the value of preparing American engineers with more than just discrete domain knowledge. As the current economy continues to shift towards smaller companies and greater demand for technical, innovative workers instead of commodity workers, these organizations continue to task engineering programs with adapting to meet those needs (Ernst, 1996). The call for situating technical education in the broader context of general education, including an emphasis on entrepreneurial traits, has been promoted by organizations such as ABET and ASEE for decades (Apelian, 1994; Ernst, 1996; Kriewall & Mekemson, 2010; Shuman et al., 2005). Initially introduced in 1996, ABET’s current set of criteria includes six professional skills (d-j):

(d) an ability to function on multidisciplinary teams
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in lifelong learning
(j) a knowledge of contemporary issues (ABET, 2014)
For almost twenty years at the time of writing, these professional skills have been a stated part of the criteria for evaluating and accrediting engineering programs.

This list of ABET’s professional skills is similar to the goals of entrepreneurial education, including skills such as communication, teamwork, and the tools and drive to pursue lifelong learning. These goals are also in line with other lists of traits that are currently being championed in modern curriculum across many disciplines. They are often grouped together and referred to as 21st Century Skills.

Demands of the New Workplace: Defining 21st Century Skills & the Entrepreneurial Mindset

In education, as a whole, there are as many lists of “vital skills” to teach students as there are policy makers debating educational reform. This study focused on two categories of these lists, and both share more commonalities than differences: the entrepreneurial mindset and 21st Century Skills. Educators often feel frustrated when trying to determine what skills are necessary for today’s students because there is not a consensus on a single set of 21st Century Skills (McComas, 2014). Another hindrance for the wide adoption of 21st Century Skills as the backbone of modern curriculum is that the variety of skills included on these lists is broad and many are not traditionally part of school curriculum but are more conventionally taught as part of family and personal culture (Saavedra & Opfer, 2012). Yet family structure and national culture are continuing to change, and the modifications are not always aligned in a way to prepare all children with the skills necessary to succeed in the modern workplace. Therefore, many students lack opportunities to learn these skills outside of their formal classroom spaces. In order to fill these gaps for all students and better prepare them for their future careers, 21st Century Skills are...
becoming more prominent as an integral part of formal education (Saavedra & Opfer, 2012). Some of the skills found on these lists include life skills such as flexibility and adaptability; workforce skills such as collaboration, the ability to lead, and teamwork; applied skills such as analyzing information and effective communication; and personal skills including curiosity, imagination, critical thinking, and problem solving (Apelian, 1994; Bellotti, Bottino, Fernández-Manjón, & Nadolski, 2014; “Education for the 21st Century,” n.d.; Saavedra & Opfer, 2012). Many of these traits are not easily conveyed via assignments or readings and require that students are motivated to possess these skills. Additionally, these traits can be difficult to assess using traditional classroom assessment methods.

Two of the major organizations working to drive change within education are the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and the Accreditation Board for Engineering and Technology (ABET), which serves as an accreditation organization for engineering and science educational programs. According to their website, UNESCO specifies the following 21st Century Skills as necessary for student success as they enter the workforce: collaboration, knowledge construction, self-regulation, real-world problem-solving, innovation, use of information and communications technologies for continued learning, and skilled communication (“Education for the 21st Century,” n.d.). Perhaps even more directly relevant to engineering education is how ABET defines 21st Century Skills, since they serve as the accreditation body for higher education engineering programs across the country. In the Roadmap to the Future of Engineering Practice, Research, and Education (2008), emphasis is placed on discovery, innovation, and entrepreneurship as the backbone of engineering education. The Roadmap also notes that 21st Century Skills such as interdisciplinary knowledge, group skills, and effective communication are considered vital ingredients in preparing students for
participation in the technological, innovative environments common in today’s workplace (Duderstadt, 2008). Both of these organizations, among many others across diverse disciplines, note the importance of teaching students 21st Century Skills as an integral part of formal education (see appendix for visual diagram of terms).

Even though they have different names and come from unique sources, these lists share many common objectives. The entrepreneurial mindset and 21st Century Skills are not synonymous, yet the overlap between the two is undeniable. By focusing on the commonalities between the lists of traits, educators can provide opportunities for students to develop traits from all of these lists of skills. The call for educational reform comes from many sources and points to the fact that preparing students for life after school cannot be so heavily focused on the transfer of independent facts and knowledge. The initiatives and research surrounding 21st Century Skills and the entrepreneurial mindset point educators in the direction of encasing the subject-based, factual knowledge students need for success in a thick coating of real-world, entrepreneurial skills. Although both sets of traits are relevant for tomorrow’s engineers, this study will use the term “21st Century Skills” when referring to this collection of important entrepreneurial skills including life skills such as flexibility and adaptability; workforce skills such as collaboration, leadership, and teamwork; applied skills such as information analysis and effective communication; and personal skills including curiosity, imagination, critical thinking, and problem-solving. With this ideal in mind, educators can embrace the long-term goal of preparing students, not just for the next exam, but for development as creative problem-solvers ready to face modern challenges with innovation and an entrepreneurial mindset.
Teaching the Entrepreneurial Mindset

With the idea that 21st Century Skills can be taught by incorporating opportunities to learn and practice entrepreneurial traits, it was also important to explore current research on entrepreneurial education. According to research, learning of the entrepreneurial mindset can be improved when instructors implement applied methodology in the classroom instead of focusing solely on a theory-based approach. Applied methods are more closely aligned with the empirical essence of entrepreneurship itself, since a learner with a developed entrepreneurial mindset tends to learn best through the active process of doing and then reflecting (Harrison & Leitch, 2005; Pittaway & Cope, 2007; Zimmerman, 2012). Yet successful entrepreneurs tend also to be experts within their field, so theory-based knowledge can not be ignored. One segment of recent cognitive research, a model called Cognitive Apprenticeship, defines four types of knowledge necessary for expertise: domain knowledge, heuristic strategies, control strategies, and learning strategies (Collins & Kapur, 2014). Prior to engaging in the applied aspect of practicing entrepreneurship, it is necessary for students to build a strong base of content, or domain knowledge, within their chosen field. Special interest knowledge, general industry knowledge, prior knowledge of markets, prior knowledge of customer problems, and knowledge of ways to serve a specific market will increase the likelihood of opportunity recognition, a crucial step on the pathway to innovative problem solving which can lead to opportunities to practice the entrepreneurial mindset (Degan, 2012; Politis, 2005). With a strong base of domain knowledge, innovators are freed up to think creatively and are therefore able to identify opportunities to solve unique problems. Not all studies show an increase in entrepreneurial self-efficacy due to exposure to entrepreneurial education. Additional exposure to a topic can highlight the breadth of needed knowledge and highlight possible obstacles, therefore decreasing students' confidence.
in their readiness to launch an entrepreneurial venture (Duval-Couetil, 2016; Krueger & Brazeal, 1994). However, it is important to note that not all students will want to become entrepreneurs, but the entrepreneurial mindset is not comprised of skills that are only useful to entrepreneurs. Being skilled in verbal and nonverbal communication, group work, problem-solving, lifelong learning, and collaboration is useful in many life situations, both inside and outside of the workplace (Saavedra & Opfer, 2012). Whether a student chooses to become a business owner or decides to take a position within an established company, aspects of the entrepreneurial mindset will serve them in either situation.

Within many university departments, specific domain knowledge has normally been covered during the first few years of university course work within a specific major. During their senior year, students often have opportunities to specialize, build upon earlier content knowledge, increase the depth of their learning, or perhaps even practice implementing their domain knowledge. Accordingly, by focusing entrepreneurial coursework in the final capstone course within a major, programs could provide opportunities for a class to focus on the entrepreneurial mindset and 21st Century Skills required for innovative thinking (Brouwer et al., 2011; S. E. Zappe, Hochstedt, & Kisenwether, 2013). The more knowledge that students acquire in their field of interest prior to this capstone course, the greater their ability for creative problem solving, allowing them to practice opportunity recognition and identify chances to innovate within their chosen field (Degan, 2012; Weisberg, 2006). By leveraging students’ prior domain knowledge, faculty can focus class time on guiding them through the practice of design thinking.

Another goal for 21st century education is to provide students with multiple chances to evaluate, explore, and increase their entrepreneurial mindset. An entrepreneurial mindset involves
recognizing problems as a chance to innovate, even when a solution initially appears to be impossible (Kriewall & Mekemson, 2010). At this point, creativity and other 21st Century Skills become a vital part of student success. Senior capstone design courses provide real world opportunities for students to choose an “unsolvable” or wicked problem and come up with an innovative solution, working through the entire creative problem-solving process with the scaffolding and guidance afforded in an educational environment (Matthew et al., n.d.; Oman, Tumer, Wood, & Seepersad, 2012). For this study, “21st Century Skills” has focused on the overlapping terms between the entrepreneurial mindset and 21st Century Skills, keeping the research that informs entrepreneurial education in sight throughout the study.

There are many different approaches to pedagogy that could be used to implement 21st Century Skills into the classroom. The answer is not one-size-fits-all because the “best” style of teaching is highly dependent on the faculty, the students, and the content covered in a course. Each instructor has natural strengths in certain types of delivery methods. Some faculty may be most effective when using discussions to teach while others may thrive in lab situations where students learn through hands-on activities. Additionally, the students within a course vary year over year, which requires constant adaptation in pedagogy to meet their needs. Different content domain areas are more suited for certain types of delivery methods than others. One pedagogical option that had recently gained recognition in engineering education is game-based learning. In order to explore this option further, our faculty team next investigated literature regarding games and how they were being used in the classroom.
Defining Games

When looking at the role that digital games play in today’s youth culture, it comes as no surprise that interest in the incorporation of digital video games into the realm of education has steadily grown over the past several decades. Gaming is a multi-billion dollar industry that already touches nearly every household in America and games have proven to capture and hold the sustained attention of players (McClarty et al., 2012). It is important to note that although the overwhelming majority of current research with games used in the classroom employs digital games, the term should not be limited to only technology-based games. Games and game design are comprised of a wide variety of media types and are, in and of themselves, transmedial (i.e. games are separate from a given media type and can be created, with the same objectives, for a variety of different final delivery platforms) (Deterding, Dixon, Khaled, & Nacke, 2011). Although digital games are not the only games with benefits for the classroom, the majority of the current literature focuses on the incorporation of digital games in learning environments.

The benefits of play as a vehicle for learning have been explored for more than a century, and the emergence of digital educational games began to gain tremendous momentum in the 1990s (Nodoushan & Ali, 2009). With the increased demand for students to retain and reproduce knowledge for standardized tests, implementing opportunities for play through educational games can help increase engagement and retention (Wheatley, 1999). Several recent studies have looked at the effectiveness of using games as a tool for increasing active learning and retention within the classroom setting. One study focused on using entertainment as a vehicle to increase knowledge retention with nursing students. Although the study did not strictly use game-based learning, the researchers looked at the use of laughter and “fun” methods in comparison to
traditional lecture- and book-style methods of teaching a nursing course. They found that entertaining educational activities can produce deep-level learning for students. The study reported that nursing students enrolled in the course that used entertaining methods of content delivery self-reported a more positive learning experience and greater retention of the course materials. In the study, researchers found that these techniques could be used to teach domain knowledge and at the same time to help students develop 21st Century Skills such as debate, critical thinking, clinical reasoning, resolution, and prioritization (Baid & Lambert, 2010).

Although the results of this study were promising, we noted the important point that the results of this study might not be replicable in our project due to class size and reliance on self-report as the only data point.

Implementation of a flipped classroom approach has also been a subject of much recent research. A flipped classroom approach refers to a pedagogical process where students are provided with lecture-type material prior to the class meeting and the classroom time is used primarily for active learning activities (Gross, Pietri, Anderson, Moyano-Camihort, & Graham, 2015). A course that employs a flipped classroom approach could provide additional classroom time for active participation in game-based learning. But defining a measurable increase in the effectiveness of this approach has been difficult. In a recent study, researchers found a 12% increase in student performance on exams in a physical chemistry course between a control and intervention version of the course. The intervention group used active learning techniques such as small group student activities, clicker responses, and example problems, and results were compared with students enrolled in a passive learning, lecture-style control group (Gross et al., 2015). Although this study showed a significant impact on student exam grades, more studies need to be conducted to validate the results and see if positive results can be replicated across different
classrooms and content areas. Yet this research does point to the potential value of using a flipped classroom approach in order for instructors to utilize valuable classroom time to encourage active engagement with the course material.

In a study that implemented a control and intervention group design in a chemical engineering course, researchers found an increase in student satisfaction with the classroom environment and a positive impact on the course learning outcomes. In this study, the course was offered using two different pedagogies, traditional active learning as the control and game-based learning strategies as the intervention version. The control section of the course included a combination of direct lecture and active learning techniques such as clicker questions, think-pair-share, group discussion, etc. The intervention section was taught using the same methods mentioned above combined with game-based learning strategies. The preliminary results identified a higher satisfaction with the classroom environment and a self-reported increase in 21st Century Skills such as critical thinking, problem solving, group work, and communication in the students enrolled in the game-based course (Bodnar & Clark, 2014). Although the results are still preliminary, they provide evidence that researchers should continue to analyze whether game-based learning does have a significant positive impact on student learning.

Based on the findings from these three research studies, games and other forms of active classroom learning could be used to disseminate content-based knowledge while also providing opportunities for students to develop 21st Century Skills such as creativity, innovation, collaboration, communication, and problem solving, but more studies are needed. Games, both those that are created for educational purposes and those that are purely marketed for entertainment, provide safe learning experiences that can include opportunities for play,
exploration, failure, problem-solving, and immediate feedback all within a highly controlled and easy to assess format. In fact, failure with limited consequence, agency, and choice are seen as critical elements of a true gaming experience (McClarty et al., 2012). Agency refers to a student’s ability to interact with the material and implies that players have choices within the game on how to proceed through the gameplay (Jalongo, 2007).

Several terms have gained popularity in recent years to describe the intersection of games and education including gamification, gameful learning, serious games, and gamified. Although not every researcher defines these terms the same, many do agree that they have overlapping but unique definitions that stem from the term “game” (Avedon & Sutton-Smith, 1971; Deterding et al., 2011). It is important to clarify the definition of games since various professions use the word “game” differently: military and business settings define it based on logistics; anthropologists and folklorists in terms of historical origins; educators in terms of curriculum tools; social scientists in terms of psychological diagnostics or research tools; and recreational guides as program content (Avedon & Sutton-Smith, 1971). Apart from differences in professional definitions, individuals define games differently on a personal level as well; children often think of physical games such as jump rope or hide and seek but many adults are more likely to think of cards or board games when picturing themselves playing a game. Preference of hobbies can also affect people’s definitions: athletes commonly think of an athletic event as a game, but gamers think in terms of digital video games. In other words, there is evidence that the meaning of games is, in part, a function of the individual’s perspective and the context of the game within the player’s life.

For the purpose of this research study, “games” were defined with a rather broad point of view, thinking of them as a system in which players engage in artificial conflict, defined by specific rules.
that result in a quantifiable outcome. What did not qualify as a game within the context of this study helped to further define the term. Games, in this study, excluded fully virtual worlds, because they often do not require measurable outcomes, and educational activities that contain elements of “gamification,” such as the implementation of game-like mechanisms (badges or levels) combined with traditional teaching methods to increase motivation or engagement (Deterding et al., 2011; Gee, 2003; McClarty et al., 2012; “The Ecology of Games,” n.d.). An important aspect of games is that they allow players to make choices within a protected environment where the consequences of wrong decisions do not reach into the player’s “real life.” Players can explore the effects of their choices based on immediate feedback and start the game over as many times as necessary to figure out the best choices and ultimately win the game. In other words, games need to have rules, an element of competition, player agency, and a measurable outcome.

For educators concerned with preparing students for future careers, marketability in the modern workforce could be increased through exposure to both content-based knowledge and experiential knowledge. Perhaps, by combining these two types of learning into a mixed pedagogical approach that included game-based learning, educators could impart the necessary domain content facts and 21st Century Skills needed to better prepare students for that future career. At the higher education level, yet another important aspect of knowledge and preparation should be considered: the epistemic framework needed to participate in a particular industry.

Defining Epistemic Frames

By the time students are studying at the University level, they spend much of their classroom time in courses that prepare them for a particular career path. Shaffer (2006) introduced the
idea of epistemic frames that could be used to scaffold students in the classroom. The epistemic frames model builds on the theory of “islands of expertise,” which focuses on developing frames as a mechanism through which a person can use experiences and knowledge from one context to help them deal with new, different situations (Crowley & Jacobs, 2002; Shaffer, 2006). Often, in education, this idea is called “transfer,” referring to the importance of being able to take knowledge from the classroom and apply it to other similar circumstances. In this sense, epistemic frames are a collection of terms, ways of knowing, and collective problem solving within a community or profession (Shaffer, 2006). These epistemic frames are created and maintained by an industry itself, not through any formal arrangement, but by practitioner agreement and use. Industry-specific epistemic frames could be a helpful part of preparing students for their future careers.

As an example of this theory in practice, medical doctors, like all professions, have a unique epistemic frame. They have a collection of terms, a way of going about decoding a patient’s symptoms, and a body of knowledge that is specific to those trained to practice in that profession. This shared vocabulary and knowledge base allow medical professionals to communicate collectively to solve problems. The same is true for any industry. A very different example may be found in the epistemic frame of the movie industry. Professionals in this industry adopt job titles such as gaffer, grip, production assistant, and frequently use terms like “that’s a wrap,” “in the can,” and “the martini shot” to communicate with others in the industry. These terms of communication and shared knowledge creation do not have the same meanings and can even seem nonsensical to those outside of this business.

Shaffer (2006) continues to describe epistemic frames by stating that they:
... are a form of knowing that comprise, for a particular community, knowing *where* to begin looking and asking questions, knowing *what* constitutes appropriate evidence to consider or information to assess, knowing *how* to go about gathering that evidence, and knowing *when* to draw a conclusion and/or move on to a different issue.... (p. 228)

Based on that definition, we determined that not only do different industries have unique epistemic frames that they operate within, but that it would be very beneficial for students to become steeped in the epistemic frame of the industry they hoped to join after graduation (Nodoushan & Ali, 2009; Tetrick et al., 2013). For the purpose of this study, epistemic frames included terminology, ways of attacking problems, and specific methods of creating and defining knowledge that are unique within each professional community. Practitioners within a certain industry create a shared epistemic framework—a collective way of thinking, communicating, and generating knowledge that is specific to members within their own trade.

Being well-versed in the epistemic frame of their desired career would allow students to literally speak the language of their future profession and troubleshoot problems using methods that are accepted within that industry (Arastoopour et al., 2014; Tsai, Chai, Benjamin Koon Siak Wong, Hong, & Tan, 2013). Therefore, when students join the industry after graduation, they will be better equipped to do so as a contributor and problem-solver instead of as a commodity worker. As yet, there is no consensus in educational research on how this can best be accomplished in the classroom, so potential pedagogical options still need to be determined.

There are several well-researched teaching methods available that can introduce students to epistemic frames in a classroom setting, such as the case study method; another option would be
the use of epistemic games (Ellet, 2007; R. K. Yin, 2003; Robert K. Yin, 2011). An epistemic game allows student-players to work and problem-solve within the context of the epistemic framework from a specific profession (Nodoushan & Ali, 2009). More specifically, an epistemic game allows students to experience critical thinking opportunities and the professional culture through a game scenario. The development of epistemic games is expanding quickly, especially in the realm of science and engineering education. In these two fields specifically, epistemic games are useful in order to allow for problem-based educational experiences without the cost and difficulty in scheduling internship and coop programs (Chesler et al., 2015). These immersive experiences help students further understand the industry they hope to one day enter and allows educators to better guide and evaluate deep student learning. In a game scenario, both poor decisions and good decisions may have grade ramifications or affect the gaming world results, but they do not have the risky consequences of affecting live consumers and the company itself as they would in an internship situation.

By providing a low-stakes environment, epistemic games allow students to participate in the process of knowledge creation and problem solving within an industry’s epistemic frame (Arastoopour et al., 2014; Chesler, Bagley, Breckenfeld, West, & Shaffer, 2010). Therefore, “epistemic games” were defined for the purposes of this study as learning environments where students would be able to “act like a professional” within a simulated real-world scenario. Studies have found that students who participate in immersion within the epistemic frames of their profession, whether through games or internships, while in school benefit in several ways. A long-term benefit is that they are more likely to be confident after graduation in communicating and collective problem solving necessary for success in their specific industry (Arastoopour et al., 2014; Chesler et al., 2015).
Building Within a Framework: Cognitive Apprenticeship

Up until this point, the important types of knowledge included and the pedagogy used in the classroom had been explored within the research literature, but the framework used to build this type of classroom experience still needed to be determined. One framework we considered promising for developing the Senior Design course, “Cognitive Apprenticeship,” is explored in depth below.

The cognitive apprenticeship framework could provide an option to answer the call for change posed by modern engineering programs and perhaps other disciplines as well. Historically, engineering programs found it difficult to address both necessary aspects of learning engineering, theoretical knowledge and hands-on learning, within the short four-year degree cycle. By combining opportunities for both types of learning, the cognitive apprenticeship model could address that need. Through implementation of a cognitive apprenticeship model in the classroom, domain content could be combined with practical knowledge and practice. Instructors could emphasize epistemic frames as they modeled current practices of the industry for students. Curriculum could provide scaffolding for students as they moved from passively watching instructors model the thought process to the point where they were ready to propose new wicked problems and look for potential solutions using the tools they had learned. By combining the strengths of the cognitive apprenticeship model to address both the domain content knowledge and the experiential element of 21st Century Skills, capstone design courses built with this model in mind could better prepare soon-to-be graduates for their future careers.
Cognitive apprenticeship, as a framework for educational environments, builds on the model of traditional apprenticeships that were widely used for centuries to train up the next generation of tradesmen within a field (A. Collins, Brown, & Newman, 1989). Some industries today still operate on a modified apprenticeship model. One modern example is the on-site training for new practitioners in the medical field, which is often called “residency” (Stalmeijer, 2015). The traditional model of learning alongside a master practitioner who provides guidance through the processes necessary for a career within a trade carries through in cognitive apprenticeship. In this framework, educators guide students through the cognitive and metacognitive processes necessary to perform tasks within an industry. In other words, with the cognitive apprenticeship model, learning is focused on the process of cognition, thinking about how an expert in the field thinks about their tasks and teaching students how to replicate those thought processes.

Cognitive apprenticeship is based on implementing four principles when designing learning environments: content, methods, sequencing, and sociology.
Table 1

*Principles for Designing a Cognitive Apprenticeship Environment in the Classroom (Collins & Kapur, 2014)*

<table>
<thead>
<tr>
<th>Content: Types of knowledge required for expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domain Knowledge</strong></td>
</tr>
<tr>
<td><strong>Heuristic Strategies</strong></td>
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<tr>
<td><strong>Control Strategies</strong></td>
</tr>
<tr>
<td><strong>Learning Strategies</strong></td>
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</tbody>
</table>

<table>
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<tr>
<th>Methods: Ways to promote the development of expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Modeling</strong></td>
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<tr>
<td><strong>Coaching</strong></td>
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<tr>
<td><strong>Scaffolding</strong></td>
</tr>
<tr>
<td><strong>Articulation</strong></td>
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<tr>
<td><strong>Reflection</strong></td>
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<tr>
<td><strong>Exploration</strong></td>
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<tr>
<th>Sequencing: Keys or ordering learning activities</th>
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<tbody>
<tr>
<td><strong>Increasing complexity</strong></td>
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<tr>
<td><strong>Increasing diversity</strong></td>
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<tr>
<td><strong>Global to local skills</strong></td>
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<tr>
<th>Sociology: Social characteristics of learning</th>
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<tbody>
<tr>
<td><strong>Situated learning</strong></td>
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<tr>
<td><strong>Community of practice</strong></td>
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<tr>
<td><strong>Intrinsic motivation</strong></td>
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<tr>
<td><strong>Cooperation</strong></td>
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</table>

Content is broken down into four subsets (see Table 1). The first is domain knowledge, which includes specific concepts and facts from a field. The other three subsets can be loosely grouped
together as strategies—heuristic (tricks of the trade), control (general metacognitive practices), and learning strategies (understanding how to learn more), all focused on the specific context of a field. The combination of domain knowledge and the three types of strategic knowledge constitutes the necessary learning needed to practice as an expert within a field (Collins & Kapur, 2014; Stalmeijer, 2015). By designing course content to cover all four areas of knowledge, students will be equipped with the knowledge of how to think like a practitioner in the industry.

In the cognitive apprenticeship model, methods focus on how a teacher and student interact in the classroom in order to promote learning and eventual expertise. Collins, et al. (1989) include six methods of student-teacher interaction- modeling, coaching, scaffolding, articulation, reflection, and exploration. Modeling, coaching, and scaffolding are directly related to traditional apprenticeship where an instructor performs (models) a particular task for students to watch then facilitates (coaches) while students try to perform the task and provides support (scaffolding) in order to help students perform the task (Stalmeijer, 2015). The next two methods, articulation and reflection, provide students with a chance to step back and analyze what they have done so far. Articulation provides an opportunity for students to reiterate their process out loud and reflection allows students to compare their performance with other examples of how to do the task. The final step, exploration, encourages students to identify and propose their own problems to solve (Collins & Kapur, 2014). By combining all of these teaching methods, instructors can guide students from the initial steps of watching a process, to doing it themselves, and finally into reflection on the experience. The final step in methods would be to have students apply the knowledge gained to a new problem.
Sequencing within the framework of cognitive apprenticeship emphasizes the importance of the order of learning activities. This framework calls for an increase the complexity and diversity of tasks over time to encourage continual challenges and student growth while working through the classroom material (Collins & Kapur, 2014; Stalmeijer, 2015). This process enables students to grasp a broader application of skills across various contexts and encourages knowledge transfer. Presenting students with a global view of the overall task prior to drilling down to performing and learning the local skills is also an important point to consider when sequencing course content and situating the student within the process while they learn.

The social aspect of learning is of great importance in the cognitive apprenticeship model. Traditional apprenticeships are, by nature, social affairs. An apprentice would work side-by-side with experts and have access to ask questions while they observed the master perform tasks. The sociology principle of cognitive apprenticeship is divided into four subcategories: situated learning, community of practice, intrinsic motivation, and cooperation (Collins & Kapur, 2014). With situated learning, students participate in learning activities within realistic contexts. Community of practice encourages students to see that there are different ways to successfully complete tasks. Encouraging students to develop intrinsic, or internal, motivation to complete situated tasks is an important aspect for developing lifelong learning habits which can lead to long term success in a field. Finally, the cognitive apprenticeship model emphasizes teamwork and cooperation with the inclusion of team-based projects and learning activities (Collins & Kapur, 2014; Stalmeijer, 2015). With purposeful guidance in regards to the social aspect of classroom learning, educators can leverage the positive impacts of social learning to help students meet learning objectives.
Research surrounding cognitive apprenticeship was initially broad including exploration in
disciplines such as science, reading, writing, nursing, and vocational education (A. Collins et al.,
1989; Futtersack M., 1994; Hennessy, 1993; Taylor & Care, 1999). Although this model is still
mentioned in medical educational research, most recent research is applied to the study of digital
learning environments focusing mostly on online and hybrid programs (Dennen, 2004; Mitterer
& John, 2006). However, with recognition of the value of internship and co-op programs for
experiential learning, the cognitive apprenticeship model should be reconsidered in a broader
context again. Although the valuable experience of an professional internship can not be fully
replicated inside a classroom, this model could provide alternatives for the high cost and risk of
inexperienced students practicing out in the field and create opportunities for students to
develop situated epistemic frames while still in the controlled safety of a classroom environment.
Instructional Design: Developing the Classroom Experience

In this section, I outline the process used to create the game-based classroom activities, covering topics such as which factors were stabilized between the control and intervention groups, how the classroom objectives for each day were determined, and how activities were developed to address each objective. By walking the reader through our procedure and reasoning, I hope to make it feasible for other interested faculty to apply the same development process to their own courses.

The course that served as the control group ran during the fall semester of 2014. The Senior Design course in Bioengineering is two semesters long. The course begins in the Fall with a semester of domain content, classroom-based learning followed by the Spring semester course where student teams apply their knowledge of the design process, learned during the Fall semester, in order to work on design projects situated in real life biomedical scenarios. When we developed the curriculum for the Fall semester of the course, we stabilized as many factors as possible between the two versions of the course, including the class size, the student population, the time and days the class met, the room, and the instructor. We also kept the same course objectives and final exam for both sections of the course. The control group had an enrollment of 76 students (n=76) and the intervention group had 82 students (n=82). The students were all Bioengineering majors, within a year of graduation. The course met twice weekly from 8–9:15 AM, Tuesday and Thursday, and the classroom meeting space was consistent both semesters as well.
The classroom had multiple display screens that projected the instructor’s computer, ten double-sided moveable whiteboards, and pod-type groupings of chairs around circular tables (see Figure 1). Dr. DesJardins taught both sections of the course with the help of five to six graduate assistants during each class period. The graduate assistants had similar demographics (graduate students in bioengineering, completed undergraduate engineering degrees at Clemson or other universities, a mix of male and female, etc.) but were different students each semester as assigned by the department. Both sections of the course utilized the same textbook, *Biodesign: The Process of Innovating Medical Technologies* (Zenios, Makower, & Yock, 2010). The textbook had many supplementary resources, including access to online videos. Readings were assigned prior to class for both sections. In addition, both versions of the course included seven guest lecturers, most of whom were the same between semesters, but two of whom were different people within the same area of expertise due to scheduling conflicts. Each scheduled guest lecture added a specific knowledge proficiency necessary for the domain content of the course.
Figure 1. Layout of the classroom for BIOE 4010 for both the control and intervention sections of the course.

The most notable distinction between the control group and the intervention group was the intervention itself, the delivery method of the course material. The control section was taught primarily with seventy-five minute lectures. Conversely, during the intervention group, the domain content was presented in a flipped classroom format. In a flipped classroom, lecture content is presented prior to classroom time either through readings, audio recordings, or video lectures that students consume on their own. Then classroom time is used primarily for activities relating to the content that focus on engaging students with the material and the instructor. Prior to each BIOE 4010 class meeting, students completed assigned readings and supplementary videos then took a ten-question auto-graded quiz. Quizzes were pulled from a bank of thirty to forty questions and the ten questions chosen were randomized for each student. Questions were
developed by the lead faculty for the course based on the book publisher’s end-of-chapter reviews, the supplementary videos, and the provided instructor-created slides. Teaching Assistants assembled and tested the quizzes prior to dispersion and occasionally provided edits or additional questions from the same originating sources. Students were allowed to take the quiz multiple times in order to improve their score, but each time they took the quiz, the randomizer produced a different set of test questions.

By utilizing the flipped classroom format in the intervention section, the seventy-five-minute classroom time was primarily leveraged to emphasize domain content knowledge through active participation in games and activities. Therefore, classroom time was designed to teach students the other three types of content necessary to attain expertise through the cognitive apprenticeship model: heuristic strategies (general techniques within an industry to solve a problem), control strategies (general approaches for moving through the design process), and learning strategies (ways to find further knowledge about a topic to solve future problems) (Collins & Kapur, 2014; Dennen, 2004; Hennessy, 1993; Pieters & de Bruijn, 1992; Stalmeijer, 2015). The class periods combined short lectures, activities, games, and reflections. Each class was customized individually and time was allocated depending on what was needed to best support the learning objective(s) for that class period.

The process of developing the intervention classroom plans involved many iterations and included input from both content and curriculum experts from across diverse areas of expertise including engineering education, bioengineering, curriculum development, measurements, entrepreneurial education, and game-based learning. During the development of the intervention curriculum, Ms. Przestrzelski and I worked closely together. She brought the perspective of being
a graduate student in bioengineering (content expertise) and an active participant in game-based learning (pedagogical experience) to the course preparations. During this phase, I brought the perspective of having experience with curriculum development, assessment, and game-based learning. By considering multiple expert opinions, across diverse backgrounds, we hoped to best serve the needs of the course material, the students, and the instructors during the planning and curriculum development process. The next steps included studying the original lecture slides, speaking in-depth with Dr. DesJardins regarding his goals for student learning in each class, honing in on the instructor-identified “take-away” points, and confirming that those points aligned with the exam material from the control semester.

We began curriculum development by first determining that the initial course schedule successfully employed the sequencing aspects of cognitive apprenticeship. To do this, the schedule needed to increase in complexity and diversity over time and introduce students to the big picture before delving into the details. One way to fulfill that aspect of the cognitive apprenticeship framework was to begin with a game or activity that looked at a global application of the particular knowledge first, then have students apply the skills and knowledge gained on the initial problems to more difficult biomedical engineering contexts.

First, we took the class schedule from the control group section and laid it out in a spreadsheet to align the class dates with the associated book and supplementary material, keeping the order of the coursework consistent with the control section of the course. Then we reviewed all the slides for each class day and summarized the material. At that point, Dr. DesJardins was asked to pinpoint a few of the most important “take-aways” from each of his lectures. We defined “take-aways” as the point during a lecture where an instructor might emphasize a particular
aspect of the material and say “if you remember only one thing from lecture today, this is what you should focus in on.” Finally, we cross-referenced the old and new course plan with the current exams to confirm that the same domain content was being covered in both versions of the course.

Table 2

<table>
<thead>
<tr>
<th>Class number</th>
<th>Date</th>
<th>Proposed Topic Covered</th>
<th>Lecture #</th>
<th>Dr. DesJardins Notes</th>
<th>Quiz</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8/25/2015</td>
<td>Introduction to Medical Device Design</td>
<td>Lecture 1</td>
<td>Slide 22 up. Careers within the design process. TA's get links to 4 job adverts for each position</td>
<td>quiz on Stage 1 &amp; 2</td>
</tr>
<tr>
<td>10</td>
<td>9/24/2015</td>
<td>Needs Filtering</td>
<td>Lecture 9</td>
<td>5 minute lecture and 5 minute reflection</td>
<td>quiz on chapter 2.5</td>
</tr>
</tbody>
</table>

** Additional Materials**

- **Most Important Takeaways**
  - Design methodologies; to design something is a PROCESS that could be different depending on what industry you’re in; specific to biotech medtech industry; design is more than just creating - it is a process; lots of paperwork; different models of design process; definition of design (define the underlined terms in this course); Slide 9 = definition needs to be emphasized; six sigma overview slide = Slide 20; six sigma is designing out problems before they occur, getting ahead of the problems and design solutions; slide 22 - place roles in the chart, type of person best for each role

- **Ideas for Games/Activities to address takeaways**
  - SLIDE 22 in lecture 1: Six hats idea with the 10 roles - groups of 10, each student is assigned a role and given a little description of that role and the Phase 1 jobs for their hat/role, as a group, they work together to place the phase 1 jobs with the correct role; 2 groups stand up to present Phase 1 as they laid it out, continue on with phase 2- phase 5; value chain of design process (who does what in the design process? potential job evaluation - what kind of career do they have?)

- **Reflection opportunities**
  - Analyze what strengths your role brought to the group for each phase of the design process, how would you perform in that role as a career, are there any particular roles/phases of the process that appeal to you, why?

- **Design methodologies**
  - To design something is a process that could be different depending on what industry you’re in; specific to biotech medtech industry; design is more than just creating - it is a process; lots of paperwork; different models of design process;
  - Definition of design (define the underlined terms in this course); Slide 9 = definition needs to be emphasized; six sigma overview slide = Slide 20; six sigma is designing out problems before they occur, getting ahead of the problems and design solutions; slide 22 - place roles in the chart, type of person best for each role

- **Mini-lecture to review the roles and jobs within the design process from Class 02 and to emphasize the importance of criteria over clinical area interest**
  - Each team has roles assigned from Class 02
  - Team members with a certain role meet together representing their group at a combined table. While together, they debate the criteria of different potential projects through the role lens they were assigned and decide on the merits of each.
  - Everyone returns to their team table and discusses the merits of each project from their individual assigned roles.
  - Reconcile 100% decision making by dividing 100 beads between group members to identify their roles “weight” on the decision to proceed with a given project.
  - Several groups present how they chose their project and negotiated the perspectives

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<table>
<thead>
<tr>
<th>Additional Materials</th>
<th>Most Important Takeaways</th>
<th>Ideas for Games/Activities to address takeaways</th>
<th>Reflection opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 roles/hats printed up for each group, each bullet point/job on a separate piece of paper divided by phase, large printed charts of empty slide for each group to fill in; large white pages/markers for final role description</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Having completed the process of laying out the content, objectives, and outcomes for each class, we were ready to begin planning the games and activities for each class. Again, we looked towards the cognitive apprenticeship model by including the six teaching methods from the framework: modeling (instructor performs a task for students to observe), coaching and scaffolding (facilitate and provide support and feedback while students perform task), articulation and reflection (give students an opportunity to speak about and reflect on their process performing the task), and exploration (allowing students in small groups or individually to propose the next problem to solve) (Collins & Kapur, 2014). By consciously building in each of these teaching methods, students would have opportunities throughout the semester to practice developing their own metacognitive process; through the stages of watching to doing to reflecting to exploration.

To plan the games and activities for each class we used group electronic brainstorming by engaging in collaboration and ideation using digital tools such as Google Docs (online document sharing), Google Hangouts and Skype (video conferencing), and phone calls combined with in-person meetings. The advantage of this type of digital brainstorming is that we could continue the development process even when we were not in close physical proximity to each other and could iterate ideas after discussions had concluded, a process called prolonged brainstorming.
Developing the games and ensuring they focused on the desired learning outcomes required many iterations. Additionally, we looked for opportunities to include each type of teaching method so that we could connect with different learning styles and provide opportunities for deeper learning across a wide range of learners. Students are often processing the activity and course material in their own way and at their own pace during class, and we felt that it was important to acknowledge those differences, especially in a class with over eighty students. In some cases, we were able to practice individual games prior to the beginning of the course in other contexts such as at entrepreneurship summer camps, during the BIOE summer DEFINE program, and in the Creative Inquiry course, The DEN. Although these trial runs were not with the same audience or numbers, they allowed us to test the learning effectiveness of the games and make important adjustments prior to the beginning of the semester based on informal participant feedback and observation.

In order to document the class plans, we adapted the Game Design Canvas from the Ideas at Play Workshop hosted by Epicenter prior to the start of the Open conference (see Figure 2). The adaptations we made provided additional space in certain categories and new areas for information that was specific to our context. The new BIOE Design canvas was replicated for each BIOE 4010 class meeting and the files were moved into an online shared folder to allow for comments and changes to be made as course plans continued to develop and change (see Figure 3).
Figure 2. Original Game Design Canvas from Ideas at Play. Available here: [https://goo.gl/YbI1hd](https://goo.gl/YbI1hd) and licensed for reuse.
Using the BIOE Design Canvas, we laid out all the necessary details for each class meeting, beginning with the learning objectives. The learning objectives were identical to those listed in the course syllabus. Then we filled in the gameplay/class schedule and the goal(s) for the class. The goal(s), although similar in nature to the learning objectives, included more detail. They specified what we hoped to accomplish during that class period and included goals such as affecting student understanding of the application of a particular 21st Century Skill. For example, a listed goal could be that students understand the application of a certain process across different circumstances, that they gain a deeper understanding of the overall process necessary for developing a successful biomedical device, or that they have a chance to practice a 21st Century Skill such as effective non-verbal group communication.

The second column of the BIOE Design Canvas had information on setting up the classroom space such as which props needed to be set out on the tables and what preparation the teaching team needed to do in advance of the class meeting. Since each class period involved unique activities which often required setup time, the instructors and teaching assistants (TAs) would arrive twenty minutes prior to each class to prepare the classroom space so that we could fully utilize the seventy-five-minute class period once students arrived. The final section in the second column was for debrief/reflection notes. In this area, we noted the reflection questions to include in the debrief questionnaire and notes on how we planned to wrap up the activities with the students prior to the conclusion of the class and student dismissal. Finally, the Design Canvas provided an area to credit where the original inspiration for the game came from, the general
topic for the day, the class period, and the date in the left header section of the BIOE Design Canvas file.

One of the most important parts of the learning experience during this course was the reflection/debrief (Bodnar & Clark, 2014). In the cognitive apprenticeship model, this phase encompasses two of the six methods necessary for developing expertise: articulation and reflection (Clancey, 1992; Collins & Kapur, 2014). Time was set-aside at the end of each class period for the articulation step. Sometimes student articulation was accomplished in small groups and other times with the entire class. During this time, the instructors would bring all the students back together and ask a few of them to speak about what they had just done during the activity and how their group had handled the task. Following those initial comments, another student would share their perspective, detailing whether they had done it the same way or employed a different approach. This verbal articulation gave students (whether they shared with the class or just listened to their classmates) a chance to compare their own performance to that of their peers with guided feedback from the instructor. This was also an opportunity for students to realize that there are many different ways to accomplish the same task and with that realization, they could then evaluate the strengths and weaknesses of the various approaches.

For the reflection step, students were sent a link to a debrief questionnaire after the class period ended. On the questionnaire, they could individually reflect on their experience and thoughts regarding that classes’ activities. Each questionnaire was developed specifically for the class period in order to provide opportunities to reflect on those experiences and how they related to the course material and 21st Century Skills specifically. The link to the questionnaire was sent to students twenty-four hours after each class period and responses were accepted for the
subsequent twenty-four hour period. This ensured that students had adequate time after each class to reflect on the activities, but they still had to complete the questionnaire while the details were still clear in their minds. Their reflections did account for a low-stakes portion of the attendance/participation grade in the course in order to encourage regular responses. The grade was based on thoughtful completion, not on whether the student's reaction to the classroom games was positive or negative.

For the final step in the reflection stage, a cross section of the debrief responses, representing both positive and negative feedback on the classroom activities, was presented during the debrief time the following week in class. All indicators were removed from the responses, but sharing them corporately allowed students to compare their own responses to those provided by their peers which is an important aspect of the cognitive apprenticeship model (Collins, Brown, & Holum, 1991). By combining a variety of reflection opportunities, students had several chances to reflect on the class games and their role in them. This process also gave instructors a chance to acknowledge both the positive and negative comments in a constructive way and share any relevant reasoning with the students as a group.

With the plan for the intervention in place, we were prepared to proceed with the study, but we recognized that if successful, the game-based activities were going to be used in future iterations of the course. Therefore, we were careful to document what aspects of the class plans were successful or needed additional development looking forward. As faculty, we know that our classroom materials and assignments need constant testing, assessing, and redevelopment. The same was true for the games and activities developed for this Senior Design course. The students enrolled in class change each semester and our learning materials need to iterate as well.
Additionally, the industry changes over time and adjustments should be made to ensure course material is still addressing timely preparation for their future careers. In order to facilitate this part of the process and look for ways to improve the course plans going forward, our instructional team met weekly during the semester for our own debriefs. At the end of each week, when the classes were still fresh in our minds, Dr. DesJardins, Ms. Przestrzelski, and I met to discuss what we felt worked in the previous two classes and what improvements could be made to those class plans for subsequent semesters. In a separate meeting, the teaching assistants also provided their own perspective weekly. Based on these discussions, I added notes to each BIOE Design Canvas so that the games and activities could continue to be iterated and improved upon for students enrolled in later versions of the course. This process was also valuable for us as an instructional design team because we were able to thoroughly consider what was working and what was not while the class events were still fresh in our minds.
Methods

This section of the study will detail the research questions, the methods chosen, the process for data collection, and the analysis methods for the data collected.

Research Questions

The purpose of this mixed methods research study was to examine the impact on self-reported 21st Century Skills between two groups of senior bioengineering students enrolled in a design capstone course: those exposed to the domain content predominantly through game-based learning techniques, compared with students enrolled in the control group where the course material was taught exclusively with a traditional lecture pedagogy. It was also important to understand what effect, if any, that changing the delivery method of the material would have on student learning of the domain content necessary to proceed into the second semester of Senior Design. Additionally, this research analyzed the process a faculty-team underwent as they developed and delivered a game-based bioengineering design course. By sharing the process of transitioning this course, it is our hope to increase recognition of game-based learning as a valuable classroom tool for embedding 21st Century Skills in a design course. Finally, in detailing the course development undertaken, we hope to provide further insight and resources for other educators interested in transitioning the pedagogy used in their own courses. This study focused on the following three research questions:

1. *What is the impact of game-based learning on the development of 21st Century Skills in Bioengineering Senior Design students?*
2. *How does changing the course delivery method, lecture-based compared to game-based, affect student learning of the domain content?*
3. What can be learned about the implications of converting a class from lecture-based to game-based curriculum from the faculty/research-team?

Analysis of the data followed the mixed methods approach, including quantitative statistical analysis, qualitative content coding, and global theme analysis, in order to fully address the proposed research questions.

Procedure

A mixed methods approach was used for this study. Mixed methods research involves the collection and analysis of both qualitative and quantitative data in order to address research question(s). This type of research is relatively new, originating in the late 1980s in research fields such as education, sociology, and health sciences. Mixed methods has been a subject of much debate, but in recent years has gained traction across many disciplines even though it is a newer method than a traditional qualitative-designed or quantitative-designed studies (Creswell, 2013). One of the strengths of mixed methods research is that the researcher can combine both qualitative and quantitative approaches to answering a question. This allows the research question to dictate the appropriate methods of analysis (Johnson & Onwuegbuzie, 2004). By combining the strengths of both types of research methods, proponents of mixed method research believe that this type of research can create a more complete picture to address the research questions.

There are several types of mixed methods research used to structure how a researcher might combine and analyze the different data points. For this research, I used an embedded mixed methods approach where different analyses and schedules were used for collecting the data in
order to address the individual research questions (Creswell, 2013; Creswell & Clark, 2007). For some questions, quantitative data analysis was the primary analysis, but results were supplemented by additional qualitative data points that were collected before, during, and/or after the quantitative data is collected. In another question, qualitative analysis was the primary data point. The results from the different analyses were combined during the interpretation phase of the research (see Figure 4).
Figure 4. Illustration showing three different ways of conducting embedded mixed methods research. The top image depicts a study where qualitative data is collected before, during, and after the qualitative data collection. The middle illustration is a study where qualitative data is collected before, during and after the quantitative data collection. The third illustration depicts a study where the qualitative and quantitative data are collected at the same time during the study. In all three studies, the data is combined during the interpretation phase (Creswell, 2013).

For instance, the survey that addressed research question one, *RQ1: What is the impact of game-based learning on the development of 21st Century Skills in Bioengineering Senior Design students?*, collected quantitative data, but analysis included qualitative data points collected before, during, and after the survey data collection. The qualitative data provided supplemental analysis to further explain the quantitative results. The second research question, *RQ2: How does changing the course delivery method, lecture-based compared to game-based, affect student learning of the domain content?*, used both qualitative and quantitative methods to fully address the question with an emphasis on the qualitative data. Again for the second research question, quantitative data from the exams was analyzed, but qualitative data points collected before, during, and after the exam provided additional analysis. The third research question, *RQ3: What can be learned about the implications of converting a class from lecture-based to game-based curriculum from the faculty/research-team?*, was examined using qualitative analysis of video interviews and footage. Collection of both types of data occurred concurrently throughout the study and the data points converged during the analysis stage (see Figure 5).
The use of an embedded mixed methods approach allowed supplemental qualitative data such as interviews and open-ended response questions to further understand the implications of the quantitative data results from the analysis of the survey and exam scores. The qualitative strand of the experiment ran before, during, and after gathering the quantitative data points in order to capture the process leading up to the intervention, the participants’ experience during the intervention, and their reflections of the outcome after completing the intervention. I hypothesized that the qualitative strand would help address the “why” and “how” questions surrounding the study that looking at the quantitative data alone would not fully answer. Another
advantage of collecting the qualitative data was that it addressed both the student and the faculty experience of participating in this intervention, and was therefore able to provide insights into the process from the participants’ perspectives.

Limitations

Limitations and threats to validity are a recognized part of social science research. Although every effort was made to plan for and counteract possible threats to validity, the following section identifies potential threats to this study. Some differences could not be controlled between the two versions of the class. Students in the intervention group were aware of the research project and signed IRB and video release forms on the first day of class. Conversely, students in the control group were not aware of their participation until the end of the semester. There is potential for a shift in performance when participants are aware of being in a research study. This phenomenon, known as “The Hawthorne Effect,” has been debated in recent years. Researchers have gone back to the original data from the 1930s study from which the term was coined and now consider “The Hawthorne Effect" to more likely be a result of uncontrolled or confounding variables in the design of the experiment rather than participant knowledge of their role in the study (Adair, 1984; Jones, 1992; Parsons, 1974; Wickström & Bendix, 2000). Whether using the moniker or not, researchers acknowledge that participation in a study and a desire to appease the researchers could have an effect on student behavior and therefore, the results of this study.

Students were reassured that their participation was not tied to their overall course grade; however, the debrief surveys was one exception where their participation was graded. On the debriefs, students were required to provide thoughtful responses, and completion was a part of a
low stakes participation/attendance grade. Whether the response was positive or negative did not impact the student’s grade; rather the debriefs were marked pass/fail based on thoughtful, timely completion. “Thoughtful completion” was measured based on answering the questions thoroughly (i.e. one word responses to short answer questions would not be considered thoughtful completion). “Timely response” was determined by whether they completed the debrief within the required twenty-four hour window. The debrief grades counted towards their attendance grade for the course.

Another difference between the two courses was my participation in the classroom. Although Dr. DesJardins was the lead instructor for both sections in the study, I was in attendance and active in the classroom during the intervention course offering, but not during the control class meetings. My presence was a unique factor in the experience of the intervention group which could also affect the results of the study. As a research team, the decision was made that my participation in the classroom provided more advantages for the study than disadvantages, despite the additional discrepancy between the control and intervention course sections. By being present in the classroom, I was able to continually and actively observe the dynamics and provide input if there was a need to pivot activities based on lack of student engagement. Another advantage to my presence was that the students would see my participation alongside them as commitment to their success in the course. By the simple act of being immersed with them in the classroom and investing myself in their learning, they might, in turn, be more engaged in the course themselves. My participation in the classroom brought advantages to the study, but also resulted in notable threats to the validity.
Video cameras were used to record the intervention class meetings. By introducing cameras into the classroom setting, this disrupted the class to some extent and perhaps caused students to display modified behavior because they were being recorded. In order to counteract this threat, cameras were set up prior to student arrival and as discreetly placed as possible. The cameras were consistently placed within the space in hopes that they would become less noticeable and obtrusive over time.

One of the challenges, which the faculty team was not able to fully anticipate the impact of during the planning stages, was the number of students enrolled in this capstone course. Ideally, game-based courses limit the number of students enrolled to keep activities small, ensure that all the students are actively involved, and provide instructors more opportunity for individualized feedback during class. However, Senior Design was a very large class with over 80 students enrolled each semester. Game planning needed to keep the course size in mind and games had to be tailored for manageability and effectiveness with larger groups of students. One way we prepared for this challenge was to have weekly team meetings to prepare the graduate assistants (TAs) to help facilitate smaller groups alongside faculty. Although having trained TAs in the class is not the same as additional faculty to run small-group activities, the teaching assistants were trained to recognize when student participation dropped. Upon noting that less students were actively engaged in an activity, we adjusted as needed to ensure active participation across the entire group. Often times this would involve reiterating the next steps in an activity again to the whole class to encourage focus, faculty briefly joining their small group, or asking students to commit their table's responses to the large white boards. The success of the games and the ability of the faculty and TAs to maintain an appropriate level of interaction and focus during the class period might have been adversely impacted by the number of students. This factor could threaten
the results of this study and impact future reproducibility in classes with more or less students enrolled.

Much of the data for this study relied on self-report. Self-report data contain bias which can impact the limitations of a study. These biases include selective memory, telescoping (inaccurate recall in regards to timelines), attribution (crediting positive events to self and negative events to external forces), and exaggeration. Student responses could not be independently verified and the study relied on accurate self-report. This is a difficult limitation to avoid in a study that looks at student learning, since we often measure learning through self-report.

The impact of the faculty team is both a strength of this study and a limitation. No single teaching style is a good fit for every instructor, just as no single pedagogy will effectively teach all learners. It is important to consider both the strengths of a faculty team and the course content prior to choosing a content delivery method. Due to this, there are limits to transferability of our methods and findings to another classroom.

Finally, because this study was conducted by a single researcher as a dissertation, there is not the opportunity to ensure inter-rater reliability. It is noted that there are weaknesses in not cross-referencing/cross-coding between several researchers on a study.

Data Collection and Analysis

Data from many sources was collected and analyzed in order to address each research question directly (see Table 3). Additional data was collected throughout the process based on the
research interests of Dr. DesJardins and Ms. Przestrzelski, but this study focuses on the data relevant to the following research questions:

1. **What is the impact of game-based learning on the development of 21st Century Skills in Bioengineering Senior Design students?**

2. **How does changing the course delivery method, lecture-based compared to game-based, affect student learning of the domain content?**

3. **What can be learned about the implications of converting a class from lecture-based to game-based curriculum from the faculty/research-team?**

To respond to these research questions, analysis would include a mixture of quantitative statistical analysis, qualitative content coding, and global theme analysis to locate stories and epiphanies from the overall experiences of both the participants and the instructors during the study.
Table 3.

Questions to Data Points: The Connection Between the Research Questions, the Method, the Data Points, and Type of Analysis.

<table>
<thead>
<tr>
<th>Research question</th>
<th>Method</th>
<th>Data points</th>
<th>Analysis</th>
</tr>
</thead>
</table>
| RQ1: What is the impact of game-based learning on the development of 21st Century Skills in Bioengineering Senior Design students? | Collect qual before, during & after quant data:                        | - End of Spring semester survey -- 3 part Engineering Entrepreneur Survey, Curiosity Index, Demographics
- Student video interviews
- Debrief responses                                                                | Quantitative-Comparative Statistical Analysis Qualitative- Global themes, Content Coding |
| RQ2: How does changing the course delivery method, lecture-based compared to game-based, affect student learning of the domain content? | Collect qual before, during & after quant data:                        | - Debrief responses
- Video tapes of the classes
- Exam results from both semester                                                  | Qualitative- Global themes, Content Coding Quantitative-Comparative Statistical Analysis |
| RQ3: What can be learned about the implications of converting a class from lecture-based to game-based curriculum from the faculty/research-team? | Collect qual throughout study:                                         | - Video journal of myself as I move through the process
- Video Interviews with Dr. DesJardins & Ms. Przestrzelski
- Video Interviews or survey with TAs from both semesters
- Video interviews with other experts in the field- 7 captured at OPEN
- Video tapes of the classes                                                        | Qualitative- Global themes                                               |
Data Collection and Analysis: Research Question One

*RQ1: What is the impact of games-based learning on the development of 21st Century Skills in Bioengineering Senior Design students?*

In this section, I will present the data collected for research question one. Three different data points were collected to address this question: the survey, student video interviews, and the debrief responses.

For the initial data point, the researchers identified a proven survey instrument that could address both the traits defined as 21st Century Skills and the specific population participating in this study. There are dozens of surveys used to analyze the entrepreneurial mindset and 21st Century Skills (Geisinger & Murphy, 2007). However, many of these surveys focused on different participants such as potential employees, managerial teams, or career-technical students that posed validity problems and would require additional editing for the questions to apply directly to our students. It was necessary to find a proven survey that had been tested on a similar population, specifically engineering students at the college level. After exploring the populations associated with different instruments in the literature, six potential surveys were worth further exploration. During the next phase, I spoke with the researchers who had developed and used the instruments (see Figure 6 & 7). After much exploration, this study combined two separate surveys to cover the traits most important in order to address the research question: the Engineering Entrepreneurship Survey (EES) and the Curiosity Index (CI-4) (see the Appendix for original surveys). In order to protect the validity and reliability of both instruments, responses to each were analyzed separately. Analysis of the final survey data looked at one construct, curiosity, based on responses to the CI-4 and other constructs were examined via responses to the EES.
Figure 6. Skype call with Dr. Duval-Couetil of Purdue University to discuss the Engineering Entrepreneurship Survey (EES) instrument she developed and had been using for her research.

Dr. Duval-Couetil is an Associate Professor of Technology, Leadership, and Innovation; Director of the Certificate in Entrepreneurship and Innovation Program at Purdue University. She had developed a survey called the Engineering Entrepreneurship Survey (EES), which is an assessment instrument designed to look specifically at engineering students involvement and interest in entrepreneurial activities (Duval-Couetil, Reed-Rhoads, & Haghighi, 2011).

Duval-Couetil developed this survey based on two other surveys—Venturing and Technology Self-efficacy and Motivations and Barriers to Starting a Business—because she found that there was not a survey that explored engineering student participation and interest in entrepreneurial activities (see Table 4) (Lucas, Cooper, Ward, & Cave, 2009; Shinnar, Pruett, & Toney, 2009; Lucas et al., 2009).

Table 4.
Categories and Original Sources for the EES Survey Instrument (Duval-Couetil et al., 2011).
During the development of the survey, Duval-Couetil tested both the reliability and validity of the EES. The content validity, or how accurately and broadly the instrument covers the topic it is attempting to measure, was tested with a panel of twenty experts. Face validity, which considers the participants’ perspective on the questions, was explored using think-aloud protocol with engineering students. Construct validity, which measures how concepts in the instrument relate to other constructs and theoretical relationships, was analyzed by working with experts and comparing results from early students taking the survey against their actual entrepreneurial exposure (Duval-Couetil et al., 2011). Through each of these phases, the instrument was edited
and validity was improved. Lastly, predictive validity, which refers to how well the instrument can be used to predict future behavior, has not yet fully been determined. As the instrument is used and longitudinal data is collected, the predictive validity will be addressed (Duval-Couetil et al., 2011).

Reliability for the EES survey was evaluated based on comparison between similar groupings of questions and analyzed using Cronbach’s coefficient alpha (see Table 5). Examining the reliability, Duval-Couetil, et al. (2011) found that all but one category, skills, reached the accepted value of 0.8. Although slight edits were made to the EES when used in this research, the changes did not adversely affect the reliability and validity already determined for this instrument.

Table 5.
Chronbach’s Alpha Values for EES Survey Categories (Duval-Couetil et al., 2011).

<table>
<thead>
<tr>
<th>Category of Items/Scale</th>
<th>Number of items</th>
<th>Cronbach’s Coefficient Alpha</th>
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<tbody>
<tr>
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<tr>
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<tr>
<td>EFFICACY (15)</td>
<td>15</td>
<td>.96</td>
</tr>
<tr>
<td>SKILLS (6)</td>
<td>6</td>
<td>.74</td>
</tr>
</tbody>
</table>

For the survey used in this research, the EES was combined with The Curiosity Index (CI-4), a twelve-item Likert Scale questionnaire analyzing the construct of curiosity. Curiosity is defined as the internal drive to keep learning about a topic when a person discovers a gap in their knowledge (Fulcher, 2004, 2008; Williams, 2015). Curiosity is often included on lists of important 21st Century Skills. Dr. Keston Fulcher (2004) originally developed the Curiosity Index as an
unpublished dissertation at James Madison University. The survey defines two factors of curiosity: the breadth of curiosity refers to a person’s desire to explore across many different experiences and knowledge types and the depth of curiosity refers to digging deeply into a single topic of interest (Fulcher, 2004; Williams, 2015). During his research, Dr. Fulcher refined and tested the validity of the instrument through a series of four different studies. The first study was used to refine and reduce the original 47-item instrument down to a 12-item instrument that provided a best fit model for the two factors of curiosity: breadth and depth (see Figure 7).
During Study 1, the Curiosity Index (CI-3) was reduced to a 12-item instrument (CI-4) in order to create a best fit two-factor model (Fulcher, 2004).

The second study correlated the breadth, depth, and total scores on the CI-4 to several other instruments measuring similar constructs. The third study compared three groups of participants to see if their scores, as a group, would comparatively match up with predicted scores. The fourth and final study in the research tested the reliability and discrimination range for each of the twelve items (Fulcher, 2004, 2008; Williams, 2015). Although further research areas are suggested, by combining the results of all four of these studies, it is reasonable to consider the CI-4 to be a valid instrument for measuring the breadth and depth of curiosity as constructs for this research.

Skype call with Dr. Julia Williams of Rose Hulman to discuss her use of the Curiosity Index (CI-4) instrument originally developed by Dr. Keston Fulcher of James Madison University.
Dr. Julia Williams, executive director of the Office of Institutional Research, Planning, and Assessment and Professor of English at Rose-Hulman Institute of Technology, recently began using the CI-4 to explore the breadth, depth, and total curiosity of engineering students at Rose-Hulman (see Figure 8). In her research, which could have implications for curriculum development focused on increasing retention in engineering education, Williams saw a difference across both major and gender for the preference of breadth versus depth of curiosity (Williams, 2015). Although publishable results are not yet available, these findings could speak to ways to positively impact gender diversity in engineering by rethinking the balance between breadth and depth of content presented in freshman engineering courses.

With a few minor edits, the EEI and the CI-4 were combined for this research. I hypothesized that, by combining the two instruments, the new survey instrument could capture a potential shift in the 21st Century Skills between the control and intervention groups without becoming too long or tedious for the participants. The intention was for the survey to take no more than twenty minutes to complete. The final instrument took the majority of participants between twelve and twenty minutes to finish.

In order to address the possibility of participant fatigue, which occurs as participants become less diligent in their responses when a survey is too long, two different versions of the survey were constructed (Porter, Whitcomb, & Weitzer, 2004). The first version had the Curiosity Index items first followed by the EES. The second version had the EES items first, then the Curiosity Index questions. Both versions ended with the demographics questions. The surveys were created online using Qualtrics and half of the participants were provided with a link to version one of the survey and the other half were provided a link to version two. The two different versions of the
survey were distributed randomly to the participants. Printed versions of both surveys were available for anyone who preferred to respond on paper rather than electronically. The results from the paper submissions were manually added to Qualtrics so that all the data would be in a single database for analysis. The Senior Design course in Bioengineering is two semesters long beginning in the Fall with a semester of classroom-based learning followed by the Spring semester course where student teams participate in design projects situated in real life biomedical scenarios. The survey was taken during class the final week of Spring semester for both sections of the course.

The analysis of the surveys included basic statistical comparison, including mean, range, and standard deviation, in order to uncover shifts in self-efficacy of 21st Century Skills between the two groups of participants. Analysis focused on the responses from the EES categories: attitudes, self-efficacy, and behaviors, the total curiosity score from the Curiosity Index, and the pre- and post- questions in the demographics segment of the instrument.

Individual participant pre/post comparison did not occur since each participant only took the survey once. Instead the analysis looked at the control versus intervention groups, as a whole, for shifts in self-reported 21st Century Skills. A pre/post comparison was considered, but it was determined that the risk of respondent fatigue and increased disinterest from seeing the survey questions more than once was not worth the risk for this study (Hess, Hensher, & Daly, 2012). Therefore, all participants from the control and intervention course section only took the survey one time, during the final week of their second semester of the Senior Design course.
Additional qualitative data points for analyzing research question one include student responses during video interviews and the debrief comments from students in the intervention section of the course. Video interviews were transcribed to aid with analysis of global themes using the process of narrative analysis. Both computer-based software and paper-based qualitative methods were used to analyze the transcriptions and the debrief comments.

Using the narrative method, the video interviews were analyzed as qualitative data points. By watching the videos and reading the transcripts to form the initial codes, the analysis identified the overarching themes and locate any common epiphanies across participants (see Table 6). By grouping the video clips based on thematic codes, a focused narration of the story in the form of a collection of short video vignettes was created (Creswell, 2012).

A similar process was employed for the debrief responses focusing on terms related to 21st Century Skills and teaching methods. Coding of the debriefs was done across all the game-based classes.

Codes centered around 21st Century Skills and game-based/lecture-based responses followed by a secondary level of positive/negative sentiment.

Emergent coding was employed to look for common themes within the qualitative content. These data points were analyzed and combined with the findings from the quantitative results during analysis. Combining the analysis of various data points collected with different methods and at varied times during the study attempted to address some of the weaknesses naturally inherent in self-report data.
Data Collection and Analysis: Research Question Two

*RQ2: How does changing the course delivery method, lecture-based compared to game-based, affect student learning of the domain content?*

This section details data collection and methods of analysis for research question two. This question was addressed using a mixed methods approach and looked at three different data points collected during the study: the student debrief responses, video tapes of each game-based class meeting, and the final exam scores (see Table 10).

This research question focused on whether student learning was positively or negatively affected by the delivery method used for this course: lecture-based delivery for the control compared to game-based delivery for the intervention. In order to answer this question it was important to gather several types of data and to use a mixed methods approach for evaluating the data points. For the first data point, exam results were collected from both sections of the course. The exam was equivalent between the two versions of the course, so by comparing them using basic statistical analysis, it could be determined whether one section of the course had an overall better mastery of the domain content than the other section. The exam was created by Dr. DesJardins, the lead faculty for the course, and included short answer questions, essay problems, matching, true/false, and fill in the blank questions with a point emphasis on the free response questions. Again, there was not a pre/post comparison of the same student over time, but instead analysis focused on the class as a whole. This allowed comparisons between the two versions of the course rather than on individual participant growth during the span of the course.

Although interaction alone does not always create opportunities for deeper understanding of domain knowledge content, nor is it always the best fit for the course material or the faculty
teaching the course, it has been shown that many students benefit from active learning. Active learning can make an impact on retention of content when compared to passive learning situations (Apelian, 1994; Bonwell & Eison, 1991; Prince, 2004). In order to analyze the level of activity and interaction from student to student and from instructor to student, each intervention class period was recorded using several video camera perspectives. These class videos served as the second data point for this research question. The video cameras captured an overhead view of the classroom and a floor-level view to show the level of interaction and movement during the game-based learning classes.

For the third data point, the debrief responses from the intervention course were qualitatively analyzed to interpret student understanding of the connection between the activities and the domain course content. Each debrief included opportunities for students to respond to open-ended questions regarding the connection and the activity itself (see Figure 9).
For research question two, these three data points, exam scores, the class videos, and the debrief responses, were analyzed and cross-referenced. Comparing the class exam scores between the control and intervention group provided insight into domain content mastery between the two class sections. The class videos were qualitatively analyzed for comparison of active learning opportunities and representation of the types of classroom interaction. Analysis of the debrief responses provided self-report data regarding student understanding of the connection between the classroom activities and the domain content. The intention of cross-comparing these data points was to draw conclusions on the effectiveness and impact of game-based learning for imparting the same course objectives as lecture-based pedagogy.
Data Collection and Analysis: Research Question Three

*RQ3: What can be learned about the implications of converting a class from lecture-based to game-based curriculum from the faculty/research-team?*

In the following section, I discuss the data collection and analysis for research question three. This question looks at the implications of converting and delivering a game-based learning course. Data for this question focused on qualitative data points and included video journaling and interviews with the faculty team and others closely involved in the project.

Different teaching methods are not necessarily a good fit for every student in a particular classroom, just as all methods of content delivery are not automatically a good fit for a given instructor. Game-based learning is not the only effective way to deliver domain content knowledge, and for some instructors it may be too far out of their comfort zone or simply not a good fit for their course material. Because teachers are an incredibly important part of any intervention and because their participation can be such a vital piece to the success or failure of a new approach in the classroom, it was important to fully explore their experience of this intervention from an instructor perspective.

Thus, research question three provides an opportunity to explore the process of this research project from the standpoint of those most closely involved with the project: Dr. DesJardins, Ms. Przestrzelski, and me. To answer this research question, the experiences faculty and curriculum developers had when transitioning a class from lecture-based to game-based learning were documented through individual video interviews with each instructor multiple times before, during, and after the research study.
During the development period, video journals were recorded each month detailing my thoughts on the process. Additionally, both Dr. DesJardins and Ms. Przestrzelski were interviewed several times during the course development phase. Mid-semester and end-semester interviews were also conducted during the intervention semester. The questions that were developed prior to the interviews allowed each individual to comment on how the process affected us, what we were witnessing in the classroom, and what we thought the implications of this transition could be for ourselves, the students, and the future direction of this course. I directed each of the interviews except for the interviews where I was in front of the camera. My interviews were conducted by either a camera operator with a list of prepared questions or by Dr. DesJardin or Ms. Przestrzelski. Although questions were predetermined and approved for the study through the IRB, all of the interviews were set up as conversations (for full list of predetermined interview questions, see appendix). Therefore, it was common that a given response would spark necessary follow-up questions for further clarification, an accepted practice for conducting video interviews.

Sample questions for TAs:

- What do you think are the goals of Senior Design?
- How would you describe how students learn in this class?
- Why do you think BioE students need to understand how to use 21st Century Skills?
- How do you think the course structure/content help them learn that mindset?

Sample questions for engineering faculty from other universities:

- Why is entrepreneurial education important?
- What delivery methods do you use in your classroom?
- How do [teaching methods] help your students gain necessary skills?
- How can you tell if these techniques are successful with your students?

Sample questions from my video journaling during the development phase:

- How do you define entrepreneurship?
● Are there different definitions of design? Entrepreneurship?
● How have those definition changed since working with BIOE?
● Can you explain what the research process is for this project?
● What are you planning on doing?
● What will change?
● How will this affect the objectives of the course? Methods?
● Specific game-based learning examples- what did they teach?
● How did you create the new lesson plans? (see appendix for full list of predetermined interview questions)

Additional supplementary interviews were conducted to fully address this research question. Teaching assistants (TAs) from both semesters of the course were interviewed in order to capture their perspectives on the process and on the success or failure of the modified course content. Faculty from other engineering programs also participated in interviews to round out the perspective of those most closely involved in the research by adding a broader view of engineering education. Over six hundred minutes of interviews were recorded before, during, and after the conclusion of this study. Video interviews were transcribed to aid with analysis of global themes using the process of narrative analysis. Qualitative research software and paper-based methods were used to analyze the transcriptions.

Using the narrative method, the video interviews were analyzed as qualitative data points. By watching the videos and reading the transcripts to form the initial codes, the analysis was able to identify the overarching themes and locate any common epiphanies across participants (see Table 6). By grouping the video clips based on thematic codes, a focused narration of the story in the form of a collection of short video vignettes was created (Creswell, 2012). Codes centered around 21st Century Skills and game-based/lecture-based responses followed by a secondary level of positive/negative responses.
Table 6.

*Strategy for Data Analysis Using the Narrative Research Approach (Creswell, 2012).*

<table>
<thead>
<tr>
<th>Data analysis and representation</th>
<th>Narrative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data organization</td>
<td>- Create and organize files for data</td>
</tr>
<tr>
<td>Reading, memoing</td>
<td>- Read through text, make margin notes</td>
</tr>
<tr>
<td></td>
<td>- Form initial codes</td>
</tr>
<tr>
<td>Describing the data in codes and themes</td>
<td>- Describe the story and place it in a chronology</td>
</tr>
<tr>
<td>Classifying the data into codes and themes</td>
<td>- Identify stories</td>
</tr>
<tr>
<td></td>
<td>- Locate epiphanies</td>
</tr>
<tr>
<td></td>
<td>- Identify contextual materials</td>
</tr>
<tr>
<td>Interpreting the data</td>
<td>- Interpret the larger meaning of the story</td>
</tr>
<tr>
<td>Representing, visualizing the data</td>
<td>- Present narration focusing on the processes and theories</td>
</tr>
</tbody>
</table>

The footage from this segment of the research was edited into video vignettes and presented as a collection of supplemental content using YouTube as a video hosting platform. Video vignettes were an appropriate format for answering this research question because an edited video could be used to tell the story of a person’s experience in their own words and by combining multiple interview subjects together, the resultant topical videos could be more dynamic than the written word alone. Millions of videos are watched online each month, and of the most popular videos viewed, the average length is under four and a half minutes long (“comScore Releases January 2014 U.S. Online Video Rankings,” n.d.; minimatters, 2014). The choice to use the vignette format to present the findings of this research in shortened topical segments was based partially on the popularity of this format and its ability to tell a tightly woven story around a single concept. A collection of shorter videos is more likely to be watched and used by other faculty and future researchers than a single long-format film. If other practitioners or researchers are interested in certain aspects of the research, then they have the ability to access the videos based on relevance,
giving them the option to explore other vignettes or gain access to the full video transcripts based on interest and need.

Results
Below I discuss the results of each research question individually, beginning with research question one.

RQ1 Synthesis:
In this section, I look at the results from research question one. Three different data points were collected to address this question: the survey, student video interviews, and the debrief responses. I used the quantitative software program SPSS to analyze the survey responses and NVivo qualitative analysis software combined with hand-coding to analyze both the video interview transcripts and the debrief responses.

Table 7. This table depicts the connection between the research question, the method(s), the data points collected, and the type of analysis used for research question one.

<table>
<thead>
<tr>
<th>Research question</th>
<th>Method</th>
<th>Data points</th>
<th>Analysis</th>
</tr>
</thead>
</table>
| RQ1: What is the impact of games-based learning on the development of 21st Century Skills in Bioengineering Senior Design students? | Collect qualitative before, during & after quantitative data: QUANT + qual | - End of Spring semester survey -- 3 part Engineering Entrepreneur Survey (EES), Curiosity Index (CI-4), Demographics  
- Student video interviews  
- Debrief responses | Quantitative-Comparative Statistical Analysis  
Qualitative- Global themes, Content Coding |
As can be seen in Table 7, I collected and analyzed three data points to examine the impact of
game-based learning on the development of 21st Century Skills: the end of the semester survey,
the video interviews with students, and the debrief responses. For this study, it is important to
note that there is significant overlap between the terms “21st Century Skills” and “the
entrepreneurial mindset.” Sometimes those terms are used interchangeably in interviews and
throughout the study to refer to a similar set of skills including: life skills such as flexibility and
adaptability, workforce skills such as collaboration, the ability to lead, and teamwork, applied
skills such as analyzing information and effective communication, and personal skills including
curiosity, imagination, critical thinking, and problem solving (Apelian, 1994; Bellotti, Bottino,
Fernández-Manjón, & Nadolski, 2014; “Education for the 21st Century,” n.d.; Saavedra & Opfer,
2012).

RQ1 Survey responses
In order to address the impact of game-based learning on student development of 21st Century
Skills, we looked at three different data points: survey, student video interviews, and student
debrief responses. The research team administered the survey to both groups of students at the
conclusion of their second semester of Senior Design using the online survey tool, Qualtrics. This
section of the paper looks at the quantitative analysis of the survey results, beginning with the
composition of the instrument. Table 8 shows the classification for each question on the survey
(behaviors, attitudes, self-efficacy, and curiosity) into constructs, grouped by topic. The table also
specifies the number of questions in each construct.

Table 8.
Construct, Questions Groupings, and Number of Questions

<table>
<thead>
<tr>
<th>Construct</th>
<th>Number of Survey Questions (Abbreviation)</th>
</tr>
</thead>
</table>

Back to top
<table>
<thead>
<tr>
<th>(source)</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behaviors (EES)</td>
<td>10 Activities (ACT) Extent to which engineering students participate in entrepreneurship education and related activities</td>
</tr>
<tr>
<td></td>
<td>7 Postgrad (POSTGRAD) Students’ post-graduation career plans</td>
</tr>
<tr>
<td></td>
<td>1 Business (BUS) Number of students who had, have, or intend to have a business</td>
</tr>
<tr>
<td></td>
<td>1 Venture (VEN) Type of businesses students are interested in starting (open ended)</td>
</tr>
<tr>
<td>Attitudes (EES)</td>
<td>9 Program (PROG) Extent to which entrepreneurship addressed in engineering programs</td>
</tr>
<tr>
<td></td>
<td>7 Interest (INT) Nature of engineering student interest in entrepreneurship</td>
</tr>
<tr>
<td></td>
<td>12 Start Business (STBUS) Reasons students would be interested in entrepreneurship</td>
</tr>
<tr>
<td></td>
<td>14 Not Start Business (NTST) Reasons students would not be interested in entrepreneurship</td>
</tr>
<tr>
<td>Self-efficacy (EES)</td>
<td>15 Efficacy (EF) Student perceptions of their technology venturing and entrepreneurship-related abilities</td>
</tr>
<tr>
<td></td>
<td>6 Skills (SK) Student perceptions of their skills in areas related to entrepreneurship</td>
</tr>
<tr>
<td></td>
<td>1 Ability (AB) Student perceptions of their entrepreneurship ability overall</td>
</tr>
<tr>
<td></td>
<td>1 Business Ability (BUSAB) Student perceptions of their ability to start a business immediately</td>
</tr>
<tr>
<td>Curiosity (CI-4)</td>
<td>16 Curiosity (CUR)</td>
</tr>
</tbody>
</table>

Analysis began with confirmatory factor analysis and examination of the correlation coefficients to determine construct validity. Then an ANOVA was conducted in SPSS to look for statistically significant differences between the control and intervention sections of the course. When looking for significance, each construct was analyzed as a whole, then we looked for significant differences in responses for each individual question.
Table 9.
ANOVA results for end of semester survey questions (results for the control group listed first). Each construct is listed first, followed by any individually significant questions from that construct (See appendix for full table results)

<table>
<thead>
<tr>
<th>Construct</th>
<th>Question</th>
<th>Mean</th>
<th>SD</th>
<th>F (1, 125)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavior (EES)</td>
<td>Activities, Post-grad</td>
<td>2.00</td>
<td>.30</td>
<td>2.08</td>
<td>.15</td>
</tr>
<tr>
<td></td>
<td>ACT6</td>
<td>1.91</td>
<td>.74</td>
<td>4.93</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.62</td>
<td>.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>While in college, have you done any of the following: Been involved in专利ing a technology or protecting intellectual property</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attitudes (EES)</td>
<td>Program, Interest, Start Business, Not Start Business</td>
<td>3.29</td>
<td>.31</td>
<td>.03</td>
<td>.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.28</td>
<td>.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>INT1</td>
<td>3.42</td>
<td>1.03</td>
<td>4.32</td>
<td>.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.00</td>
<td>1.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Please rate your level of agreement with the following: I have a general interest in the subject of entrepreneurship</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>INT6</td>
<td>3.82</td>
<td>.82</td>
<td>6.80</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.34</td>
<td>1.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Please rate your level of agreement with the following: Entrepreneurship education can broaden my career prospects and choices</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NTST12</td>
<td>2.55</td>
<td>1.11</td>
<td>4.59</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.00</td>
<td>1.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>If I wasn’t going to start a business, the reason I would NOT start a business is because... Doubts about personal abilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NTST13</td>
<td>2.59</td>
<td>1.05</td>
<td>3.89</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.98</td>
<td>1.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>If I wasn’t going to start a business, the reason I would NOT start a business is because... Having to work too many hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-Efficacy</td>
<td>Efficacy, Ability, Business Ability, Skills</td>
<td>39.95</td>
<td>9.18</td>
<td>7.83</td>
<td>.01</td>
</tr>
<tr>
<td>(EES)</td>
<td>EF6</td>
<td>34.62</td>
<td>12.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>51.46</td>
<td>25.21</td>
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<td>.03</td>
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<tr>
<td></td>
<td></td>
<td>51.46</td>
<td>25.34</td>
<td></td>
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</tbody>
</table>

For each statement indicate how confident you are that you could perform that skill or possess that ability now: Recruit the right employees for a new...
OPPORTUNITIES FOR INNOVATION

For each statement indicate how confident you are that you could perform that skill or possess that ability now:

<table>
<thead>
<tr>
<th>Statement</th>
<th>EF9</th>
<th>EF10</th>
<th>EF11</th>
<th>EF12</th>
<th>EF13</th>
<th>EF14</th>
<th>EF15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convert a useful scientific advance into a practical application</td>
<td>66.93</td>
<td>72.88</td>
<td>67.17</td>
<td>73.67</td>
<td>69.88</td>
<td>69.12</td>
<td>72.99</td>
</tr>
<tr>
<td>Develop your own original hypothesis and a research plan to test it</td>
<td>21.90</td>
<td>18.13</td>
<td>19.61</td>
<td>18.71</td>
<td>19.48</td>
<td>19.69</td>
<td>18.14</td>
</tr>
<tr>
<td>Grasp the concept and limits of a technology well enough to see the best ways to use it</td>
<td>6.37</td>
<td>11.22</td>
<td>6.73</td>
<td>15.85</td>
<td>8.51</td>
<td>15.02</td>
<td>16.94</td>
</tr>
<tr>
<td>Design and build something new that performs very close to your design specifications</td>
<td>57.05</td>
<td>60.34</td>
<td>56.87</td>
<td>58.18</td>
<td>58.56</td>
<td>53.54</td>
<td>57.62</td>
</tr>
<tr>
<td>Lead a technical team developing a new product to a successful result</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Understand exactly what is new and important in a groundbreaking theoretical article</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Translate user needs into requirements for a design so well that users will like the outcome</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Curiosity (CI-4)

<table>
<thead>
<tr>
<th>Curiosity</th>
<th>4.74</th>
<th>5.35</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.47</td>
<td>5.35</td>
</tr>
<tr>
<td></td>
<td>.56</td>
<td>.73</td>
</tr>
<tr>
<td></td>
<td>.54</td>
<td>.73</td>
</tr>
<tr>
<td></td>
<td>7.84</td>
<td>4.46</td>
</tr>
<tr>
<td></td>
<td>.01</td>
<td>.04</td>
</tr>
</tbody>
</table>

Please indicate your level of agreement: I like variety in my life.
OPPORTUNITIES FOR INNOVATION

CUR4  4.89  .91  7.67  .01
      4.44  .92

Please indicate your level of agreement: I am always finding new things to do.

CUR11  4.77  1.12  7.49  .01
      4.25  1.04

Please indicate your level of agreement: I prefer to mix up my days with a variety of activities.

CUR12  4.91  .84  3.73  .01
      4.59  .89

Please indicate your level of agreement: I immerse myself in information pertaining to a topic that I find fascinating.

CUR13  5.34  .83  7.32  .01
      4.93  .89

Please indicate your level of agreement: Very few things interest me.

CUR14  4.88  1.06  5.03  .03
      4.48  .96

Please indicate your level of agreement: I like to get involved in a wide-variety of activities.

CUR15  4.88  .81  11.17  .00
      4.39  .82

Please indicate your level of agreement: When learning something, I try to gain the fullest possible understanding of the phenomenon.

CUR16  5.00  .96  3.89  .05
      4.67  .91

Please indicate your level of agreement: I find myself fascinated by lots of different things.

Note. EES = Engineering Entrepreneurship Survey; CI-4 = Curiosity Index

ACT questions required a no (1), yes (2), or planning to (3) response; POSTGRAD, PROG, INT, STBUS, and NTST questions were coded 1-5 with 5 = strongly agree and 1 = strongly disagree; EF questions had a slider scale with a range of 0-100 with 0 = not at all confident and 100 = completely confident; AB, BUSAB, and SK questions were coded on a scale of 1 to 5 with 5 = excellent and 1 = poor; CUR was coded on a scale of 1-6 with 6 = strongly agree and 1 = strongly disagree.

Looking at the constructs as a whole, analysis indicated that there was a significant difference between the two groups of students in two out of the four constructs- Self-Efficacy and Curiosity.

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In both of these constructs the intervention group of students showed a significant decrease (see Table 9). Although the analysis indicated that the construct, as a whole, was not significant, there were individual questions in all four constructs that indicated a significant difference between the groups. Those questions that indicated a significant result are addressed individually.

The students from both sections of the course were equivalent in regards to the Behaviors construct which included questions addressing the extent to which engineering students participate in entrepreneurship education and related activities (ACT) and students’ post-graduation career plans (POSTGRAD) (Duval-Couetil et al., 2011). In activities, the only question that showed any significant main effect was ACT6- Been involved in patenting a technology or protecting intellectual property, \(F(1, 125) = 4.93, p = .03\), with more control students reporting that they have \(M = 1.91, SD = .74\) than intervention students \(M = 1.62, SD = .71\).

Questions from four categories measured student’s attitudes including: the extent to which entrepreneurship is addressed in engineering programs (PROG), nature of engineering student interest in entrepreneurship (INT), reasons students would be interested in entrepreneurship (STBUS), and reasons students would not be interested in entrepreneurship (NTST) (Duval-Couetil et al., 2011). Results indicated that students from both sections of the study were similar regarding attitudes and the construct showed no significant difference between the student groups. When each question was analyzed individually, two interest (INT) questions did show a significant difference that was worth further consideration: “I have a general interest in the subject of entrepreneurship,” \(F(1, 125) = 4.32, p = .04\), and “Entrepreneurship education can broaden my career prospects and choices,” \(F(1, 125) = 6.98, p = .009\). The control group \(M = \)
OPPORTUNITIES FOR INNOVATION

3.42, \( SD = 1.03 \) showed a significantly higher mean for having a general interest in the subject of entrepreneurship than the intervention group (\( M = 3.00, SD = 1.24 \)). The control group (\( M = 3.82, SD = .82 \)) also reported a higher mean when asked if entrepreneurship broadened their career options than the intervention group (\( M = 3.34, SD = 1.18 \)). This suggests that the control group showed an overall higher interest in entrepreneurship as a subject area and in the survey indicated more often that entrepreneurship could broaden their career choices.

Two questions from those looking at reasons to not start a business (NTST) showed a significant difference when analyzed alone: “If I wasn’t going to start a business, the reason would be- Doubts about personal abilities,” (\( F(1, 125) = 4.59, p = .03 \)), and “If I wasn’t going to start a business, the reason would be- Having to work too many hours,” (\( F(1, 125) = 3.89, p = .05 \)).

Students in the intervention section (\( M = 3.00, SD = 1.28 \)) had more doubt in their ability to start a business than students in the control section (\( M = 2.55, SD = 1.11 \)). In addition, students in the intervention section (\( M = 2.98, SD = 1.19 \)) reported that the number of hours they would have to work was a deterrent to becoming an entrepreneur more than students in the control group (\( M = 2.60, SD = 1.05 \)). This could suggest that the intervention group was more aware of the difficulties associated with starting their own business, such as the broad spectrum of skills required for entrepreneurship or the large number of hours necessary for success when starting a business.

In addition, the video interviews with the intervention students revealed similar sentiments. One student said “I’m kind of interested in [entrepreneurship]. I don’t know that I’m ... I don’t feel equipped enough to do it at this point.” Another stated that he intended to become an entrepreneur, but first he was “planning on coming back and getting [his] masters in biomedical engineering and then hopefully going into industry after that. Then maybe coming back to get
Based on this statement, the student is confident he could become an entrepreneur, but he does not feel fully prepared at this point to pursue a business. Furthermore, one student described an entrepreneur as practically super-human. He stated that that entrepreneurs “have to do everything; they do the business, they do the design, the legal, they’re kind of all over the place, because we have a handful of people at a small business ... so they have to be a jack-of-all-trades, and hopefully, they’re at least okay at everything, and don’t have any glaring weaknesses,” a definition that could deter even the most capable student considering entrepreneurship.

In the survey, self-efficacy was measured with questions from four categories: student perceptions of their technology venturing and entrepreneurship-related abilities (EF), student perceptions of their skills in areas related to entrepreneurship (SK), student perceptions of their entrepreneurship ability overall (AB), and student perceptions of their ability to start a business immediately (BUSAB) (Duval-Couetil et al., 2011). As seen in Table 3, there was no significant difference between the two groups on the questions regarding skills (SK), ability (AB), or business ability (BUSAB). However, a significant difference was detected on eight out of fifteen questions regarding efficacy (EF). An ANOVA on the group means for the efficacy questions showed a significant difference, \( F(1, 125) = 7.97, p = .01 \), between the two sections of the course. The efficacy construct addressed student perceptions of their technology venturing and entrepreneurship-related abilities; therefore the intervention section \( M = 51.34, SD = 18.42 \) showed a statistically significant lower self-efficacy than the control group \( M = 59.47, SD = 13.89 \) regarding their entrepreneurship abilities. In a previous study, this survey was used to measure entrepreneurship self-efficacy with engineering students who either had or had not taken entrepreneurship courses, it was found that entrepreneurship self-efficacy was
significantly higher for those who had taken entrepreneurship courses in the past (Duval-Couetil, Reed-Rhoads, & Haghighi, 2012). Perhaps the students in the intervention section had less entrepreneurship exposure than those in the control section of the course. Moreover, anecdotal evidence points to the possibility that during the intervention section of the course faculty might have been less explicit when talking about entrepreneurship topics, focusing more on the individual skills and traits.

The curiosity construct included sixteen questions that looked at respondents’ breadth and depth of curiosity (CUR). A significant difference was also shown on eight out of sixteen questions regarding curiosity. An ANOVA showed that the control group ($M = 4.74, SD = 0.56$) had a higher mean than the intervention group ($M = 4.47, SD = 0.54$), in curiosity ($F(1, 125) = 7.84, p = .01$).

In order to better understand the implications of this result, additional questions about curiosity were added to the intervention student interviews as shown in Figure 10. In the interviews, all of the students interviewed ($n = 11$) described themselves as curious. Students pointed out that their curiosity is affected by passion and interest in the subject at hand. Perhaps students felt less generally curious and more focused on graduation and their next steps because they filled out the survey during the final week of their undergraduate classes. When asked, one student said that curiosity was “what led [her] to engineering, just because [she] likes to question how things work, you know? And figuring that out, and learning how to do it on your own is really cool.” When asked during the interview if they felt that Senior Design had an impact of their curiosity levels, students had mixed responses. Some students mentioned that the course made a positive impact on their curiosity, such as giving them tools to focus their curiosity, even if it did not create an increase in the level of curiosity.
Figure 10. This video shows footage from student interviews where they discuss curiosity. Direct link to video: https://youtu.be/f5oFcmQvhPc

Notes: Some of the quotes include:
- “I couldn’t give a specific example from one of the activities that we did, but I’m sure that, with everything put together, with all those activities that we went through, to help our minds think that way, I would definitely say that I became more curious through the first semester.”
- “I have always been but senior design made me realize like how much I can do about it.”
- “I think I’ve learned how to be curious. I think I’ve kind of learned how to have more discipline with my curiosity, so not necessarily just be, I guess, floating around being curious about things, but learning how to be more pointed, to learn how, where to go to ask questions, learning how to ask those questions, learning when and where, and learning where my starting point is, and what my next step will be.”

RQ1: Student Interviews

The second piece of data analyzed for research question one was interviews with students from both sections of the course. Student interviews were conducted with the control group (n = 7) and intervention group (n = 11) of students. All interviews took place at the end of the student's second semester of the course. The Senior Design Expo, an event where Senior Design teams presented their final projects for faculty, students, and industry partners, served as the location for student video interviews.
In both sections of the course, participation in the Expo was a requirement, but taking part in the video interview was voluntary. Recruitment for the interviews relied on the student’s response on the final question of the survey indicating willingness to participate. In addition, graduate assistants randomly recruited additional interviewees during the event. The length of interviews ranged from 3 minutes to twelve minutes long depending on how the student responded to the questions. The lead researcher conducted all video interviews and the videos were transcribed in full for qualitative analysis.

The semi-structured interview format allowed for some variability of the questions, but the standard questions included:

- What does entrepreneurship mean to you?
- How do you define innovation?
- What does the term design-thinking mean to you?
- What did you learn (if anything) about innovation and entrepreneurship in Senior Design?
- What did you learn (if anything) about design-thinking in Senior Design?
- What was the most important/interesting thing you learned in senior design?
- Do you think you’ll be able to use [what you learned in this course/ what they just talked about in previous question] in your career?

Video interviews were transcribed to aid with analysis of global themes using the process of narrative analysis. Qualitative research software and paper-based methods were used to analyze the transcriptions.

Using the narrative method, the video interviews were analyzed as qualitative data points. By watching the videos and reading the transcripts to form the initial codes, the analysis was able to identify the overarching themes and locate any common epiphanies across participants (see Table 6). By grouping the video clips based on thematic codes, a focused narration of the story in the form of a collection of short video vignettes was created (Creswell, 2012). For research
question one, codes centered around: defining entrepreneurship, identifying the most valuable thing learned in the course (with respect to 21st Century Skills and/or domain content), curiosity, and the most impactful game-based learning activity. The footage from these interviews was edited into video vignettes and presented as a collection of short videos on a YouTube channel as well as embedded in the written document. Video vignettes are an appropriate format for addressing this data point because an edited video tells the overarching story of these students’ experience in their own words. By combining multiple interview subjects together, the resultant topical videos shows the facial expressions and voice inflections that provide more context for the interviewees’ statements than the written word alone.

**Student Interviews: Defining Entrepreneurship**

As seen in Figure 11, when asked about entrepreneurship the two groups of students defined the term differently. Although individual answers varied, students in the control group thought entrepreneurship was the realm of business. They stated that, as engineers, they don’t really have much exposure to business topics. Students did not think that entrepreneurship was something engineers participate in.

Conversely, the intervention students defined entrepreneurship more broadly mentioning creativity, problem-solving, pursuing an idea, and starting a business. None of the students from the intervention group stated that entrepreneurship was for business majors, not engineers. Interviewees from the intervention group talked about a broader application of entrepreneurship and recognized the 21st Century Skills needed by entrepreneurs for success.
Figure 11. This video shows student responses to the question “What is entrepreneurship?”
Direct link to video: https://youtu.be/V8XegnAjHec

Notes: Sample transcription from control interviews:

- “A lot of us come in and we are strictly bioengineering – we don’t really have a lot of business background”
- “I guess in my mind entrepreneurship is a little bit more on the business side. Design and innovation is more the science – the engineering side – the actual building and testing.”
- “I’ve never taken any business classes, so to me, when I think of entrepreneur – I think of pursuing different business ideas or pursuing your own idea – trying to start something new”

Sample transcription of intervention interviews:

- “I think it means looking at different ideas that you’re interested in, and pursuing those ideas to eventually come up with something that’s marketable to society. I think it means being creative, thinking outside the box and also taking risks; risks, but they’re also responsible risks.”
- “I know that, basically, you have to do everything; they do the business, they do the design, the legal, they’re kind of all over the place, because we have a handful of people at a small business, for an entrepreneur, so they have to be a jack-of-all-trades, and hopefully, they’re at least okay at everything, and don’t have any glaring weaknesses.”
- “I think it’s having an idea and then knowing the market and being able to fit that idea into the marketplace so it actually has somewhere to go. A great idea isn’t necessarily useful unless it has a market for it. I think being able to figure out a market for your idea is the best way.”
- “I think is just creating something from your imagination and being able to apply it.”
- “Entrepreneurship, I would say is, I guess, finding a problem and solving it. Working through all of the aspects of the need, the problem, figuring out how to fix it, and just growing on that, and actually solving that actual problem, would be entrepreneurship.”
- “You can’t get a loving attachment [to your idea/product]. You have to be able to remember that at the end of the day, this product could fail, but try to figure out every way possible how it can’t fail, or how it’s going to be so pertinent that they’re going to need it, and do everything you can to adjust it in that way so it fits into the market, but that’s entrepreneurship, I think is having a stake in the game. It’s really gutsy, real gutsy.”
Student Interviews: Most valuable/interesting thing learned in Senior Design

As seen in Figure 12, when asked about the most valuable thing they learned in Senior Design, students from both groups mentioned the design process and 21st Century Skills in their response. Some of the skills commonly included were teamwork, perseverance, communication, leadership, brainstorming, and iteration.

Figure 12. This video shows student responses when asked about the most valuable/interesting thing they learned in Senior Design. Direct link to video: [https://youtu.be/trPK9b-t6u0](https://youtu.be/trPK9b-t6u0)

Notes: Sample transcription from control interviews:
- Your first design is never your best design. I would say that. There can always be improvements.
- A lot of working with teams. You have team projects before, but this is like, you and your team, you’re with your team. You become so close, and you work through all these different problems together, and sort of going over all these different things with your team was a really valuable experience.
- Even a crazy idea is a good idea. Throw it all out there and see what comes out of it, I guess. No idea is a bad idea basically.
- I think the most interesting thing [was a] crash course on professionalism.
- This course wasn’t necessarily introducing the testing and building and designing phase, but being able to work with other people and bringing their ideas and collaboration.
- Definitely, the whole process of it. Learning the whole process of going through design

Sample transcription from intervention interviews:
- Probably the steps of the design process and then taking that into the next semester and actually applying those steps.
- I think one of the things that helped us was we talked a lot about what we think our core competencies were. That was helpful in order to find a good team.
- I think that presenting skills that we’ve learned over the course of the semester, teamwork skills- I think that those are two extremely invaluable skills sets.
• Just working as a team and getting everyone’s perspectives.
• Definitely about leadership, I was never a leader, like I did not want leadership positions or never went for them but when like I became my team leader, I could do this, like I have the ability to work on this.
• So one of the other things is that learning to make mistakes, because like in school if you made a mistake then you lose a letter grade or you know, your GPA suffers a lot but in senior design you could make mistakes and learn from them.

Teamwork was listed as the most important item learned in Senior Design by three out of seven students from the control group and eight out of eleven intervention students. Both groups of interviewees mentioned iteration, brainstorming, communication, teamwork, collaboration, and the design process. Furthermore, brainstorming was the second most valuable thing intervention students learned during the intervention behind teamwork. The intervention students specified several unique responses including perseverance (overcoming a challenge), identifying personal strengths to form a team, developing confidence, problem solving, leadership skills, and understanding failure/ the value of making mistakes.

Student Interviews: Most valuable game from intervention
The student interviews took place six months after the conclusion of the intervention and several students could not recall specific games we had done during the Fall semester. For example, one student stated that “[she] didn’t even remember what we did in the fall semester besides those online quizzes that [she] would wake up and remember that [she] had to do them before 8am.” Students with no distinct memories of the games tended to answer more generally about what they had learned in regards to domain content and 21st Century Skills practiced during the course.

Eight out of the eleven interviewees did recall specific classroom games from the fall semester as seen in Figure 13. The class activities remembered most frequently included the structured
brainstorming games (Class 11 & Class 12). The class games where students identified personal strengths and the strengths of classmates (Class 05) was also referenced as valuable to team formation. Other class games cited include: patent searching (Class 09), the mini-design process (Class 03 & Class 04), and roles in BIOE (Class 02).

Figure 13. In this video students reflect on the intervention games that they remembered the best and had the most impact on them. Direct link to video: https://youtu.be/cuJzpkU1DQc

Notes: Full transcription of quotes used in this video vignette:

- “I thought the hat thing was kind of cool, although I kind of wish we were assigned those hats that we’re good at. I wish they didn’t tell us what the hats were beforehand, because I felt like while I was taking a survey, I knew which hat I thought I was, and it was more biased ... But I did like the ideas, and they have hats, and also people can just try them on. “You need the black hat, because you need to think critically what can go wrong, what will go wrong,” but also, you don’t too much of that, so you’ve got to balance it, or think creatively ... Think about how people are going to feel about it, and all the different hats that they had, like red, and yellow, and green, and blue ... I thought that one was really, really interesting.”

- “I remember there were some games that we were playing, where you had to work on something, and say the first thing that came to your mind, and then remove it, and then you’d see new things. I think definitely that helped, learning new ways to think about something, and just to view it in a different light, you might not have seen before.”

- “I really liked when we went ahead and learned about all the different paths that we could take as bioengineers ... We thought about our own strengths, and how we could fit into that, because then you think about new job possibilities, that you hadn’t really thought of before.”
• “I would say abstract thinking ... Before Senior Design, I definitely had a hard time looking at things from every angle ... Like I was saying earlier, trying to find that one ... You turn something upside down, and have a different use for it than somewhere else, and finding that specific ... That’s how you design something, you’ve got to think about it backwards sometimes, and come with a solution that way. We did one activity, I know, where we looked at a picture, and then it was, “Okay, now turn it sideways, turn it upside-down, think about all the things that it could be ...” I think that definitely probably helped the most with the whole process, is thinking outside the box, and trying to come up with those ideas.”

• “What I’ve learned from the fall semester, I learned a lot of different things, so I’ve learned one, that there’s a lot of different jobs out there that don’t necessarily say “bioengineer.” If you were to Google, bio-engineering jobs at other companies, it’s really difficult to find one that says bioengineer. You’re going to find quality engineer, you’re going to find probably development team, you’re going to find marketing sales, you’re going to find different management positions. Literally they all fit in to bioengineer. That’s one thing I love about engineering. There’s so many different options that can stand, and you can move around within a company just off of what you feel like doing, or what you think your passions are. I definitely learned that during the fall semester.

• I learned what attributes of different people fit in a group setting, in a team, to make a really productive teamwork. I’ve learned a lot about myself. I’ve learned that there’s a lot of other people like me, who think like I do, who work like I do, whose strengths are similar. I’ve also learned I’m very different and that diversity in a team is very important.”

• “I think one of the things that helped us was we talked a lot about what we think our core competencies were. That was helpful in order to find a good team. We already had our team pretty much set of who we thought would be together. I think it just confirmed. We had different people; some were good at presentation skills and some were better at the mathematics and the CAD systems, the design of that. I think it really just confirmed that we had a very diverse group to have all aspects of the design of the device and in the marketability of it.”

• “Definitely a better understanding of finding stuff, finding patents, research articles, and everything ... I want to get more into the research lab focus, a better experience of finding everything, and who to talk to, and just having understanding of where to go for things helps a lot.”

• “Very early on in the semester when we did the whole chair thing, when we made the chairs I think that was pretty cool. I wish we did that with our teams so that we would actually like do a run of trying to work together on a team and make something and do testing and fail and all of that but with like a small device, but that was one of the best things we did I guess, I liked it a lot.”

RQ1: Debriefs

The final data point for research question one was the student debrief responses. The responses from the student-submitted debriefs echoed similar sentiments as the student interviews. As seen in Figure 14, students frequently mentioned many 21st Century Skills in the debriefs. Students stated that they had opportunities to practice these skills prior to experiencing “the real thing” such as working on their Senior Design project, choosing their groups, or in their future careers.
Debrief comments that indicate that the games allowed them to practice different skills:

In the debrief comments below, students wrote about how the games gave them opportunities to practice skills such as critical thinking, brainstorming, application of theory, critique and iteration, and communication skills.

- “To practice coming up with ideas, thinking critically, and delve deeper into idea possibilities. To practice due diligence by continually questioning and critiquing your ideas and evaluate them with respect to other competing products.”
- “Today’s activities helped us to practice brainstorming methods found in the book. Doing so helped us determine which methods might work best for us as we continue along the design process.”
- “The purpose was to practice writing needs statements. The activities allowed us to try out what we had learned in the slides and had observed being done in all the videos online. I thought it was great practice, especially because I learned that it is much more difficult to do than I originally had anticipated.”
- “I think that the point of today’s activities was to have us practice analyzing a product and improving it using TRIZ steps to make these improvements. It also allowed us to review various design theories and methodologies.”
- “The purpose was for us to practice sketching designs that would be suitable for the machine shop to actually produce. They gave us good feedback so we could learn from our mistakes and not waste time and money once we are prototyping our device.”
- “The purpose of today’s activity was to give us practice communicating plans/specifications to other groups of people.”
Debrief comments that indicate that students made the connection between game-based learning and acquiring these skills:

In the following comments from the debriefs, students reflect on the connection between the game or activity performed during class with the specific skills they attained. Specifically, they noted that the games allowed them to recognize weaknesses in how they approached the task and iterate the process to be more effective. The game-based learning aspects of the course provided low-stakes opportunities for students to fail and try again as they grappled with practicing these skills.
● “I believe that the activity based aspect of this course will enhance my learning of the material during Senior design. These activities will help one to experiment different manners in communicating the best way to complete a task.”

● “With the 10 sticky note activity, we did not communicate at all as a group and did our own things and hoped it worked out in the end. We did not have a planning phase and did not have any quality control going on. We simply just passed the paper to the next member and so on. We should’ve discussed what we wanted to do and how we would approach it and then outline what member does what and implement a quality control phase to ensure nothing went wrong (such as having the person to the right critiquing before the item was passed on). For some reason, we still did not have a cohesive phase when building the chairs. We did discuss what we wanted to do but we did not do an assembly line type building process. Each person built a chair with another person helping. We did however discuss flaws but did not address how to eliminate them in the future. Rather, we just covered them up. No one really had a defined/designated role in any of the activities. We all sort of took on every role together. We made our plan together, gathered supplies together, built together, and then tested together.”

● “I thought the design process was really insightful and helpful. We had to come up with the different features for our design, and we had to brainstorm on the different ways we could implement that feature in our design. We realized that our products didn’t come out as uniform as we had hoped, and we could have improved it by forming an assembly line instead of each individually creating our own product. Every member from our group had the chance to pitch in and come up with a different feature and explain how it worked.”

In some cases, the learning outcomes were focused on practicing the design process as it is defined in this field. Students’ reflections showed the connection between the “game” version of the process and how it applied to the Bioengineering process that they would undergo during the second semester of the course.

● “First, my group sat down and discussed the five basic features that we wanted the chair to possess, which included durability, mobility, and comfort. We then created a small assembly line in order to effectively and efficiently create our product. I was responsible for reinforcing the seat and back of the chair with strong tape, and for taping the legs together.”

● “The purpose of our activities seemed to focus on defining a problem and then communicating one’s thoughts on that problem to a team.”

● “The purpose of today’s activity was to see how well one can [graphically] communicate an idea to another [person]. This activity showed that there are a lot of concepts that need to be included in a drawing to ensure that the part is made correctly.”

● “Today’s activities were supposed to help us prepare for when we need to have things built by the machine shop. It is a lot more technical than I expected it to be. It showed how
important communication is, and to make sure that your design can be built before you invest a lot of extra time into it.”

● “We were discovering how to use TRIZ and seeing how a tightly defined set of solution can sometime be beneficial to problem solving, but can also sometimes hinder it.”

In other debriefs, students mentioned how the games created a chance to practice specific 21st Century Skills such as creativity, communication, teamwork, problem solving, and perseverance.

● “Players are more involved in their learning and are actively engaged in games. The advantages are that it targets different modes of communication including action and explaining concepts.”
● “I believe the team-based, hands-on, approach will allow me to grasp concepts more easily and increase my creativity over time.”
● “The activities promote creativity and team building.”
● “I believe the activity based aspect of the course will help solidify learned material and will help us all in learning how to embrace team-work and problem solving.”
● “I think especially today’s activities were good for us because engineers have a tendency to not work well in groups, and not only did we have to work as a group but then we had to take our original idea and make it work with another group which took some creative problem solving.”
● “I think an importance should be placed on interpersonal skills. It is good to have a creative and brilliant mind; however, if you cannot communicate your idea or collaborate with others then what is the point. You need to be able to ask for assistance or present the ideas for others to jump on board and offer help or support. I think that skill would be helpful for all stages of the process from designing to marketing. Patience is also important because it needs to be understood that things take time and with that also comes perseverance. I think knowledge is important but more focus should be placed on how a person approaches things and makes their way through challenges. Patience, perseverance, interpersonal skills, understanding, etc.. these are all valuable.”

Group work is commonplace in classrooms and selecting members of a team is an important skill, but seldom part of formal discussion during class (Vik, 2001). Recognizing the difficulty students can have in forming productive teams and the importance of carefully selected teammates, several of the intervention class periods focused on group member selection. Comments in the debriefs recognized that learning objective and mentioned skills that students practiced during those games.

● “The traits you need to look for in potential group members for me is a fairly high level of grit and focus because I tend to jump from one idea or project to another fairly quickly.
This is problematic for long projects like senior design. They would be able to keep the
team and I focused and motivate us to complete the project.”

- “Understanding my strengths and others strengths allowed me to see the variety of skills
  that everyone has. It taught me that it’d be wise to not pair myself with a group of people
  that had the same strengths as me, but to pair myself with others that have strengths that
  are my weakness.”
- “I look for group members that are organized and can help plan meetings so that all of the
  members can utilize their skills efficiently.”

RQ2 Synthesis:
In this section, I will review the results from research question two by looking at three different
data points collected during the study: the student debrief responses, video tapes of each
game-based class meeting, and the final exam scores (see Table 10). I used NVivo qualitative
analysis software to analyze the debrief responses, and the video tapes of the classes were used
to observe the range of student interactions during class. The quantitative software program
SPSS was used to analyze the the final exam grades.

Table 10.
*This table depicts the connection between the research question, the method(s), the data points
collected, and the type of analysis used for research question two.*

<table>
<thead>
<tr>
<th>RQ2: How does changing the course delivery method, lecture-based compared to game-based, affect student learning of the domain content?</th>
<th>Collect qual before, during &amp; after quant data:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Debrief responses</td>
<td></td>
</tr>
<tr>
<td>- Video tapes of the classes</td>
<td></td>
</tr>
<tr>
<td>- Exam results from both semesters</td>
<td></td>
</tr>
<tr>
<td>Qualitative- Global themes, Content Coding</td>
<td>Quantitative- Comparative Statistical Analysis</td>
</tr>
</tbody>
</table>
The course delivery method was a key change between the two versions of the course. The control section of the course was taught using traditional lecture delivery methods and the intervention section of the course used a flipped classroom approach and game-based learning as the delivery method. This research question looked at the impact that course delivery had on student learning of the domain content for the course.

RQ2: Debrief Response Analysis

The first data point used to address research question one was the debrief responses. We administered the debriefs by sending students a link to a debrief questionnaire twenty-four hours after each class period ended and students responded during the subsequent twenty-four hours. This time frame ensured that students had adequate time after each class to reflect, but that the specific details would still be clear. Tailored questions for each class provided opportunities for students to comment on specific games and how they related to the domain content for the course and 21st Century Skills. Reflection is an important part of the cognitive apprenticeship model, and the questions encouraged students to reflect on their experience during class and share thoughts regarding the class activities and games. In order to encourage students to respond regularly, the reflections did account for a low-stakes portion of the attendance/participation grade in the course. The grading was based on thoughtful completion, not on whether the student’s reaction to the classroom games was positive or negative.

In the visual representation of this data on the website, a selection of debrief responses is presented for each class period to show the diversity, or in some cases the consistency, in student responses to the debrief questions. A short synthesis of the debriefs is also available on the website in the info tab for each individual class and is included in Table 11.
Table 11.

Debrief Synthesis for Each Class

<table>
<thead>
<tr>
<th>Class #</th>
<th>Class title</th>
<th>Synthesis of student reflections</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Welcome to BIOE Senior Design</td>
<td>Students wrote about how they evaluated their personal goals and compared them with their classmates’ goals for the course. Based on their responses, they understood from the course introduction and the game that this will be a different classroom experience than what they are used to so far in school. The third objective, understanding there is no one right answer, was not mentioned in their responses. However, students did state that they are looking forward to hearing other student’s perspectives through the activities and see that communication regarding perspectives as an advantage of this classroom format.</td>
</tr>
<tr>
<td>02</td>
<td>Why Design: Processes and Professions</td>
<td>Students stated that they learned about the different roles on a biomedical engineering team. They were comfortable with some of the roles presented, but were less familiar with the important contributions of others, especially cross-functional management and quality control. Students articulated what 21st century skills were most important for success in the different roles. Finally, they stated that the responsibilities of individuals on a biomedical engineering team overlapped and that everyone must work together on the project to attain success. How the GATEs from BIOE 4030 are connected to this process was not mentioned.</td>
</tr>
<tr>
<td>03</td>
<td>Design Methodologies and Needs-Based Design</td>
<td>For the low-stakes chair build, students wrote in the reflections that implementing a design process such as Six Sigma or Robust Design would be advantageous. They recognized that implementing those design models allowed for a more consistency in the end products and higher quality products. Six Sigma and Robust Design require more planning, better manufacturing, and a chance to really look at each of the design features. In addition, students mimicked biomedical engineers using the Kano method to determine how best to incorporate excitement features that add value to a design. As a result of their experiences in class, they acknowledged through the debriefs that by utilizing a documented design process they could improve quality, planning, consistency, and manufacturing of their product.</td>
</tr>
<tr>
<td>04</td>
<td>Design Methodologies and Needs-Based Design, Day 2</td>
<td>In the debriefs for Class 04, students connected the games with all of the stated learning objectives and goals. Emphasis was placed on using the excitement/performance threshold graph in order to avoid emotional response to the analysis of specific design features. Furthermore, students connected how the Kano and TRIZ methods from the lecture materials impact a real design scenario. Finally, they mentioned that their first prototype/idea will not be their best. This acknowledgement of the importance of iteration is an important 21st century skill for biomedical engineers because it encourages a process of continual improvement when developing a unique final product.</td>
</tr>
<tr>
<td>05</td>
<td>Strength identification and Group Formation</td>
<td>In their reflections, students stated that they understood the connection between the domain content for the course and the class games completed today. They...</td>
</tr>
</tbody>
</table>
wrote that through the games they identified potential team mates in the class that they had not considered working with before.

06 Observation, Problem Identification, and Needs Statement Development

This topic was originally scheduled to take up a single class period, but ended up taking two classes to teach needs finding. In the debriefs, students commented on understanding the difference between looking (passive) and observing (active) from the in-class games. They also wrote about how observation is a necessary step when you try to understand what problem exists in a given situation. Students discussed all the listed objectives in the reflections. In the responses, there was a heavy emphasis on how this class provided a chance to practice observing problems. The practice during class will help them apply this process when visiting their clinicians rather than depending on the clinician to point out what they need the device to do. Furthermore, students acknowledged the importance of accurately recording observations, that a problem/need statement must be quantified, and that different people recognize diverse things when observing the same situation.

07 The Introduction to Design Controls

Students stated that the class games gave them practice creating a Quality function deployment (QFD). Part of this process involves quantifying measurements for the inputs and the outputs for each design specification. This practice in class will aid students when they create a QFD for their own senior design process. Students noted a strong connection between the slides and videos watched prior to this class.

08 Needs Screening

A large amount of content was covered in this class period and no individual student mentioned all of the goals for the class in their responses. However, collectively, the class as a whole mentioned all the objectives. Students stated that the games helped clarify the Four Factors (quantitative measurements)- mortality, morbidity, incidence, and prevalence- in a way that reading about them did not. Students emphasized how using the Four Factors to quantify needs combined with guesstimation would help them identify needs worth pursuing this semester for a senior design project. They practiced convincing other people of the value of their need using quantitative values for the Four Factors.

09 Needs Screening- Stakeholder and Market Analysis

Students wrote about practicing the process of thinking outside of the box by pushing through a quantity of ridiculous ideas in order to allow team members to build an idea into something original and worthy of pursuit. Students mentioned the competitor part of the class less frequently in the debriefs, but stated the importance of understanding the competition in order to innovate past what is already available on the market. These ideas connected to the process of market analysis. Students specified several 21st Century Skills including creativity, persistence, teamwork, brainstorming, and collaboration.

Students had an upcoming deadline with their groups and used the debriefs as a platform to request class time to work on assignments. I believe that this looming deadline reduced their patience with the games/activities because a graded assignment should take priority.

10 Needs Finding and Screening Tools

Across their debrief responses, students mentioned the objectives from this class including: the tools used for needs finding and screening, the different roles professionals perform within the design process, understanding the importance of
opportunities for innovation

when determining needs, and practicing the negotiations involved in
determining the "best" need to pursue as a team. Students admitted that the head
negotiation within their "companies" did not go smoothly within their groups. They
wrote that everyone thought that their opinion (based on the role in the company
they played) was the most important when choosing which need to address. They
recognized during this game that everyone's opinion can not be the most important
when making a decision, therefore, as in real life, the weight of opinions must be
negotiated within a team in order to come to a consensus.

| 11 | Part 1: Concept Generation and Brainstorming | Students commented about the effects of trying to enact different roles than what
came naturally to them and how that process created new perspectives and
different approaches to a problem. In addition, they mentioned the opportunity to
build off of each other when employing structured brainstorming methods with
their group. This practice allowed teams to determine a method that works best for
them as a group. By recognizing the individual brainstorming preference of their
teammates, the teams continued to analyze how best to work together. According
to the student responses, this class had an impact on group dynamics and bonding. |
| 12 | Part 2: Concept Generation and Brainstorming | Students stated that practicing the structures brainstorming techniques had
advantage over just reading about them in the slides prior to class. They noted that
the different techniques actually produced different ideas. In addition, they
mentioned letting go and looking for quantity over quality of ideas which is an
important 21st Century Skill for biomedical engineers at this stage in the process.

According to the student reflection responses, the instructors did not convey the
connection between the games and their natural brainstorming colors (objective 3).
Emphasizing this would be an important improvement to the class because
understanding those dynamics in a team can help members balance brainstorming
styles when working together to solve a problem. To be more effective in this area
next time, we need to reiterate their natural brainstorming colors during day two of
the games to maximize that impact. |
| 13 & 14 | Instruments of Design: Computer Aided Design, Dimensioning, and Tolerances | Students wrote about visual communication and how much detail is needed to
accurately convey their design with the machine shop. They recognized that this
was important in order to ensure that their part could be prototyped at the campus
facilities and was cost effective to produce. Students noted that hand drawing was
an unnecessary step for communicating with the machine shop and solidworks
would be a better option for accuracy. In addition, students who had already toured
the machine shop related better to the games than those who had not yet attended
their tour. |
| 15 & 16 | Student-based Game Design | In their reflections, students expressed surprise at the creativity of their peers’
games and at how they enjoyed playing them. Students mentioned how quickly the
class time went when they taught their game and played other team’s games.
Students recognized that games can be a good way to learn because they are
interactive and engaging, but they could also over-simplify difficult concepts in an
effort to be fun. Students mentioned in their debriefs that the game design process
that they engaged in this week was similar to the medical device design process
they are preparing for next semester. |
Although enthusiasm for the games varied, the debrief responses indicated that the students showed a strong understanding of the connection between the in-class games, the learning objectives, and the domain course content provided before and during class (see Table 11). Even students who expressed discomfort with the games consistently articulated this connection.

RQ2: Analyzing Video Recordings of Class

The second data point analyzed for research question two was the video recordings from each game-based class. In a lecture-based class, students are expected to sit still and passively absorb the course materials being presented by an expert. The content is delivered primarily through audial and visual sensory modes. In this type of class, instructor-to-student interactions dominate the classroom and are rarely bidirectional (Dancy & Henderson, 2007; Mayer, 2009; O’Connor & Michaels, 1993; Weaver, Qi, Qi, & Weaver, 2005). Conversely, the video recordings of each intervention class meeting show a wide range of student interactions including student-to-student, instructor-to-student, student-to-instructor, and student-to-materials. Two minute video loops from each class are available on the website.

The debrief responses indicated a positive student reaction to the increased interactions of the intervention section of the course. Many students commented on how the games helped them “stay awake” and “engaged” in class. They mentioned a preference for “applying what they read about” and “learning by doing” in class. It should be noted that some students in the course stated...
that they preferred to learn in a more traditional lecture-based classroom, and one student opted out from participation in the study ($N = 82$).

RQ2: Final Exam Analysis

The third data point analyzed for this research question was final exam scores which were analyzed quantitatively with SPSS software. There are a few factors that should be considered when comparing the final exam scores between the two sections of the course. The lead professor in the course determined that some questions used on the control exam were not relevant for the intervention section, and he replaced those with equivalent questions. Therefore, the exams were equivalent between the two class sections but not the same. Equivalency was determined by the lead instructor, who wrote both exams. All questions were still factored into the exam grades and therefore, included in the statistical analysis. In addition, this was a take-home exam in both sections of the course and therefore was open book, open note. Once students returned the exams, they were divided into piles amongst the TAs for grading. Only one TA was employed during both the control class and intervention class; consequently, the scoring was likely inconsistent between the two semesters. Finally, there was not a record of the exact bonus points awarded in the control section, so those points could not be removed prior to comparison and so bonus points were included in the grades for both semesters. Students could earn up to twenty bonus points, which could create a significant alteration in the grade that would not reflect increased domain content knowledge.

Quantitative analysis was conducted using SPSS to compare the means between the two class sections. The mean for the control group ($N = 75$) was 91.23 ($SD = 6.34$) and the mean for the intervention group ($N = 81$) was 86.53 ($SD = 11.02$). Concerns regarding the fidelity of this data
point made quantitative analysis unreliable; therefore, further statistical analysis was not included in the analysis.

RQ3 Synthesis:

In this section, I will present the results gleaned from research question three by analyzing hundreds of hours of video footage collected throughout the study (see Table 12). The video interviews with Dr. DesJardins and Ms. Przestrzelski were conducted before, during, and after the intervention. Through the course of multiple interviews collected over the two-year period, the footage captured the impact of developing and delivering the intervention in our own words as the study was unfolding. In addition, video interviews with the teaching assistants from each course section were conducted after the completion of the semester. The video tapes from the class meetings were used to document the intervention and as b-roll to supplement the final edited videos. All the video interviews were transcribed and the full transcripts analyzed qualitatively using a combination of hand coding and NVivo qualitative analysis software.

Table 12.

This table depicts the connection between the research question, the method(s), the data points collected, and the type of analysis used for research question three.

<table>
<thead>
<tr>
<th>RQ3: What can be learned about the implications of converting a class from lecture-based to game-based curriculum from the faculty/research-team?</th>
<th>Collect qual throughout study:</th>
<th>Qualitative: Global themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Video journal of myself as I move through the process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Video Interviews with Dr. DesJardins &amp; Ms. Przestrzelski</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Video Interviews or survey with TAs from both semesters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Video tapes of the classes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Faculty play a vital role in developing and delivering the course material. For this study, the faculty team consisted of Dr. DesJardins, Associate Professor and lead faculty for Bioengineering Senior Design, Ms. Przestrzelski, PhD Candidate in Bioengineering and Assistant Instructor in Senior Design, and me, Lecturer in Graphic Communications and PhD Candidate in Curriculum and Instruction in the School of Education. With influential advisors from many departments and from outside of the University, the curriculum was developed for the intervention section of the course. The faculty team also included six teaching assistants each semester. These assistants played an important role during class and worked on student development teams.

I felt that it was important to document the process that a faculty team experiences when transitioning a class from lecture-based delivery to game-based delivery. By capturing the process as it unfolded around us, I felt the resultant videos would capture the steps along the way in an honest and important way. The resultant footage would also provide an opportunity to use video as a medium to analyze and share the results of this study. In an effort to capture this research as it progressed, I conducted multiple interviews with Dr. DesJardins, Ms. Przestrzelski, and myself spanning from the beginning of curriculum development through to the end of the two-year research cycle. Due to their active role in the classroom, I also interviewed Teaching Assistants at the conclusion of both the control and intervention semesters. Through these interviews, I hoped to share the story of how this study was developed and the impact this process had on the members of our faculty team.

Video, by nature, requires editing in order to clarify what is said. However, there is not a single set of ethical standards for documentary filmmakers and many filmmakers feel conflicted when “trying to serve three conflicting sets of responsibilities: to their subjects, their viewers, and their
own artistic vision and production exigencies” (Aufderheide, Chandra, & Jaszi, 2009; “What to Do About Documentary Distortion? Toward a Code of Ethics,” n.d.). For this research, being true to the interviewees’ words was important in order to accurately convey the participants’ experience.

Qualitative researchers often rely on inter-rater reliability (IRR) to ensure that data is interpreted accurately. However, there was not an opportunity to cross-code the video transcripts for this study. Therefore, I requested participant feedback from each of the teaching assistants and faculty members represented in the videos. By requesting participant feedback, a researcher can feel more confident that their interpretation was true to the words and feelings of participants. The teaching assistants (n=4) confirmed that the videos showed an accurate representation of their experience (A. Cobb, C. Morton, Z. Reinhardt, Z. Ronaghi, personal communication, July 14–25, 2016). Dr. DesJardins and Ms. Przestrzelski also approved the edits (J. DesJardins & B. Przestrzelski, personal communication, August 2–10, 2016). Based on their responses, I felt confident that the videos accurately depicted their experience as a part of the faculty team involved in this study.
Figure 15. In this video Dr. John DesJardins, lead faculty for Clemson Senior Design, Bre Przestrzelski, teaching assistant, and Erica Walker, lead researcher discuss how and why they formed a multidisciplinary team to approach the development of the BIOE Senior Design curriculum. Direct link to video: https://youtu.be/gPGxGBZ_k
Figure 16. In this video, Dr. John DesJardins, lead faculty for Clemson Senior Design, Bre Przestrzelski, teaching assistant, and Erica Walker, lead researcher reflect on developing the BIOE Senior Design curriculum. Direct link to video: https://youtu.be/nvqK0pWE4VI

Notes: Topics covered include:
- What did we change?
- How did we create the games?
- What about 21st Century Skills?
- Now what? Time to Iterate!
Figure 17. In this video, Dr. John DesJardins, lead faculty for Clemson Senior Design, Bre Przestrzelski, teaching assistant, Erica Walker, lead researcher, and four teaching assistants (Zahra Ronaghi, Zach Reinhardt, Clay Morton, & Andrew Cobb) reflect on the impact of using game-based learning the BIOE Senior Design curriculum. Direct link to video: https://youtu.be/fZ5nhw7e5jk
Figure 18. In this video, Dr. John DesJardins, lead faculty for Clemson Senior Design, Bre Przestrzelski, teaching assistant, Erica Walker, lead researcher, and four teaching assistants (Zahra Ronaghi, Zach Reinhardt, Clay Morton, & Andrew Cobb) reflect on how we looked at success during this project. Direct link to video: https://youtu.be/MfaqPjDB6M

Notes: Topics covered in this video include:
- Based on Classroom Engagement
- Based on Student Feedback
- Based on Student Learning of The Domain Content, The Design Process, & 21st Century Skills

Figure 19. In this video, Dr. John DesJardins, lead faculty for Clemson Senior Design, Bre Przestrzelski, teaching assistant, and Erica Walker, lead researcher reflect on what they have learned during the development of the BIOE Senior Design curriculum. Direct link to video: https://youtu.be/-wCZaaE_EEk

Notes: Topics covered in this video include:
1. Groupthink
2. It’s all about the pivot
3. Minds change (& that’s ok)
4. What they don’t know (can hurt)
5. Know the rules of the game
6. The next move

In summary, every member of the team experienced a wide breadth of emotions while developing and delivering the course. The students were not the only ones learning through this
process. As a faculty team, some of the most important lessons we learned came from working as a group that included a diverse range of expertise and skills. From the beginning, we hoped our journey through this process would benefit other instructors who might wish to incorporate games in their classrooms. The class plans are available as open educational resources under the Creative Commons license for other faculty and curriculum developers to borrow, edit, and implement for their classroom.

Discussion

Below I discuss the findings from this research. Each research question will be addressed individually first, followed by a discussion of the findings as a whole.

RQ1

In this section, I discuss the findings from research question one, *What is the impact of games-based learning on the development of 21st Century Skills in Bioengineering Senior Design students?*, by looking at three different data points collected during the study: the survey, student video interviews, and the debrief responses. These three data points were combined during analysis in order to provide a robust look at the impact of game-based learning on student development of 21st Century Skills. I used the quantitative software program SPSS to analyze the survey responses and NVivo qualitative analysis software combined with hand-coding to analyze both the video interview transcripts and the debrief responses.

The end of semester survey showed that students in both sections of the course had similar experiences and interest in entrepreneurship. It was interesting to note that during the video
interviews, students in the control group considered entrepreneurship to be separate from the world of engineering. Conversely, student interviews from the intervention group indicated a broader definition of entrepreneurship, one that included problem-solving, creativity, risks, and market analysis. During the video interviews, students from the intervention section indicated that entrepreneurship was not just limited to business majors, but a valid career choice for bioengineers as well.

In addition, the survey results indicated a significant difference between students in the intervention group and the control group in regards to their self-efficacy and creativity. The intervention students also reported a lower interest in becoming an entrepreneur. Specifically, they indicated a significantly lower response to these two questions: “If I wasn’t going to start a business, the reason would be- Doubts about personal abilities” and “If I wasn’t going to start a business, the reason would be- Having to work too many hours.” This could suggest that the intervention group was more aware of the difficulties associated with starting their own business, including the broad spectrum of skills required or the large number of hours necessary for success. Perhaps the more they learned about entrepreneurship, the more difficult that path appeared. In an unpublished study, researchers using the same survey instrument, the EES, found that graduate students exposed to entrepreneurial education indicated a similar decline in self-efficacy:

Interestingly, while the assessment data showed improvements in self-efficacy, it also shows that participation in the course did not significantly increase their short-term interest in pursuing technology commercialization activities. If anything, it tempered them. These findings suggest that the class gives participants a better understanding of the complexities associated with commercialization and entrepreneurship within the
university. The fact that some participants changed their responses from "very interested" to "somewhat interested" may suggest they will be more inclined to pursue these activities when and if they feel prepared and ready (Duval-Couetil, 2016).

Similarly, during the video interviews, intervention students who mentioned wanting to become entrepreneurs stated that they did not feel prepared. One student described his reluctance and fear of not being fully prepared, "I know that, basically, [as an entrepreneur] you have to do everything; they do the business, they do the design, the legal, they’re kind of all over the place, because we have a handful of people at a small business, for an entrepreneur [sic], so they have to be a jack-of-all-trades, and hopefully, they’re at least okay at everything, and don’t have any glaring weaknesses." Comments like these combined with the survey results suggest that students in the intervention course may have learned more about entrepreneurship, but this additional knowledge tempered their confidence in their own entrepreneurial abilities.

The survey results suggest that the intervention students, as a group, had lower curiosity. Conversely, every intervention student described him or herself as very curious during the video interviews. When asked if he had seen similar results, Tony Ribera, who also uses the same instrument, the Curiosity Index (CI-4), in his research with engineering students at Rose-Hulman University, stated that based on the nature of the items he did not think exposure to a teaching method in one course would lower a student’s likelihood of researching a topic in depth, trying new things, etc. which is what the CI-4 was developed to measure (T. Ribera, personal communication, July 11, 2016). Further study is needed to what effect, if any, the intervention had on student curiosity. Without further inquiry, it is difficult to determine if this group of students was just innately less curious than the control group or if there is another explanation of
the results. In future studies, I recommend a pre/post design for the Curiosity Index (CI-4) to look for shifts in this construct at an individual level rather than at a class level.

The student debrief comments combined with the video interviews indicate that students recognized that they were practicing 21st Century Skills in the game-based learning section of this course. Student video interviews from both groups mentioned the impact of participating in the design process, the impact of working as a group, and some of the 21st Century Skills they acquired and applied during Senior Design. The timing of the video interviews might have affected student response. They were interviewed at the end of Spring semester, after completing both semesters of Senior Design. At this point, students from both the control and intervention sections had completed the second semester Senior Design project, which stayed consistent during the study. However, the intervention video interviewees talked about specific 21st Century Skills such as collaboration, communication, brainstorming, iteration, perseverance, and leadership as the most valuable thing they learned in Senior Design more consistently and with more detail than the students in the control group.

In addition to detailed comments regarding 21st Century Skills during the student interviews, the debriefs also included frequent references to specific 21st Century Skills. When analyzing word frequency from across all the debrief responses, skills required for teamwork and groupwork were commonly used words and phrases. In addition, the word cloud indicated “communication,” “brainstorming,” and “strengths” as regularly discussed skills in their debrief responses, see Figure 14.
Although comments from Dr. DesJardins were not an official data point for this research question, during an interview at the conclusion of the study, the lead instructor did note one specific difference between the control group and the intervention group which is relevant to this discussion. As seen in Figure 15, the lead faculty thought that teamwork was a noticeable difference between the two sections of the course. The quote indicates that perhaps the coursework used in the intervention section helped students develop the skills needed to identify good team members and therefore they were more likely to avoid group-related problems. Causation cannot be assumed, though, so the improvement in teamwork could also have been due to innate differences between the two groups of students. Again, a pre/post design during a future study could be used to look at the impact of the intervention material and methods on student development regarding this specific skillset.
Figure 20. This video indicates that the lead faculty noticed a difference in the intervention teams teamwork. Direct link to video: https://youtu.be/MBksLtNDU6w

Notes: Full interview transcript: "One thing that I noted just yesterday to a colleague was that this year’s team of 18 teams as compared to last year’s 18 teams, there have been no team related issues at all. Last year there were some train wrecks and there were some disputes that had to be taken care of and this year not one team has come to me with an issue that is collaborative or team dynamic or not pulling their weight and things like that. That I found to be a little odd. Where that came from, I don’t know but you know, if you try to think back to a possible cause, they spent a lot more time and their first semester together as a team doing things. There weren’t any switches. Nobody switched up groups or changed out groups or things like that. They’re for nothing. A year ago we had two or three teams that were having trouble. That’s one thing I noticed for sure."

The analysis of all three data points for research question one suggests that both course delivery methods, lecture-based and game-based, were successfully employed to deliver the domain content during the fall semester of the Senior Design course. Through the full year-long course, students in both sections also learned and practiced 21st Century Skills. During the Fall semester of the intervention, students had additional opportunities to reflect upon their use of 21st Century Skills through the debriefs and class reflections. The game-based learning delivery method provided increased emphasis on the acquisition of 21st Century Skills. In addition, students in the intervention section indicated a broader understanding and an increased doubt about their ability to immediately pursue entrepreneurship. As Dr. DesJardins said during his December 2015 interview, “I think that doing the game-based activity adds, so in my mind, if you just did lecture based stuff, you’re not getting as much [content] as if you did lecture-based content plus game-based. I think it’s an add. You can’t say I could do it either way and teach the same thing because you’re not.” By design, the intervention section incorporated an additional layer of content, the 21st Century Skills, to the required domain content for the course.
RQ2

The course delivery method was a key change between the two versions of the course. The control section of the course was taught using traditional lecture delivery methods and the intervention section of the course was taught using a flipped classroom approach and game-based learning as the delivery method. Research question two, *How does changing the course delivery method, lecture-based compared to game-based, affect student learning of the domain content?*, takes into consideration an important concern when making a large-scale change in delivery method, to ensure that domain content learning is not adversely affected. In this section, I will look at the findings from research question two by looking at three different data points collected during the study: the student debrief responses, video tapes of each game-based class meeting, and the final exam scores. I used NVivo qualitative analysis software to analyze the debrief responses and the video tapes of the classes were used to observe the range of student interactions during class. The quantitative software program SPSS was used to analyze the the final exam grades.

By implementing a mixed methods approach to investigate research question two, I combined the analysis from three data points: the final exam scores, the debrief responses, and the video recordings of the classroom. Analysis of the exam scores showed that the mean grade for both groups was a B or above, which suggests that both classes demonstrated a good understanding of the domain content for the course. In addition, as seen in Table 11 and the visual representation on the website, the debrief responses from the intervention section of the course indicated that the students consistently expressed the connection between the class games and the domain content. The final data point for this question was the class videos. Each class meeting was
recorded with two static cameras and a third, roaming camera. Previous studies indicate that active engagement can lead to increased student learning (Baid & Lambert, 2010; Bodnar & Clark, 2014; Bonwell & Eison, 1991; Gross et al., 2015; Prince, 2004) and these videos showed students actively engaged during the game-based classes. When students are actively engaged in a relevant activity, they are processing and retaining information and staying focused on the task at hand.

Due to the complexity of a classroom environment and considering only the results from this study, it would be erroneous to say that one type of course delivery is superior to the other. In both sections of the course, students displayed strengths and weaknesses in their comprehension and application of the course materials. Furthermore, both groups displayed adequate understanding of the technical domain content required to successfully complete the second semester of the course, where the knowledge from the first semester of the course was applied in order to complete a semester-long, group project. Although the difference did not impede the control section from successful completion of their projects, the lead faculty of the course noted that the intervention section showed a slightly stronger understanding of the design process than students enrolled in the control section of the course (Figure 16).
Figure 21. In this video from an interview at the completion of the research study, Dr. DesJardins, lead faculty for BIOE 4010 and 4030, compared the control and intervention sections of the course. Direct link to video: [https://youtu.be/jmuNBA997A](https://youtu.be/jmuNBA997A)

**Notes:** Full interview transcript: “In terms of what they produced, at a design level, the quality of the work this year [intervention section], I would say is comparable maybe slightly above what they made and their understanding of the process of design. I’d say it is a little stronger this year. Teams have gotten higher marks. This will have to be looked at. I perceive that teams got higher marks in what we call using the design process, making sure that what they were making solved the need. Maybe we’re just getting better at instructing them of that in this second semester course but that certainly has been my perception. The technical content I would say is about the same.”

To summarize, analysis indicates that students in both sections of the course successfully learned the domain content knowledge. However, the increased engagement, practice, and interaction designed into the intervention allowed students frequent opportunities to apply the content prior to working on their final Senior Design project. Results indicate that through this additional practice and application, the intervention students developed a greater understanding of the biomedical design process, which was a key learning objective for this course. We can conclude
that student learning of domain content was not significantly impacted, positively or negatively, by the delivery method and that both delivery methods successfully imparted the necessary domain content knowledge. A curriculum developer should consider all teaching methods as potential tools for content delivery and choose the best method based on the course material, the temperament and strengths of the instruction team, and the needs of the students.

RQ3
Research question three, *What can be learned about the implications of converting a class from lecture-based to game-based curriculum from the faculty/research-team?*, looked at the impact that participating in this research had on the faculty team, and this section will discuss those findings. In this section, I will discuss the findings from analyzing hundreds of hours of video footage collected throughout the study. The video interviews with Dr. DesJardins and Ms. Przestrzelski were conducted before, during, and after the intervention. Through the course of multiple interviews collected over the two year period, the footage captured the impact of developing and delivering the intervention in our own words as the study was unfolding. In addition, video interviews with the teaching assistants from each course section were conducted after the completion of the semester. The video tapes from the class meetings were used to document the intervention and as b-roll to supplement the final edited videos. All the video interviews were transcribed and the full transcripts analyzed qualitatively using a combination of hand coding and NVivo qualitative analysis software.

Every member of the faculty team experienced a breadth of emotions while developing and delivering this course. Through engaging as a team of participant-researchers, the faculty learned many impactful lessons from working on this study. Some of the most important lessons came
from working with team members who had a diverse range of expertise and skills. Although
detailed planning leading up to the intervention was important, observation and iteration
became important tools to encourage student participation and help ensure that we adequately
addressed their diverse learning needs. We also relied on regular meetings throughout the study
for preparation and reflection as a team.

From the beginning, we hoped our journey through the development and implementation of this
study would benefit other instructors interested in incorporating games into their classroom. The
class plans are available as open educational resources under the Creative Commons license for
other faculty and curriculum developers to borrow, edit, and implement for their classroom.
Although these plans were specifically developed to meet the needs of our students and
curriculum, each class lesson plan is listed by domain-content keywords that may provide a
starting point for faculty interested in developing games in their own classroom based on a
particular topic. For quick, two- to three-minute synopsis videos explaining each game-based
class, visit our class video playlist.

Video vignettes featuring members of the faculty team are available on our Youtube Channel. The
videos address topics such as working on a multidisciplinary team, how we developed the
curriculum, and why we chose game-based learning as the pedagogy for this course. Videos also
address topics such as how we measured success during this study and the most important
lessons learned through this process.

Each member of the faculty team discovered personal strengths and weaknesses in the classroom
and by working together, we learned from each other. There are many lessons from participating
in the Bioengineering Senior Design course which I intend to incorporate in my own classroom at the conclusion of this study. I would be remiss if I did not take a moment to recognize the two lead contributors on this team. Breanne Przestrzelski spent countless hours working alongside me to plan and execute the intervention. I could not have completed this study without her advice, knowledge, and friendship. An enormous thank you is also due to Dr. DesJardins and the Bioengineering department for allowing us to upend his classroom over the span of two years. It would be difficult for any lead instructor to share control of their course and trust in a team, but he did so with grace, encouragement, and enthusiasm. I learned as much from both of them as I did from this study.

Looking at the big picture
This study looked at the effectiveness of a game-based learning intervention from multiple perspectives. The first two research questions used a mixed methods approach to analyze the impact of teaching methods on student learning. Research question one looked at how pedagogy influenced student learning of 21st Century Skills and the second research question looked at how it affected student learning of domain content. Both types of content are important for preparing future engineers. One of the priorities of accredited engineering programs is to prepare students for entry into the engineering profession, which includes a broad understanding of engineering principles and also the ability to think creatively, problem-solve, and work well with a team (ABET, 2014; Felder, 1996; Herrmann, 1995; Lumsdaine & Lumsdaine, 1995; Shuman et al., 2005; Walesh, 2012). The call for situating technical education in the broader context of general education includes an emphasis on 21st Century Skills, a mission that has been promoted by organizations such as ABET and ASEE for decades (Apelian, 1994; Ernst, 1996; Kriewall &
Mekemson, 2010; Shuman et al., 2005). Initially introduced in 1996, ABET’s current set of criteria includes six professional, 21st Century Skills (d-j):

- (d) an ability to function on multidisciplinary teams
- (f) an understanding of professional and ethical responsibility
- (g) an ability to communicate effectively
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- (i) a recognition of the need for, and an ability to engage in lifelong learning
- (j) a knowledge of contemporary issues (ABET, 2014)

For almost twenty years now, these professional skills have been emphasized as an important part of criteria for evaluating and accrediting engineering programs. Therefore, engineering students need exposure to and opportunities to practice both domain content and 21st Century Skills. In order to address these demands, the intervention for this study was developed using a game-based learning approach to the classroom pedagogy and the cognitive apprenticeship framework for developing the course materials.

Based on recent research studies, games and other forms of active learning can help instructors disseminate content-based knowledge while also providing opportunities for students to develop 21st Century Skills such as creativity, innovation, collaboration, communication, and problem solving (Baid & Lambert, 2010; Gross et al., 2015; Bodnar & Clark, 2014; Baid & Lambert, 2010). Games, both those that are created for educational purposes and those that are purely marketed for entertainment, provide a safe learning environment that incorporates opportunities for play, exploration, low-stakes failure, problem-solving, and immediate feedback all within a highly controlled and easy to assess format. In fact, failure with limited consequence, agency, and choice are seen as critical elements of a true gaming experience (McClarty et al., 2012). Agency refers to a student’s ability to interact with the material and implies that players have choices within the game on how to proceed through the gameplay (Jalongo, 2007).
Cognitive apprenticeship, as a framework for educational environments, builds on the model of traditional apprenticeships which were widely used for centuries to train the next generation of tradesmen within a field (A. Collins et al., 1989). The traditional model of learning alongside a master practitioner who provides guidance through industry processes carries through in cognitive apprenticeship. In this framework, educators guide students through the cognitive and metacognitive processes necessary to perform tasks within a given industry. In other words, with the cognitive apprenticeship model, learning is focused on the process of cognition, learning how an expert in the field thinks about their tasks and teaching students how to replicate and apply those thought processes. Cognitive apprenticeship is based on implementing four principles when designing learning environments–content, methods, sequencing, and sociology (see Table 1).

Throughout this study, qualitative and quantitative data was collected in order to address all three research questions. Some questions were answered, but as with much research, more questions were also raised. Results from this study are not conclusive regarding the effectiveness of game-based learning as a more effective method for delivering domain content and 21st Century Skills. Students from both sections of the course indicated acceptable levels of domain content learning. Qualitative data indicates that the intervention section showed higher levels of 21st Century Skills. Conversely, survey results suggest that intervention students had a lower self-efficacy and interest in pursuing entrepreneurship. Further study would be necessary to determine what role the intervention played in these conflicting results.
However, the study did produce a library of topic-driven, game-based lesson plans for future Bioengineering Senior Design courses that are available through Creative Commons licensing. Educational games, just like any class plans, need continued iteration and adaptation to ensure that they remain timely and appropriate for both the instructor and the students. Yet the demand for high-quality, open educational resources continues to grow so perhaps the class plans created during this study might be a starting point for instructors wishing to apply game-based learning in their own classrooms and provide opportunities for future studies exploring this topic.

Implications and Directions for Future Research

The purpose of this mixed methods research is to examine the impact of two different teaching methods on student learning when implemented in a bioengineering design capstone course. The control section of the course was taught exclusively with traditional lecture pedagogy and the intervention delivered to the domain content predominately through game-based learning techniques. Researchers also wanted to understand what effect, if any, the delivery method had on student learning in two areas: the domain content and 21st Century Skills. In addition, this study examined the process a faculty-team undergoes as they develop and deliver a game-based design course. By sharing the process of transitioning this course, it is our hope to increase recognition of game-based learning as a valuable classroom tool for embedding 21st Century Skills into an engineering design course. In examining the impact of the course development process, we also hoped to provide further insight and resources for other educators interested in transitioning the pedagogy used in their own courses. This study focused on the following three research questions:

1. **What is the impact of game-based learning on the development of 21st Century Skills in Bioengineering Senior Design students?**
2. *How does changing the course delivery method, lecture-based compared to game-based, affect student learning of the domain content?*

3. *What can be learned about the implications of converting a class from lecture-based to game-based curriculum from the faculty/research-team?*

Analysis of the data included quantitative statistical analysis, qualitative content coding, and global theme analysis in order to fully address the research questions with a mixed methods approach to research.

This study analyzed the impact of a game-based classroom intervention from several different perspectives. The first two research questions used mixed methods to explore the impact of teaching methods on student learning. Research question one looked at how pedagogy influenced student learning of 21st Century Skills and the second research question looked at how the classroom methods affected student learning of domain content. Both types of content are recognized as important elements for preparing future engineers. In fact, part of engineering accreditation requires that programs address student understanding of both engineering principles and the ability to think creatively, problem solve, and work well with a team (ABET, 2014; Felder, 1996; Herrmann, 1995; Lumsdaine & Lumsdaine, 1995; Shuman et al., 2005; Walesh, 2012).

Every effort was made to address possible threats to validity during this study, but the following threats should be identified. Some differences between the two versions of the course could not be controlled. Students in the intervention section of the course were aware of their participation in the study, which could impact participant behavior. This is known as The Hawthorne Effect. Another difference between the two courses was my presence in the classroom. Although Dr.
DesJardins was the lead instructor for both sections in the study, I was in attendance and active in the intervention classroom, but not during the control section of the course. My presence was a unique factor in the experience of the intervention group which could impact the results of the study. As a research team, we felt that the advantages of my presence in the classroom outweighed the disadvantages. Future studies would want to consider the advantages and disadvantages of using an “insider” participant-researcher design to determine if they should use this same approach.

One of the challenges that our faculty team was not able to fully anticipate during the planning stage was the impact of the number of students in the classroom on the planned games. Game-based courses often have smaller student numbers to help ensure that all the students are actively involved and provide instructors more opportunity for individualized feedback during class. However, in this study, the Senior Design class was very large with over 80 students enrolled each semester. Although we made a focused effort to counteract this limitation each week, the success of the games and the ability of the faculty and TAs to maintain an appropriate level of individual interaction during the class period could have been adversely impacted due to the number of students enrolled. This factor could threaten the results of this study and impact future reproducibility in classes with more or less students. Future studies may want to implement the intervention curriculum with a lower number of students in order to observe what impact number has on student learning in a game-based classroom.

Much of the data for this study relied on self-report. By nature, self-report data contains bias which can impact the results of a study. These biases include: selective memory, telescoping (inaccurate recall in regards to timelines), attribution (crediting positive events to self and
negative events to external forces), and exaggeration (Prince, 2004; “Teaching That Emphasizes Active Engagement,” n.d.). Student responses were not independently verified and therefore the study relied on the students themselves to accurately self-report. This is a difficult limitation to avoid in a study on learning since researchers often measure that construct through self-report. Perhaps implementing a pre/post design would shed more light on individual shifts in students’ self-efficacy regarding the development of 21st Century Skills. In future studies, having an external group examine the success of the students’ final design projects may be a less biased way to measure student application of learned material in the course. In addition, a longitudinal study might help researchers determine long-term learning and real-world application of 21st Century Skills garnered during the intervention.

Finally, the impact of the faculty team is both a strength in this study as well as a limitation. No single teaching style is a good fit for every instructor, just as no single pedagogy will effectively teach all types of learners or effectively deliver course content. It is important to consider both the strengths of a faculty team and the type of domain content prior to choosing a content delivery method for a course. Due to this factor, there are limits to the transferability of our methods and findings outside of our course objectives and faculty team.

Although this two-year long study builds on previous research and attempts to address the questions, the results still do not fully explain the impact that game-based learning has on student learning. By using multiple data points and a mixed methods approach, this study found contradictory evidence that did not clearly determine the impact of this pedagogy. However, the study does provide new insights into a cross-disciplinary curriculum development process. Since this study has provided detailed lesson plans as Open Educational Resources, other interested
faculty can implement the class plans used in this study to address difficult bioengineering content in their own classrooms. The videos created as a part of this research can provide insights and encouragement for other interested faculty as they detail the active engagement that took place in the intervention classroom. Finally, this study leads us to more direct questions that can guide future research regarding game-based learning, the teaching of 21st Century Skills in a Senior Design course, and the process of working on a multi-disciplinary team to develop curriculum.

Directions for future research
The purpose of this mixed methods research was to examine the impact of two different teaching methods on student learning when implemented in a bioengineering design capstone course. The control section of the course was taught exclusively with traditional lecture pedagogy and the intervention delivered to the domain content predominately through game-based learning techniques. Researchers also wanted to understand what effect, if any, the delivery method had on student learning in two areas: the domain content and 21st Century Skills. In addition, this study examined the process a faculty-team undergoes as they develop and deliver a game-based design course.

Although some questions were answered during this study, new questions emerged. Recommendations for future research include further testing of the open educational resources created for the intervention section of this course. Questions worth addressing include the transferability of these class plans across faculty teams and classrooms. The number of students enrolled in the intervention class for this study was 82 and some of the games and activities might have been impacted by the number of students. In addition, the impact of the faculty
themselves is unknown. If these class plans were implemented by a different faculty team, we may better understand the impact that faculty had during this study.

In addition, future studies might consider using a pre/post design. Although data was gathered throughout this study, the two quantitative data points- the survey instrument and the exam- were administered at the end of the course for both groups of students. The end of the semester is stressful for graduating seniors. Therefore, timing of data collection could have impacted student responses. Due to the research design, we were only able to compare the control and intervention groups as a whole. By implementing a pre/post design, a future study could provide a clearer understanding of how the intervention impacted individual student growth.

Early in the research cycle, studies must commit to using certain terms and definitions when discussing the research. Terms such as the entrepreneurial mindset and 21st Century Skills continue to evolve in the context of education. A continued push in academia towards equipping future entrepreneurs has impacted how students and faculty define these terms even during the two years of this project. The Engineering Entrepreneurship Survey (EES) used for this study uses the term “entrepreneur” heavily and the loaded nature of that term could have impacted student response. A future study could look at the impact of using this terminology and if another instrument would be a better fit for measuring 21st Century Skills.

Finally, every class and faculty team is unique and curriculum does not have to stick to only one delivery method for an entire semester. Future studies could look at determining a balance between lecture-based and game-based delivery in order to optimize student learning of both domain content and 21st Century Skills.
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Appendix

Defining terms
UNESCO

- self-regulation
- knowledge construction
- skilled communication

ABET

- ethical & professional responsibility
- effective communication
- collaboration
- multidisciplinary teamwork
- group skills

Entrepreneurial Skills

- communication
- life-long learning
- innovation
- problem solving
- verbal communication
- non-verbal communication
- opportunity recognition
- grit
- perseverance

ABET- (ABET, 2014)
Entrepreneurial skills- (Sawedra & Opfer, 2012; Matthew et al., n.d.; Oman, Tumer, Wood, & Seepersad, 2012; Kiewall & Mekemson, 2010)
Definition for this study:
Life skills such as flexibility and adaptability, workforce skills such as collaboration, the ability to lead, and teamwork, applied skills such as analyzing information and effective communication, and personal skills including curiosity, imagination, critical thinking, and problem solving.
Curiosity Index (CI-4)

Curiosity Index (CI-4)
©2004 James Madison University
Keston Fulcher

Please indicate your level of agreement with each of the statements provided below using the following scale:

<table>
<thead>
<tr>
<th>Agree Strongly</th>
<th>Agree Moderately</th>
<th>Agree Slightly</th>
<th>Disagree Slightly</th>
<th>Disagree Moderately</th>
<th>Disagree Strongly</th>
</tr>
</thead>
</table>

1. I spend a great deal of time researching areas that I wish to learn about in depth.
2. When learning about something new, I try to find out everything I can about it.
3. I like variety in my life.
4. I rarely spend time investigating one thing.
5. I am always finding new things to do.
6. The more I learn about something, the more I want to learn about it.
7. I rarely try new things.
8. I seldom research a topic in great depth.
9. I am always trying out new things.
10. I often spend sustained periods of time investigating a topic of interest to me.
11. I prefer to mix up my days with a variety of activities.
12. I immerse myself in information pertaining to a topic that I find fascinating.
13. Very few things interest me.
14. I like to get involved in a wide-variety of activities.
15. When learning something, I try to gain the fullest possible understanding of the phenomenon.
16. I find myself fascinated by lots of different things.

Items are coded 1-6 with 6 = agree strongly and 1 = disagree strongly.
Total curiosity is a sum of all 16 items with a maximum possible score of 96.
Breadth is the sum of items 3, 4, 9, 11, 14, & 16 with a maximum possible score of 36.
Depth is the sum of items 1, 2, 6, 10, 12, & 15 with a maximum possible score of 36.
Engineering Entrepreneurship Survey (EES)

This survey is to gather information about your experiences and involvement in entrepreneurship activities and education. Entrepreneurship refers to the practice of starting business ventures based on the development of new products and/or services.

This survey is voluntary and you may skip any questions. If necessary, you can stop the survey and complete it at a later time. Use the same link used to access the survey to pick up where you left off. You must be 18 years or older to participate. Personal information, such as your name and email, is requested so that we may conduct follow-up interviews with a small sample of students. At the end of the survey, you will be given the option to opt-out of being contacted for a follow-up interview. Identifying information will not be released in any way.

Please select "yes" indicating that you have read the above statement and agree to be included in this survey. If you do not wish to continue, you may close the Web browser now.

I agree to participate in this survey. (AGREE)

Yes (1)
No

INSTRUCTIONS:

- Please take your time to answer each question as honestly and as accurately as possible.
- You will need to click on the arrow button at the end of each page to save it and move on to the next.
- Please be sure to click the 'Submit' button on the last page to complete the survey.

The survey should take approximately 15 minutes. If you need assistance or have questions, please contact:

Survey Administrator
University Name
Email Address
Phone

Thank you for your time.
What university do you attend?  (UNIV)
   University A  (1)
   University B  (2)
   University C  (3)

What is your major?  (MAJOR1)
   Aeronautics and Astronautics Engineering  (AAE)
   Agricultural and Biological Engineering  (ABE)
   Architectural Engineering  (AE)
   Biomedical Engineering  (BME)
   Biomolecular Engineering  (BE)
   Chemical Engineering  (CHE)
   Civil Engineering  (CE)
   Computer Engineering  (CompE)
   Computer Science  (CS)
   Construction Engineering  (CEM)
   Electrical Engineering  (EE)
   Environmental/Ecological Engineering  (EEE)
   Industrial/Systems Engineering  (IE)
   Interdisciplinary Engineering  (IDE)
   Manufacturing Engineering  (ManE)
   Materials/Materials Science Engineering  (MSE)
   Mechanical Engineering  (ME)
   Multidisciplinary Engineering  (MDE)
   Nuclear Engineering  (NE)
   Textile Engineering  (TE)
   Other (please list)  (OTHER)/(MAJOR1_TEXT)

If you have a double major, please list it (if not, leave blank).  (MAJOR2)

If you have one or more minors, please list it/them (if not, leave blank).
   Minor 1  (MINOR1_TEXT)
   Minor 2  (MINOR2_TEXT)
   Minor 3  (MINOR3_TEXT)

What is your sex?  (SEX)
   Male  (1)
   Female  (2)

Please enter your age (in years).  (AGE)

Please indicate your residence status.  (RESIDENCE)
   In-state student  (1)
   Out-of-state student  (2)
   International student  (3)

If you are an international student, what is your home country?
(HOMECOUNTRY)
OPPORTUNITIES FOR INNOVATION

What is your ethnic/racial background? Select all that apply. (RACE)
- American Indian or Alaska Native (1)
- Asian (2)
- Black or African American (3)
- Hispanic or Latino (4)
- Native Hawaiian or Other Pacific Islander (5)
- White (6)
- Multiracial (7)
- Other (please specify) (8)/(RACE_TEXT)
- Decline (9)

Are either of your parents entrepreneurs? (PARENTS)
- Yes (1)
- No (2)
- I’m not sure (3)

Is anyone in your family (not including your parents) an entrepreneur? (FAMILY)
- Yes (1)
- No (2)
- I’m not sure (3)

How many entrepreneurship courses have you taken in your college career, outside of engineering? (COURSES)
- None (1)
- 1 (2)
- 2 (3)
- 3 or more (4)

If you have taken any entrepreneurship courses outside of engineering (see previous question), please list the course name(s) and number(s). (COURSE NAME)

Have you participated in any of the following types of academic entrepreneurship programs? (ESHPROGRAM)
- Certificate in Entrepreneurship (1)
- Major in Entrepreneurship (2)
- Minor in Entrepreneurship (3)
- Other (4)/(ESHPROGRAM_TEXT)
While in college, have you done any of the following: *(ACTIVITIES)*

<table>
<thead>
<tr>
<th>Activity</th>
<th>No (1)</th>
<th>Yes (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taken an entrepreneurship course within the College of Engineering at your university (ACTIVITIES_1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interned or worked for an entrepreneurial or start-up company (ACTIVITIES_2)</td>
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<tr>
<td>Conducted market research and analysis for a new product or technology (ACTIVITIES_3)</td>
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<tr>
<td>Developed a product or technology for a real client/customer (ACTIVITIES_4)</td>
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<tr>
<td>Given an “elevator pitch” or presentation to a panel of judges about a product or business idea (ACTIVITIES_5)</td>
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<tr>
<td>Been involved in patenting a technology or protecting intellectual property (ACTIVITIES_6)</td>
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<tr>
<td>Been involved in entrepreneurship- or business-related student organizations (ACTIVITIES_7)</td>
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<tr>
<td>Written a business plan (ACTIVITIES_8)</td>
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<tr>
<td>Participated in an entrepreneurship-related competition (e.g., product development, business plan) (ACTIVITIES_9)</td>
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<td></td>
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<tr>
<td>Participated in entrepreneurship-related workshops (extra-curricular, non-credit) (ACTIVITIES_10)</td>
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</tbody>
</table>

Rate your level of agreement with the following: *In general, in my engineering courses...* *(PROGRAM)*

<table>
<thead>
<tr>
<th>Program</th>
<th>Strongly disagree (1)</th>
<th>Disagree (2)</th>
<th>Undecided (3)</th>
<th>Agree (4)</th>
<th>Strongly agree (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty discuss entrepreneurship (PROGRAM_1)</td>
<td></td>
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<tr>
<td>Students are taught entrepreneurial skills (PROGRAM_2)</td>
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<tr>
<td>Students are encouraged to develop entrepreneurial skills (PROGRAM_3)</td>
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<tr>
<td>Students are encouraged to take entrepreneurship courses (PROGRAM_4)</td>
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<tr>
<td>Students are encouraged or required to participate in entrepreneurship-related activities (PROGRAM_5)</td>
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</tr>
<tr>
<td>Students are encouraged to consider starting their own companies (PROGRAM_6)</td>
<td></td>
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<tr>
<td>Entrepreneurship is presented as a worthwhile career option (PROGRAM_7)</td>
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<tr>
<td>There are opportunities to interact with entrepreneurs (PROGRAM_8)</td>
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<td>-------------------------------------------------------------------</td>
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<tr>
<td>Students should learn more about entrepreneurship (PROGRAM_9)</td>
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</tbody>
</table>
Consider your post-graduation options and please rate your level of agreement with the following: I plan to... (POSTGRAD)

<table>
<thead>
<tr>
<th>Strongly disagree (1)</th>
<th>Disagree (2)</th>
<th>Undecided (3)</th>
<th>Agree (4)</th>
<th>Strongly agree (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start my own business or be self-employed (POSTGRAD_1)</td>
<td></td>
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<tr>
<td>Work for a small business or start-up company (POSTGRAD_2)</td>
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<tr>
<td>Work for a medium- or large-size business (POSTGRAD_3)</td>
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<tr>
<td>Work for the government (POSTGRAD_4)</td>
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<tr>
<td>Serve in the military (POSTGRAD_5)</td>
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<tr>
<td>Work for a non-profit organization (POSTGRAD_6)</td>
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<tr>
<td>Attend graduate/professional school (POSTGRAD_7)</td>
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</tbody>
</table>

Please rate your level of agreement with the following: (INTEREST)

<table>
<thead>
<tr>
<th>Strongly disagree (1)</th>
<th>Disagree (2)</th>
<th>Undecided (3)</th>
<th>Agree (4)</th>
<th>Strongly agree (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I have a general interest in the subject of entrepreneurship (INTEREST_1)</td>
<td></td>
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<tr>
<td>I want to become an entrepreneur (INTEREST_2)</td>
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<tr>
<td>I have an idea for a business product or technology (INTEREST_3)</td>
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<tr>
<td>I would like to know if I have what it takes to be an entrepreneur (INTEREST_4)</td>
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<tr>
<td>I am interested in taking entrepreneurship classes (INTEREST_5)</td>
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<tr>
<td>Entrepreneurship education can broaden my career prospects and choices (INTEREST_6)</td>
<td></td>
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<tr>
<td>I would like to learn about entrepreneurship in my engineering courses (INTEREST_7)</td>
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</tbody>
</table>
Please check the answer that best fits your current situation.  
(BUSINESS)
I had my own business  (1)
I have my own business now  (2)
I would like to start a business in the next year  (3)
I would like to start a business in the next 5 years  (4)
I would like to start a business in the next 10 years  (5)
I don’t have any plans to start a business at this time  (6)

If you are interested in being an entrepreneur, what type of business are you interested in starting? Please describe the product or service and industry or market.  
(VENTURE)
Please rate your level of agreement with the following: *I would start a business in order to...* (STARTBUS)

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree (1)</th>
<th>Disagree (2)</th>
<th>Undecided (3)</th>
<th>Agree (4)</th>
<th>Strongly agree (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on a technology that interests me</td>
<td></td>
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<tr>
<td>Satisfy a need in a market</td>
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<tr>
<td>Solve a social problem</td>
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<tr>
<td>Create something of my own</td>
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<tr>
<td>Have more flexibility and independence</td>
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<tr>
<td>Have more free time</td>
<td></td>
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<tr>
<td>Make more money</td>
<td></td>
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<tr>
<td>Be at the head of an organization</td>
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<tr>
<td>Manage people</td>
<td></td>
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<tr>
<td>Create jobs</td>
<td></td>
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<tr>
<td>Follow a family tradition</td>
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<tr>
<td>Gain high social status</td>
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</tbody>
</table>

If there are any reasons unlisted above for why you would start a business, please list them here. (STARTBUS2)

Please rate your level of agreement with the following: *I would NOT start a business in order to...* (NOTSTART)

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree (1)</th>
<th>Disagree (2)</th>
<th>Undecided (3)</th>
<th>Agree (4)</th>
<th>Strongly agree (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of ideas regarding what business to start</td>
<td></td>
<td></td>
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<tr>
<td>Lack of assistance available to assess business viability</td>
<td></td>
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<tr>
<td>Excessively risky</td>
<td></td>
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<tr>
<td>Lack of initial capital for start-up</td>
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<tr>
<td>Lack of legal assistance or counseling</td>
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<tr>
<td>Lack of knowledge of the business world and the market</td>
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<tr>
<td>Lack of experience in management and finance</td>
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<tr>
<td>Current economic situation</td>
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<tr>
<td>Irregular income</td>
<td></td>
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<tr>
<td>Lack of support from people around</td>
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</tbody>
</table>
If there are any reasons unlisted above for why you would start a business, please list them here. (NOTSTART2)

Please rate your level of knowledge or skill in the following areas related to entrepreneurship. (FAMILIAR)

<table>
<thead>
<tr>
<th>Characteristics of entrepreneurs (1)</th>
<th>Poor (1)</th>
<th>Below average (2)</th>
<th>Average (3)</th>
<th>Above average (4)</th>
<th>Excellent (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role of entrepreneurship in the world economy (2)</td>
<td></td>
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<tr>
<td>Business ethics (3)</td>
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<td>Risk management (4)</td>
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<td>Legal structures for ventures (5)</td>
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<td>Intrapreneurship (6)</td>
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<tr>
<td>Social entrepreneurship (7)</td>
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<td>Leadership (8)</td>
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<td>Managing teams (9)</td>
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<tr>
<td>Project management (10)</td>
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<td>Negotiation (11)</td>
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<tr>
<td>Product development (12)</td>
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<td>Product life cycle (13)</td>
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<td>Economies of scale (14)</td>
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<td>Feasibility study (15)</td>
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<td>Prototype (16)</td>
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<td>Intellectual property (17)</td>
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<tr>
<td>Technology commercialization (18)</td>
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<td>Patents (19)</td>
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<tr>
<td>Finance and accounting (20)</td>
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<tr>
<td>Venture capital (21)</td>
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<tr>
<td>Skill</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<td>----------------------------------------------------------------------</td>
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<tr>
<td>Know the steps needed to place a financial value on a new business venture</td>
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<tr>
<td>(EFFICACY_1)</td>
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<tr>
<td>Pick the right marketing approach for the introduction of a new service</td>
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<tr>
<td>(EFFICACY_2)</td>
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<tr>
<td>Work with a supplier to get better prices to help a venture become successful</td>
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<tr>
<td>(EFFICACY_3)</td>
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<tr>
<td>Estimate accurately the costs of running a new project (EFFICACY_4)</td>
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<tr>
<td>Recognize when an idea is good enough to support a major business venture (EFFICACY_5)</td>
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<tr>
<td>Recruit the right employees for a new project or venture (EFFICACY_6)</td>
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<tr>
<td>Convince a customer or client to try a new product for the first time (EFFICACY_7)</td>
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<tr>
<td>Write a clear and complete business plan (EFFICACY_8)</td>
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<tr>
<td>Convert a useful scientific advance into a practical application (EFFICACY_9)</td>
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<tr>
<td>Develop your own original hypothesis and a research plan to test it (EFFICACY_10)</td>
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<tr>
<td>Grasp the concept and limits of a technology well enough to see the best ways to use it (EFFICACY_11)</td>
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</tbody>
</table>
Design and build something new that performs very close to your design specifications (Efficacy_12)

Lead a technical team developing a new product to a successful result (Efficacy_13)

Understand exactly what is new and important in a groundbreaking theoretical article (Efficacy_14)

Translate user needs into requirements for a design so well that users will like the outcome (Efficacy_15)

Overall, how would you rate your entrepreneurial ability? (Ability)

<table>
<thead>
<tr>
<th>Poor</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below average</td>
<td>2</td>
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<tr>
<td>Average</td>
<td>3</td>
</tr>
<tr>
<td>Above average</td>
<td>4</td>
</tr>
<tr>
<td>Excellent</td>
<td>5</td>
</tr>
</tbody>
</table>

How would you rate your ability to start a business now? (Busability)

<table>
<thead>
<tr>
<th>Poor</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below average</td>
<td>2</td>
</tr>
<tr>
<td>Average</td>
<td>3</td>
</tr>
<tr>
<td>Above average</td>
<td>4</td>
</tr>
<tr>
<td>Excellent</td>
<td>5</td>
</tr>
</tbody>
</table>

Rate your skill levels in the following areas: (Skills)

<table>
<thead>
<tr>
<th>Communication skills (Skills_1)</th>
<th>Poor (1)</th>
<th>Below average (2)</th>
<th>Average (3)</th>
<th>Above average (4)</th>
<th>Excellent (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation skills (Skills_2)</td>
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<tr>
<td>Analytical skills (Skills_3)</td>
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<tr>
<td>Ability to evaluate business ideas (Skills_4)</td>
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<tr>
<td>Level of risk tolerance (Skills_5)</td>
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<tr>
<td>Ability to deal with uncertainty (Skills_6)</td>
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</tbody>
</table>
Please enter your last name. (LASTNAME)

Please enter your university assigned email address. (EMAIL1)

Please list an alternate email address, if applicable (optional). (EMAIL2)

Are you willing to be contacted for a follow-up interview? (FOLLOWUP)
   Yes  (1)
   No   (2)
<table>
<thead>
<tr>
<th>Category, Code, No. of Items</th>
<th>Specific Topic Addressed by EES Item Categories and Scales</th>
<th>Source of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BEHAVIORS</strong></td>
<td></td>
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</tr>
<tr>
<td>ACTIVITIES (10)</td>
<td>Extent to which engineering students participate in entrepreneurship education and related activities</td>
<td>New items</td>
</tr>
<tr>
<td>POSTGRAD (7)</td>
<td>Students’ post-graduation career plans</td>
<td>Purdue surveys</td>
</tr>
<tr>
<td>BUSINESS (1)</td>
<td>Number of students who had, have, or intend to have a business</td>
<td>New items</td>
</tr>
<tr>
<td>VENTURE (1)</td>
<td>Type of businesses students are interested in starting</td>
<td>Purdue surveys</td>
</tr>
<tr>
<td><strong>ATTITUDES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROGRAM (9)</td>
<td>Extent to which entrepreneurship addressed in engineering programs</td>
<td>New items</td>
</tr>
<tr>
<td>INTEREST (7)</td>
<td>Nature of engineering student interest in entrepreneurship</td>
<td>Purdue surveys</td>
</tr>
<tr>
<td>STARTBUS (12)</td>
<td>Reasons students would be interested in entrepreneurship</td>
<td>Shinnar et al.</td>
</tr>
<tr>
<td>NOTSTART (14)</td>
<td>Reasons students would not be interested in entrepreneurship</td>
<td>Shinnar et al.</td>
</tr>
<tr>
<td><strong>KNOWLEDGE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAMILIAR (37)</td>
<td>Student familiarity with entrepreneurship terms and concepts</td>
<td>New items, Purdue surveys</td>
</tr>
<tr>
<td><strong>SELF-EFFICACY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EFFICACY (15)</td>
<td>Student perceptions of their technology venturing and entrepreneurship-related abilities</td>
<td>Lucas et al.</td>
</tr>
<tr>
<td>SKILLS (6)</td>
<td>Student perceptions of their skills in areas related to entrepreneurship</td>
<td>New items, Purdue surveys</td>
</tr>
<tr>
<td>ABILITY (1)</td>
<td>Student perceptions of their entrepreneurship ability overall</td>
<td>Purdue surveys</td>
</tr>
<tr>
<td>BUSABILITY (1)</td>
<td>Student perceptions of their ability to start a business immediately</td>
<td>Purdue surveys</td>
</tr>
<tr>
<td><strong>DEMOGRAPHICS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple codes (14)</td>
<td>Characteristics of engineering students participating in entrepreneurship education</td>
<td>New items, Purdue surveys</td>
</tr>
</tbody>
</table>
### ANOVA Results for End of Semester Survey Questions (Control listed first), Significant Questions Listed Below the Results of that Question

<table>
<thead>
<tr>
<th>Construct</th>
<th>Question</th>
<th>Mean</th>
<th>SD</th>
<th>F (1, 125)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavior (EES)</td>
<td>Activities, Post-grad</td>
<td>2.00</td>
<td>.30</td>
<td>2.08</td>
<td>.15</td>
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<tr>
<td></td>
<td>ACT1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.45</td>
<td>.56</td>
<td>1.02</td>
<td>.31</td>
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<tr>
<td></td>
<td>ACT2</td>
<td>1.20</td>
<td>.44</td>
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<tr>
<td></td>
<td>ACT3</td>
<td>1.88</td>
<td>.33</td>
<td>.53</td>
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<td>ACT4</td>
<td>1.74</td>
<td>.51</td>
<td>.39</td>
<td>.54</td>
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<tr>
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<td>ACT5</td>
<td>1.89</td>
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<td>.41</td>
<td>.53</td>
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<tr>
<td></td>
<td><strong>ACT6</strong></td>
<td><strong>1.91</strong></td>
<td><strong>.74</strong></td>
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While in college, have you done any of the following: Been involved in patenting a technology or protecting intellectual property

| ACT7            | 1.20                                   | .44  | .21 | .65    |
| ACT8            | 1.36                                   | .51  | 3.62| .06    |
| ACT9            | 1.42                                   | .72  | 1.02| .31    |
| ACT10           | 1.20                                   | .44  | .70 | .41    |

| POSTGRAD1<sup>b</sup> | 2.08                                   | 1.22 | 2.86| .09    |
| POSTGRAD2        | 2.44                                   | 1.04 | .13 | .72    |
| POSTGRAD3        | 3.03                                   | 1.15 | .16 | .69    |
| POSTGRAD4        | 2.76                                   | 1.12 | .18 | .67    |
## OPPORTUNITIES FOR INNOVATION

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Please rate your level of agreement with the following: I have a general interest in the subject of entrepreneurship.

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**Please rate your level of agreement with the following: I have a general interest in the subject of entrepreneurship.**
Please rate your level of agreement with the following: Entrepreneurship education can broaden my career prospects and choices

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If I wasn’t going to start a business, the reason I would NOT start a business is because... Doubts about personal abilities

| NTST13 | 2.59 | 1.05 | 3.89 | .05 |

If I wasn’t going to start a business, the reason I would NOT start a business is because... Having to work too many hours

| NTST14 | 2.23 | .80  | 1.37 | .24 |

<table>
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<tr>
<th>Self-Efficacy (EES)</th>
<th>Efficacy, Ability, Business Ability, Skills</th>
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<tr>
<td>EF6</td>
<td>61.58 25.21 5.08 .03</td>
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For each statement indicate how confident you are that you could perform that skill or possess that ability now: Recruit the right employees for a new project or venture

<table>
<thead>
<tr>
<th>EF7</th>
<th>56.73 23.67 .01 .92</th>
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</table>
For each statement indicate how confident you are that you could perform that skill or possess that ability now:

**Convert a useful scientific advance into a practical application**

EF10  
72.88  
60.34

**Develop your own original hypothesis and a research plan to test it**

EF11  
67.17  
56.87

**Grasp the concept and limits of a technology well enough to see the best ways to use it**

EF12  
73.67  
58.18

**Design and build something new that performs very close to your design specifications**

EF13  
69.88  
58.56

**Lead a technical team developing a new product to a successful result**

EF14  
69.12  
53.54

**Understand exactly what is new and important in a groundbreaking theoretical article**

EF15  
72.99  
57.62

**Translate user needs into requirements for a design so well that users will like the outcome**

AB1  
2.86  
2.72

BUSAB1  
2.42  
2.72

SK1  
3.94  
3.94
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| Curiosity (CI-4) | Curiosity | 4.74 | .56 | 7.84 | .01 |
|                 |          | 4.47 | .54 |      |    |
|                 | CUR1*    | 4.64 | 1.05| .01  | .94 |
|                 |          | 4.62 | .86 |     |    |
|                 | CUR2     | 4.85 | .95 | .94  | .33 |
|                 |          | 4.69 | .90 |     |    |
|                 | CUR3     | 5.35 | .73 | 4.46 | .04 |
|                 |          | 5.02 | 1.02|     |    |

Please indicate your level of agreement: I like variety in my life.

| CUR4 | 4.89 | .91 | 7.67 | .01 |
|      | 4.44 | .92 |      |    |

Please indicate your level of agreement: I am always finding new things to do.

| CUR5 | 3.11 | 1.19| .27  | .60 |
|      | 3.21 | 1.11|      |    |
| CUR6 | 4.56 | .95 | .81  | .37 |
|      | 4.41 | .94 |     |    |
| CUR7 | 4.99 | .99 | 3.45 | .07 |
|      | 4.63 | 1.16|     |    |
| CUR8 | 4.52 | 1.17| .21  | .65 |
|      | 4.44 | .97 |     |    |
| CUR9 | 4.68 | 1.05| 2.91 | .09 |
|      | 4.38 | .97 |     |    |
| CUR10| 4.48 | 1.08| .88  | .35 |
|      | 4.31 | .99 |     |    |
| CUR11| 4.77 | 1.12| 7.49 | .01 |
|      | 4.25 | 1.04|     |    |

Please indicate your level of agreement: I prefer to mix up my days with a
variety of activities.

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Please indicate your level of agreement: I immerse myself in information pertaining to a topic that I find fascinating.

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Please indicate your level of agreement: Very few things interest me.

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Please indicate your level of agreement: I like to get involved in a wide-variety of activities.

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Please indicate your level of agreement: When learning something, I try to gain the fullest possible understanding of the phenomenon.

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Please indicate your level of agreement: I find myself fascinated by lots of different things.

*Note. EES = Engineering Entrepreneurship Survey; CI-4 = Curiosity Index

ACT questions required a no (1), yes (2), or planning to (3) response; POSTGRAD, PROG, INT, STBUS, and NTST questions were coded 1-5 with 5 = strongly agree and 1 = strongly disagree; EF questions had a slider scale with a range of 0-100 with 0 = not at all confident and 100 = completely confident; AB, BUSAB, and SK questions were coded on a scale of 1 to 5 with 5 = excellent and 1 = poor; CUR was coded on a scale of 1-6 with 6 = strongly agree and 1 = strongly disagree.

Video Interview Questions

**Questions for current student video interviews:**

What does entrepreneurship mean to you?

How do you define innovation?
What does the term design-thinking mean to you?

What did you learn (if anything) about innovation and entrepreneurship in Senior Design?

What did you learn (if anything) about design-thinking in Senior Design?

What was the most important/interesting thing you learned about innovation and entrepreneurship?

Do you think you’ll be able to use [what you learned in this course/ what they just talked about in previous question] in your career?

How might you use [what you learned in this course/ what they just talked about in previous question] in your career?

**Questions for current TAs video interviews:**

What do you think are the goals of Senior Design?

Describe how students learn in this class....

Why do you think BioE students need to understand how to think with an entrepreneur mindset?

How do you think the course structure/content help them learn that mindset?

**Questions for OPEN 2015 interviews:**

How do you define entrepreneurship?

Why is entrepreneurial education important?

What delivery methods do you use in your classroom?

How do [teaching methods] help your students gain necessary skills?

How can you tell if these techniques are successful with your students?
Questions for Dr. DesJardins video interviews:

What does entrepreneurship mean to you?

How do you define innovation?

What does the term design-thinking mean to you?

What do you hope students learn (if anything) about innovation and entrepreneurship in Senior Design?

What do you hope students learn (if anything) about design thinking in Senior Design?

Why do exiting seniors need to know those things?

From your perspective, how do you think BioE students learn about the entrepreneurial mindset?

Thinking about the course, as it is taught right now, what do you think are the strengths of the course? Weaknesses?

What do you think could be done differently in order to prepare students for innovative, design-focused careers?

What outcomes or learning objectives would you like to change in the course and why?

How do you think delivery methodology affects student learning?

Questions for Dr. DesJardins & Ms. Przestrzelski half of semester video interviews:

Thinking specifically about the intervention version of the course:

- How do you feel that things are going so far?

Do you think the games are translating to the students in the way we anticipated?

- Any specific examples of successes?

- Any specific examples of failures?
How will we know if we are being effective?

Have you had to pivot at all yet?

- Name an example and how/why you chose to pivot.

Thinking big picture: is there anything you’d do differently if you were to do this again?

Any advice that you would give to another program/instructor considering doing this for their class?

**Questions for Dr. DesJardins & Ms. Przestrzelski end of semester video interviews:**

Thinking specifically about the intervention version of the course:

- What do you hope students learned (if anything) about innovation and entrepreneurship in Senior Design?
- What do you hope students learned (if anything) about design thinking in Senior Design?
- From your perspective, do you think BioE students learned about the entrepreneurial mindset this semester?
- What do you think was the most successful change we made to the course this semester? Why?
- What do you think was the least successful change we made to the course this semester? Why?

Thinking big picture: is there anything you’d do differently if you were to do this again?

Any advice that you would give to another program/instructor considering doing this for their class?

What do you think the students thought about the changes to the course?
Questions for committee members video interviews:

What does entrepreneurship mean to you?

How do you define innovative thinking?

What skills and mindset characteristics do you think graduating seniors from Clemson need to have?

Which are most important?

Do you think we are currently preparing students for life after college?

What do you think we could do differently to better prepare graduating seniors from any major?

How does a teacher’s methodology affect student learning?

Are there advantages to different teaching styles?

Questions for Erica video interviews:

How do I define entrepreneurship?

Are their different definitions of Design? Entrepreneurship?

How has that definition changed since working with BIOE?

How do these definitions work together through this research?

Can you explain what the research process is for this project?

• What are you planning on doing?

• What will change?

• How will this affect the objectives of the course? Methods?

• What are you hoping to see in the results?

Why this particular course?

Why are you working with Dr. DesJardins and BIOE?
Who are your committee members?

- What expertise do they bring into this project?

What did you learn at OPEN?

- What sort of movement are you seeing in the education aspect of engineering?

Specific games-based learning examples- what did they teach?

How did you create the new lesson plans?
Debrief/Reflections Sample
Sample Exam Questions

1. How does the philosophy of “Design for Manufacturing” influence the design of a product?

2. Draw and label the basic components of an Ishikawa Diagram describe how can it assist in the design process?

3. Using the TRIZ methodology, give a specific example a biomedical device, list 2 general engineering principles that are in conflict, and describe a solution to this conflict that makes use one of the inventive principles?

4. A Morphological Chart is used to generate ideas in an analytical and systematic manner, whereby different sub-functions are identified, and new combinations of sub-functions are generated, explored and evaluated.

5. Match the correct document to the correct definition:
   
a. Design History File (DHF)
b. Device Master Record (DMR)
c. Device History Record (DHR)
d. Technical Documentation File (TF)
e. Design Documentation Record (DDR)
f. Design Master File (DMF)

___ Compilation of records containing the specs and procedures for a finished device (usually currently on the production floor)
___ Contains or indicates the location of the actual production records for a particular device, to show the processes, tests, rework, etc from beginning to end
___ Contains relevant design data which demonstrates that essential safety requirements are satisfied. Allows assessment of the conformity of the product with requirements of the Medical Device Directives
___ Compilation of records which describes the design history of a finished device, from development to production to labeling. Contains or references the records necessary to prove that the design was developed in accordance with approved QSR design plans. Contains ‘institutional’ memory of previous design activities