Advances in Engineering Education

SPRING 2020

Re-Designing The Senior Design Classroom Experience With Game-Based Learning

ERICA WALKER

AND

JOHN DESJARDINS
Clemson University
Clemson, S.C.

AND

BRE PRZESTRZELSKI
University of San Diego
San Diego, CA

ABSTRACT

Historically, classroom content delivery has relied on lecture, but recently there has been a call for educators to use active learning to promote student engagement and a deeper understanding of the material (Bonwell and Eison 1991; Erickson 1984; Cross 1987; Prince 2004; Bodnar and Clark 2014). According to Prince (2004) active learning is any method that promotes engagement with the material through activities and requires students to think about what they are doing. This mixed methods study used Game-Based Learning as an active learning methodology to embed 21st Century Skills and epistemic frames into the domain content of a Bioengineering Senior Design Course. The control section was taught primarily with seventy-five minute lectures and the intervention section used a flipped classroom approach where in-class time focused on games and activities. The intervention was developed using Game-Based Learning (GBL) as the pedagogy within the Cognitive Apprenticeship framework. The framework is based on the traditional model of apprenticeship where students learn how to replicate the thought processes of an industry professional and then apply those techniques to their own project (Collins and Kapur 2014; Pieters and de Bruijn 1992; Mitterer and John 2006; Stalmeijer 2015). The quantitative data indicated that students from both sections of the course learned acceptable levels of domain content. However, qualitative data which included student reflections and semi-structured interviews did indicate that students in the intervention section developed a better understanding of 21st Century Skills. This led us to the conclusion that Game-Based Learning within the Cognitive Apprenticeship model can be used as a valuable classroom tool for delivering curriculum in senior design courses.

Key words: Game-based Learning, Flipped Classroom, Cognitive Apprenticeship Model

LITERATURE

The idea that play can provide opportunities for learning is a concept that educators have explored for more than a century, but research in this area gained significant momentum in the last 30 years (Nodoushan and Ali 2009). Games, both educational and those created purely for entertainment, provide a safe environment that incorporates opportunities for play, exploration, low-stakes failure, problem-solving, and immediate feedback within a controlled environment. Previous studies indicate that a Game-Based Learning (GBL) approach to teaching can positively impact student retention and engagement (Baid and Lambert 2010; Bodnar et al. 2016; Wheatley 1999; Bodnar and Clark 2014).

Two national organizations that govern engineering education, the Accreditation Board for Engineering and Technology (ABET) and the American Society for Engineering Education (ASEE), have long recognized the value of preparing engineers with more than just discrete domain knowledge. Both of these organizations have promoted the importance of teaching 21st Century Skills such as communication, teamwork, and lifelong learning (Shuman, Besterfield-Sacre, and McGourty 2005; Ernst 1996; Apelian 1994; Kriewall and Mekemson 2010). Recent research has demonstrated that games and active learning can encourage students to learn content-based knowledge while developing valuable 21st Century Skills such as creativity, innovation, collaboration, communication, and problem solving (Baid and Lambert 2010; Gross et al. 2015; Bodnar and Clark 2017). The intervention focused on promoting the 21st Century Skills–creativity, communication, teamwork, innovation, and problem solving–defined by industry partners as necessary for success in the Biodesign industry.

In addition to teaching both the course-defined domain content and 21st Century Skills, another challenge for educators is providing both practical and theoretical learning opportunities when striving to meet diverse educational goals within a compressed four-year degree cycle. Engineering students of the 20th century learned practical applications under the guidance of a master practitioner, including instruction on industry-specific strategies and the best ways to accomplish specific tasks (Apelian 1994; Emmerson 1973; McGivern 1960). However, providing one-on-one guidance is not practical for educating the large numbers of students currently seeking engineering degrees in the 21st century. However, there is an educational framework based on the model of apprenticeship that can convey in a classroom setting, Cognitive Apprenticeship. In this model, gaining expertise requires mastering three types of knowledge in addition to the core domain knowledge- (1) heuristic strategies, (2) control strategies, and (3) learning strategies (Collins and Kapur 2014; Stalmeijer 2015; Pieters and de Bruijn 1992; Hennessy 1993; Dennen 2004), see Table 1. In a Cognitive Apprenticeship classroom, instructors perform the role of the expert and guide student-apprentices through the cognitive processes required to complete industry tasks and students benefit from an active and interactive learning environment (Dennen 2004; Poitras and Poitras 2011). Through

Table 1. The Cognitive Apprenticeship Model is Based on Implementing Four Principles when Designing Learning Environments: Content, Methods, Sequencing, and Sociology (Collins and Kapur 2014).

Content- Types of knowledge required for expertise	
Domain Knowledge	Subject matter specific concepts, facts, and procedures
Heuristic Strategies	Generally applicable techniques for accomplishing tasks
Control Strategies	General approaches for directing one's solution process
Learning Strategies	Knowledge about how to learn new concepts, facts, and procedures
Methods- Ways to promote the development of expertise	
Modeling	Teacher performs task so students can observe
Coaching	Teacher observers and facilitates while students perform a task
Scaffolding	Teacher provides supports to help students perform a task
Articulation	Teacher encourages students to verbalize their knowledge and thinking
Reflection	Teacher enables students to compare themselves with others
Exploration	Teacher invites students to pose and solve their own problems
Sequencing- Keys or ordering learning activities	
Increasing complexity	Meaningful tasks gradually increasing in difficulty
Increasing diversity	Practice a variety of situations to emphasize broad application
Global to local skills	Focus on conceptualizing the whole task before executing the parts
Sociology- Social characteristics of learning	
Situated learning	Students learn in the context of working on realistic tasks
Community of practice	Communicating about different ways to accomplish meaningful tasks
Intrinsic motivation	Students set personal goals to seek skills and solutions
Cooperation	Students work together to accomplish their goals

this framework, students learn how to think, talk, and solve problems like professionals in the field (Collins and Kapur 2014).

INSTRUCTIONAL DESIGN

The intervention for this study was developed by a team of three co-instructors with different areas of expertise–Dr. John DesJardins, an Associate Professor in Bioengineering and the lead instructor for Senior Design, Bre Przestrzelski, a PhD student in Bioengineering with a research focus on Biodesign and learning experience design, and Erica Walker, a lecturer in Graphic Communications and a PhD student with an emphasis in Curriculum and Instruction. Both sections of the Bioengineering Senior Design course used the same domain content, learning objectives, and exams, but the intervention section used Game-Based Learning (GBL) as the delivery method and Cognitive Apprenticeship as the educational framework. The instructional design for both sections of the course remained focused on the overall objective which was preparing student teams with fundamental domain content and the 21st Century Skills required to complete a start-to-finish design project.

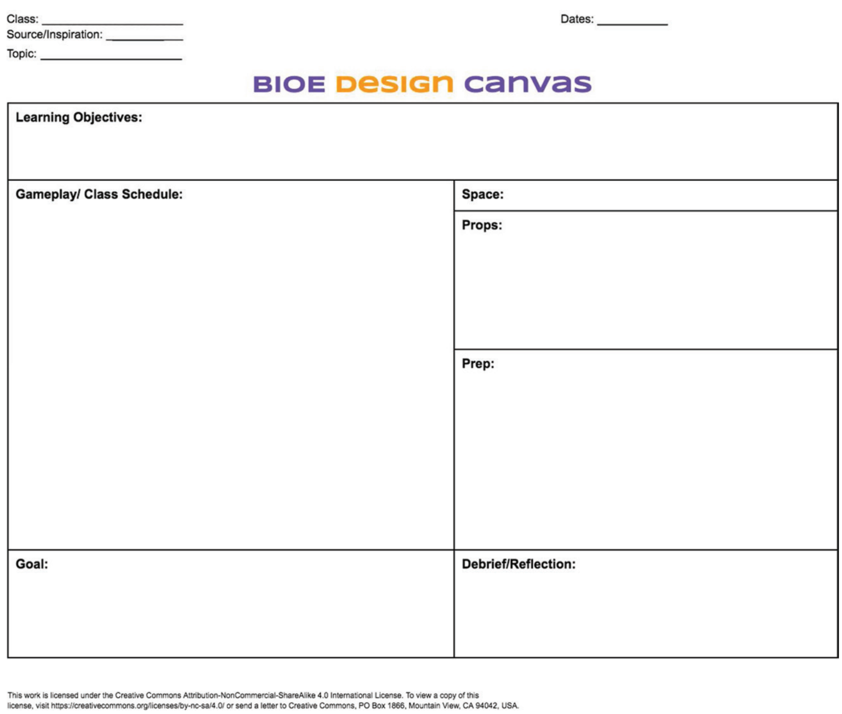
Using a flipped classroom model, students in the intervention section of the course reviewed domain content prior to class through slides and videos. Class time was devoted to activities, games. Class meetings (75 minute periods) focused on one to two games that emphasized key applications of the domain content and created embedded opportunities for students to practice 21st Century Skills. Class began with a brief content review and preparation for the day's activities which included cognitive modeling of the processes needed to participate. The game followed the introduction and consumed the majority of the allotted time. Class concluded every meeting with a group reflection on the learning objectives and student experience.

Game development began with DesJardins' "take-away" points for each class. These were defined as the point during a lecture when he might say "if you remember only one thing from today…it should be this." These defined learning objectives became the basis for that game or activity, see Figure 1.

Figure 1. In this video, the faculty team reflects on developing the BIOE Senior Design intervention. Topics covered include: What changed?; How to create the games?; What about 21st Century Skills?; Now what? Time to Iterate! Video link- https://youtu.be/nvqKOpWE4VI

Reflection was a vital part of the intervention because it is included in two of the six instructional methods necessary for developing expertise in the Cognitive Apprenticeship model (Collins and Kapur 2014; Clancey 1992; Stalmeijer 2015). Therefore the intervention had multiple opportunities for reflection including a group debrief at the end of each class and individual written reflections after dismissal each day. The group debrief provided students a chance, whether they shared or just listened during the debrief, to compare their learning experience to that of their peers with guided feedback from the instructors. Through these discussions, they heard different ways to accomplish tasks and noted the strengths and weaknesses of each. After class, students received structured prompts providing an opportunity to individually reflect and write about connections made between the games, the course material, and 21st Century Skills during class that day.

Prior to finalizing the intervention, the team compared the intervention content to the material on the final exam to ensure that students in both sections were exposed to the same course material. Once solidified, each class plan was recorded in a BIOE Design Canvas (see Figure 2), which was


Class: ____________________
Source/Inspiration: ___________
Topic: ____________________
Dates: _________

BIOE Design Canvas

Learning Objectives:	
Gameplay/ Class Schedule:	Space:
	Props:
	Prep:
Goal:	Debrief/Reflection:

This work is licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License. To view a copy of this license, visit https://creativecommons.org/licenses/by-nc-sa/4.0/ or send a letter to Creative Commons, PO Box 1866, Mountain View, CA 94042, USA.

Figure 2. A blank BIOE Design Canvas based on the Game Design Canvas. Available here: https://goo.gl/SidmYR. Licensed for modification and reuse.

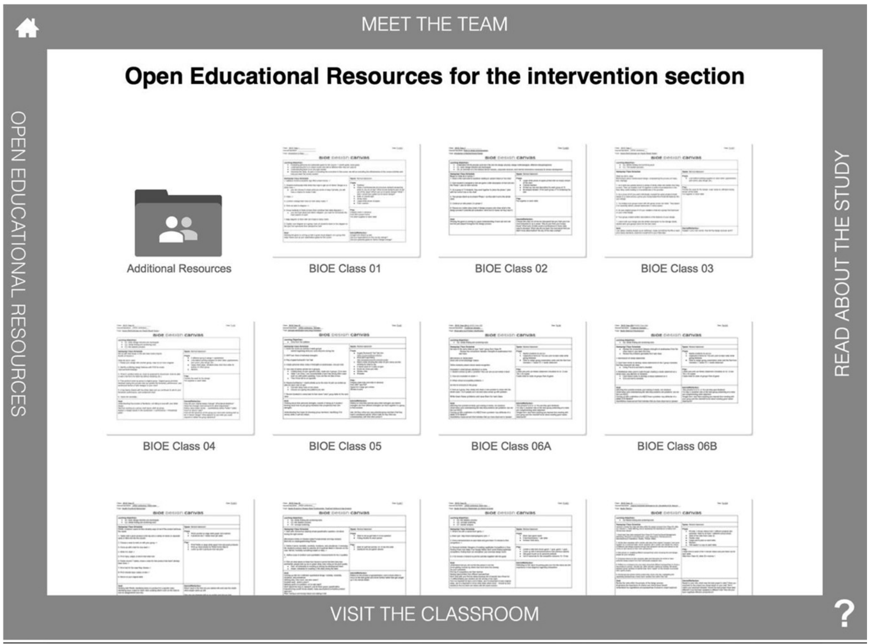


Figure 3. Open Education Resources developed for the intervention are available online at http://gamebasedseniordesign.com/class-plans.html

adapted from the Game Design Canvas introduced at the Venturewell "Ideas at Play" Conference. All of the BIOE Design Canvases developed for this intervention are available for download under the Creative Commons license, see Figure 3.

AN EXAMPLE CLASS

While 15 classes were developed for the intervention course, the authors have selected one class period as an example for this paper. This class period was situated about ¾ of the way through the semester and focused on Needs Filtering and Screening.

Lesson 10: Needs Filtering and Screening

One of the challenges of creating a game for this lesson was building upon the domain course content consumed prior to class and helping students identify the complexities involved in this part of the bioengineering process. For Lesson 10, the instructors wanted students to understand the value of choosing the best senior project to pursue while also introducing needs

Class number	Date	Proposed Topic Covered	Lecture #	Book Chapters	Additional Materials
10	9/24/2015	Needs Filtering	Lecture 9	2.5	Provide brief summary videos of different from projects last semester. Videos need to span different clinical areas. Slide of the roles from Class 02 Stickie notes Large post-it pads on each table Markers

Most Important Takeaways	Ideas for Games/Activities to address takeaways
Weighing the needs/ acceptance criteria, ranking those needs; choose which project they want to move forward with; developing a defensible position; acknowledging that different companies have different strict filters; recognizing that student design groups shouldn't bite off more than they can chew	Lecture to review the roles and jobs within the design process from Class 02- slide 22 in lecture 1, needs filtering, and to emphasize the importance of specific criteria perspectives over clinical area interest 1. Each team member has roles assigned from Class 02 2. All the team members with a certain role meet together at a combined table. While all the group members with a certain role from each group are together, they debate the criteria of different potential projects through the role lens they were assigned and determine the merits of each. 3. Mini-lecture on weighting different perspectives when choosing as a group 4. Everyone returns to their team table and discusses the merits of each project from the perspecive of their individual assigned roles. Beads are used to negotiate the value of different persepctives to choose a project that best fits the team goals and strengths 5. Reflect as a group how you reconciled different perspectives to chose a final project 6. Several groups present how they chose their project and negotiated the perspectives

Reflection opportunities	outcomes	Syllabus-stated learning outcome
Based on your role, which was the best project to take? Were you surprised by the project you chose based on your role? Did it match your personal interests? Would the best project have been different if you had been assigned a different role? How did your team negotiate different perspectives? How did you place value on the beads used to determine which project was the best fit for your team?	Review the roles within the process of the design process Emphasize the importance of criteria over clinical area interest Understand the negotiations and perspectives involved in project approval. Determining value of persepctives within a team using a set number of beads to negotiate	2. needs finding and screening tools

Figure 4. Final spreadsheet used for planning Class 10: Needs Filtering.

finding and screening tools, the Learning Objective for this class meeting. Previous student teams tended to pick a design project based on personal interest or appeal, but avoided serious consideration of the criteria necessary to choose a "best-fit" project. While brainstorming these goals, ideas for addressing the defined take-away points were placed into a spreadsheet, see Figure 4.

Elements of GBL and Cognitive Apprenticeship were intentional within the class plan. For instance, the game had a storyline [team members played specific Bioengineering roles within a team] and conflict [one hundred beads needed to be negotiated and divided between the team members and each team had to agree on one final project to pursue]. Completion required both individual and team problem solving and strategy skills and instructor feedback throughout the process allowed teams to continually adjust their tactics. Even if the team failed to complete the task, the stakes were low [no actual risk of company failure or loss of investment capital].

From a Cognitive Apprenticeship perspective, students employed domain content knowledge [needs finding and screening tools] as well as strategies in a situated learning environment [real world task, based on bioengineering companies decision-making process] that required cooperation within a community of learning. Instructors leveraged the first five teaching methods–modeling, coaching, scaffolding, articulation, and reflection–during this class period.

The final class plans and reflection questions for Class 10 were added to the BIOE Design Canvas, see Figure 5. A video on the YouTube channel about this lesson includes classroom footage and narration from the instructional team regarding the development process, see Figure 6.

Class: BIOE Class 10 Date: Tu 9/24
Source/Inspiration: Original worksheet developed by Dr. DesJardins & Dr. Mercuri
Topic: Needs Filtering

BIOE Design canvas

Learning Objectives:
- O2 Needs finding and screening tools

Gameplay/ Class Schedule: Lecture to review the roles and jobs within the design process from Class 02- slide 22 in lecture 1, needs filtering, and to emphasize the importance of criteria over clinical area interest 1. Each team has roles assigned from Class 02 (Cross-functional Management, Marketing, Research & Development, Legal, Regulatory, Reimbursement, Manufacturing & Operations, Quality, Clinical, Sales) 2. All the team members with a certain role leave their original "company" and come together at a combined table. As a group, students with the same role debate the criteria of different past design projects through their assigned role lens and decide on the merits of each based on the perspective of their role. 3. Mini-lecture on weighting different perspectives when choosing the best design project for your company and explain the rules of the negotiation game. 4. Everyone returns to their company table and discusses the merits of each potential design project from their individually assigned roles. As a company determine how many beads each member should get and members negotiate and leverage their perspective. Visually see 100% decision making by dividing 100 beads between group members to identify their perspective's "weight," and therefore value, on the decision-making process to proceed with a given project. 5. Reflect as a company how you reconciled different perspectives to choose a final project to pursue as a group. 6. Several groups present which project they chose and why, highlighting the negotiating perspectives of each team member from within their role. Instructors provide guidance and reveal the success rate of the original projects based on awards and patents.	**Space:** Normal classroom **Props:** • Provide brief summary videos from 7 different projects. Each video is from different clinical areas. • Slide of the roles from Class 02 • Sticky notes • Large post-it pads on each table • Markers • 100 beads in a cup on each table **Prep:** Create links to each of the 4 minute videos and print them out for each table Slide from Class 02, slide 22 in lecture 1
Goal: Review the roles within the process of the design process Emphasize the importance of criteria over clinical area interest Understand the negotiations and perspectives involved in project approval	**Debrief/Reflection:** Based on your role, which was the best project to take? Were you surprised by the project you chose based on your role? Did it match your personal interests? Would the best project have been different if you had been assigned a different role? How did your team negotiate different perspectives?

Figure 5. The final BIOE Design Canvas for Class 10: Needs Filtering. Direct link to canvas- https://goo.gl/8u0qcl

Figure 6. Lesson 10 - Needs Filtering and Screening Tools video. Direct link to Video- https://youtu.be/PG402v1ZgQs

RESULTS AND DISCUSSION

Both qualitative and quantitative data were collected throughout this embedded mixed methods study and results from the different data were combined during interpretation (Creswell 2013; Walker 2016). Results were examined to determine the impact of the intervention on student learning of domain content and 21st Century Skills. Final exam scores were analyzed quantitatively to address domain content learning and debrief responses from the intervention section were analyzed using qualitative methods to determine the acquisition of 21st Century Skills. The mean for the control exam scores (N = 75) was 91.23 (SD = 6.34) and the mean for the intervention exam scores (N = 81) was 86.53 (SD = 11.02). This indicated that both sections of the course learned the required domain content for the course to a satisfactory level.

The individual student-written debriefs provided additional qualitative data regarding student learning. Responses were analyzed using a narrative approach with emergent coding, see Table 2 (Creswell 2012). The emergent codes centered on students' connection between the domain content and the games played in class, mentions of practicing 21st Century Skills, and positive or negative sentiment. For the purpose of consistent analysis, researchers defined domain course content by the predetermined objectives and goals for each class period. Throughout all fifteen of the

Table 2. Strategy for Data Analysis Using the Narrative Research Approach (Creswell 2012).

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

intervention-based classes, students showed a strong understanding of the connection between the in-class games and the domain course content, see Table 3.

Table 3. Debrief Synthesis for Sample of Classes.

Class #	Class title	Synthesis of student reflections
03	Design Methodologies and Needs-Based Design	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 more consistency in the end products and higher quality products. Six Sigma and Robust Design required 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.
04	Design Methodologies and Needs-Based Design, Day 2	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 material 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.
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 criteria when determining needs, and practicing the negotiations involved in determining the "best" need to pursue as a team. Students admitted that the bead 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 cannot 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.

Note. The synthesis statements from all the intervention classes can be viewed within the context of the classroom on the website at: http://gamebasedseniordesign.com/class01.html

Table 4. A selection of debrief comments referring to specific 21st Century Skills (in bold).

21st Century Skill	Debrief Comment
Communication	"We are more involved in learning and are actively engaged in games. The advantages are [sic] that [playing a game] targets different modes of **communication** including action and explaining concepts."
Creativity	"I believe the team-based, hands-on, approach allows me to grasp concepts more easily and increase my **creativity** over time."
Creativity Teamwork	"The activities promote **creativity** and **team building**."
Teamwork Problem Solving	"I believe the activity based aspect of the course will help solidify learned material and will help us all in learning how to embrace **teamwork** and **problem solving**."
Teamwork 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 **[teamwork]** but then we had to take our original idea and make it work with another group which took some creative **problem solving**."
Communication Collaboration 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...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 **[problem solving]**. Patience, perseverance, interpersonal skills, understanding, etc.. these are all valuable."

Analysis of the debrief comments looked at student recognition of chances to practice and develop 21st Century Skills through the games in class. Narrative analysis was used to identify themes and locate common epiphanies across participants (Creswell 2012). Specific skills such as creativity, communication, teamwork, and problem solving were mentioned in the debrief comments across multiple class meetings, see Table 4.

In conjunction with the qualitative analysis of the debriefs, an end-of-course survey was analyzed quantitatively to explore student learning of 21st Century Skills through the intervention. The survey combined two pre-existing surveys–the Engineering Entrepreneurship Survey (EES) and the Curiosity Index (CI-4)–which had been proven valid and reliable with similar populations of engineering students (K. H. Fulcher 2004; Keston H. Fulcher 2008; Duval-Couetil, Reed-Rhoads, and Haghighi 2011, 2012; Williams 2015). These surveys were implemented because researchers felt that, combined, they examined key 21st Century Skills valued by engineering programs and examined important skills necessary for the overarching goal of this course which was to prepare student teams to complete a start-to-finish design project with the potential to patent and/or commercialize the resulting product, see Table 5. Although there is significant overlap in traits associated with Entrepreneurial and 21st Century Skills a future study may observe different results by using a survey that deemphasizes entrepreneurial terminology, Figure 7.

Table 5. Construct, Questions Groupings, and Number of Questions.

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

Statistical analysis of the survey examined the intervention and the control sections of the course for shifts in self-efficacy. Analysis looked at four constructs–attitudes, self-efficacy, behaviors, and curiosity. Analysis showed no significance between two constructs, Behaviors and Attitudes, suggesting that both groups had comparable experiences regarding entrepreneurship and similar levels of interest in starting a company. Although individual questions within these two constructs were found to be significant, this article will focus on the two constructs that were significant as a whole: Self-Efficacy and Curiosity, see Table 6.

Within the Self-efficacy construct, analysis indicated no significant difference between the two groups regarding skills (SK), ability (AB), or business ability (BUSAB). This suggests that students from both sections of the course had similar self-efficacy regarding 21st Century Skills and their entrepreneurial abilities.

However, an ANOVA revealed a significant difference on eight out of fifteen efficacy (EF) questions, ($F(1, 125) = 7.97$, $p = .01$) between the two sections of the course. The intervention group ($M = 51.34$,

Table 6. 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.

Construct	Question	Mean	SD	F (1, 125)	p
Behavior (EES)	Activities, Post-grad	2.00 1.92	.30 .26	2.08	.15
Attitudes (EES)	Program, Interest, Start Business, Not Start Business	3.29 3.28	.31 .41	.03	.87
Self-Efficacy (EES)	**Efficacy, Ability, Business Ability, Skills**	**39.95** **34.62**	**9.18** **12.14**	**7.83**	**.01**
	EF6	**61.58** **51.46**	**25.21** **25.34**	**5.08**	**.03**
	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				
	EF9	**66.93** **57.05**	**21.90** **22.17**	**6.37**	**.01**
	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**	**18.13** **23.85**	**11.22**	**.00**
	For each statement indicate how confident you are that you could perform that skill or possess that ability now: Develop your own original hypothesis and a research plan to test it				
	EF11	**67.17** **56.87**	**19.61** **24.98**	**6.73**	**.01**
	For each statement indicate how confident you are that you could perform that skill or possess that ability now: Grasp the concept and limits of a technology well enough to see the best ways to use it				
	EF12	**73.67** **58.18**	**18.71** **24.90**	**15.85**	**.00**
	For each statement indicate how confident you are that you could perform that skill or possess that ability now: Design and build something new that performs very close to your design specifications				
	EF13	**69.88** **58.56**	**19.48** **25.44**	**8.51**	**.00**
	For each statement indicate how confident you are that you could perform that skill or possess that ability now: Lead a technical team developing a new product to a successful result				
	EF14	**69.12** **53.54**	**19.69** **25.44**	**15.02**	**.00**
	For each statement indicate how confident you are that you could perform that skill or possess that ability now: Understand exactly what is new and important in a groundbreaking theoretical article				
	EF15	**72.99** **57.62**	**18.14** **23.75**	**16.94**	**.00**
	For each statement indicate how confident you are that you could perform that skill or possess that ability now: Translate user needs into requirements for a design so well that users will like the outcome				

Continued

Table 5. (Continued).

Construct	Question	Mean	SD	F (1, 125)	p
Curiosity (CI-4)	**Curiosity**	**4.74** **4.47**	**.56** **.54**	**7.84**	**.01**
	CUR3	**5.35** **5.02**	**.73** **1.02**	**4.46**	**.04**
	Please indicate your level of agreement: I like variety in my life.				
	CUR4	**4.89** **4.44**	**.91** **.92**	**7.67**	**.01**
	Please indicate your level of agreement: I am always finding new things to do.				
	CUR11	**4.77** **4.25**	**1.12** **1.04**	**7.49**	**.01**
	Please indicate your level of agreement: I prefer to mix up my days with a variety of activities.				
	CUR12	**4.91** **4.59**	**.84** **.89**	**3.73**	**.01**
	Please indicate your level of agreement: I immerse myself in information pertaining to a topic that I find fascinating.				
	CUR13	**5.34** **4.93**	**.83** **.89**	**7.32**	**.01**
	Please indicate your level of agreement: Very few things interest me.				
	CUR14	**4.88** **4.48**	**1.06** **.96**	**5.03**	**.03**
	Please indicate your level of agreement: I like to get involved in a wide- variety of activities.				
	CUR15	**4.88** **4.39**	**.81** **.82**	**11.17**	**.00**
	Please indicate your level of agreement: When learning something, I try to gain the fullest possible understanding of the phenomenon.				
	CUR16	**5.00** **4.67**	**.96** **.91**	**3.89**	**.05**
	Please indicate your level of agreement: I find myself fascinated by lots of different things.				

Note. EES = Engineering Entrepreneurship Survey; CI-4 = Curiosity Index
[a]ACT questions required a no (1), yes (2), or planning to (3) response; [b]POSTGRAD, PROG, INT, STBUS, and NTST questions were coded 1-5 with 5 = strongly agree and 1 = strongly disagree; [c]EF questions had a slider scale with a range of 0-100 with 0 = not at all confident and 100 = completely confident; [d]AB, BUSAB, and SK questions were coded on a scale of 1 to 5 with 5 = excellent and 1 = poor; [e]CUR was coded on a scale of 1-6 with 6 = strongly agree and 1 = strongly disagree.

SD = 18.42) showed a significantly lower self-efficacy than the control group (M = 59.47, SD = 13.89) regarding confidence in their entrepreneurial abilities. Anecdotal evidence indicates that faculty might have been less explicit when talking about entrepreneurship during the intervention section of the course, instead using terminology that focused on individual 21[st] Century Skills and traits,

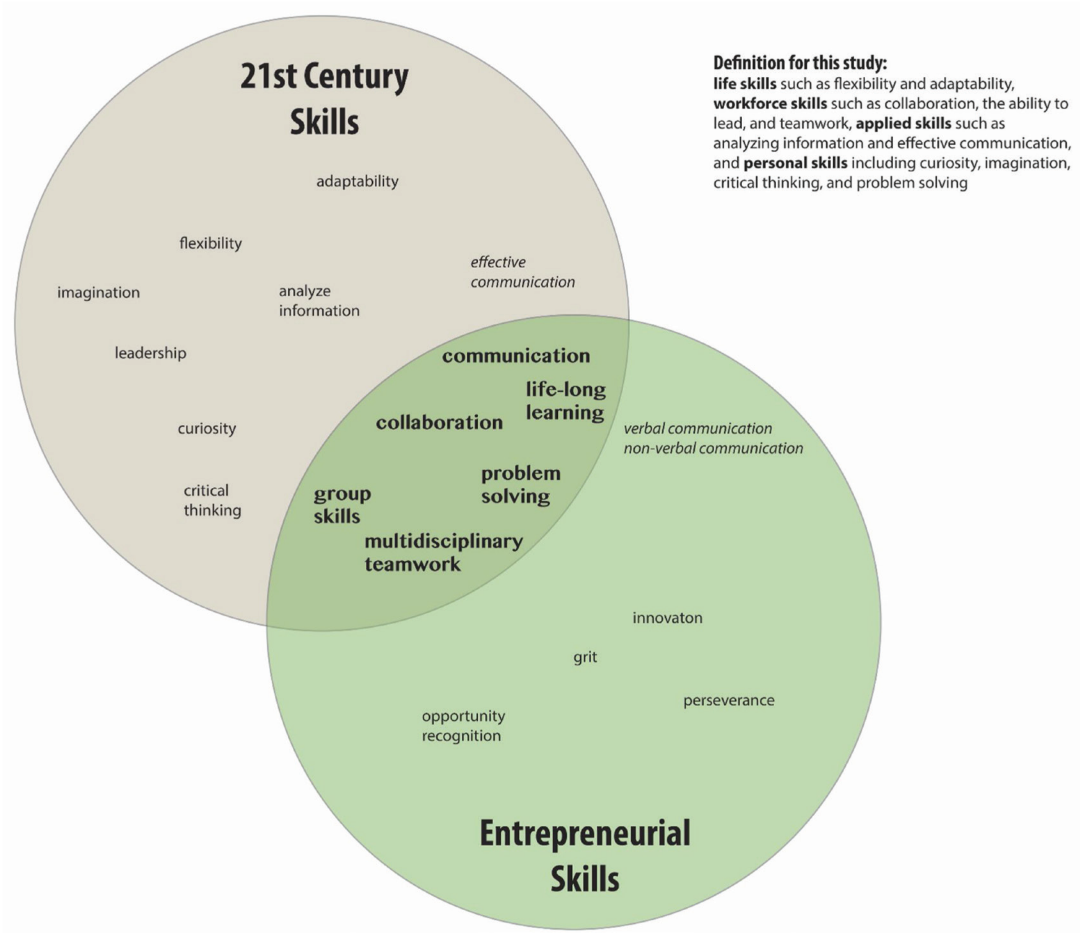


Figure 7. Chart depicting the overlap of skills listed in the literature between 21st Century Skills and Entrepreneurial skills (Apelian 1994; Bellotti et al. 2014; "Education for the 21st Century" n.d.; Saavedra and Opfer 2012; Matthew et al., n.d.; Oman et al. 2012; Kriewall and Mekemson 2010; Walker 2016)

see Figure 7. The choice of words used by the teaching team might have impacted this result since the ratings and number of team projects moved forward at the end of the year was comparable between the two groups of students.

The CI-4 survey instrument measured breadth and depth of curiosity and analysis indicated a significant difference on eight out of sixteen questions in this construct (CUR). An ANOVA showed that the control group ($M = 4.74$, $SD = 0.56$) had a higher mean than the intervention group ($M = 4.47$, $SD = 0.54$) for this construct ($F(1, 125) = 7.84$, $p = .01$). This suggests that the intervention students, as a group, had lower curiosity. Interestingly, another researcher using the same instrument did not think exposure to an intervention in one course would impact a student's breadth and depth of curiosity (T. Ribera, personal communication, July 11, 2016). Further study on this construct is needed to see what impact, if any, the intervention had on curiosity.

CONCLUSIONS

Results from this study are not conclusive regarding the effectiveness of GBL within a Cognitive Apprenticeship framework for delivering domain content and 21st Century Skills in a Senior Design Class. Students from both sections of the course indicated satisfactory levels of domain content learning and all teams participating in this study successfully completed their final design projects. External judging by industry and academic experts indicated that both sections of the course produced the same quality of senior design projects. Qualitative data indicated that the intervention appeared to encourage higher levels of 21st Century Skills, especially in regards to teamwork. However, quantitative analysis suggests that intervention students also had lower self-efficacy and less interest in pursuing entrepreneurship. This leads us to posit that GBL within a Cognitive Apprenticeship framework can provide an additional tool for faculty teaching this type of course, but as with any teaching tool there are strengths and weaknesses. More research would need to be completed to show a definitive advantage or disadvantage to using this tool.

Limitations for this study include transferability. Although participation in the intervention was random, a pre- and post-evaluation was not conducted on the two groups of students. Therefore a change based on the intervention cannot be separated from the innate characteristics of the group of students who participated. The number of students could also have impacted the results. Both sections of this course had a large number of students ($n = 76$, $n = 82$) which impacted the quantity of time instructors could provide individualized feedback for teams during the games. Without running a similar study using a different teaching team, the faculty team could also impact the results of this study. Full class plans are available through Creative Commons license, so future studies could test them with different faculty and student groups to further determine the impact of this intervention.

REFERENCES

Apelian, Diran. 1994. "Reengineering Engineering-Education: Paradigms and Paradoxes." *Advanced Materials and Processes* 145 (6). digitalcommons.wpi.edu: 110. http://digitalcommons.wpi.edu/mechanicalengineering-pubs/62/.

Baid, Heather, and Nicky Lambert. 2010. "Enjoyable Learning: The Role of Humour, Games, and Fun Activities in Nursing and Midwifery Education." *Nurse Education Today* 30 (6): 548–52. https://doi.org/10.1016/j.nedt.2009.11.007.

Bellotti, Francesco, Rosa Maria Bottino, Baltazar Fernández-Manjón, and Rob Nadolski. 2014. "Guest Editorial: Game- Based Learning for 21st Century Transferable Skills: Challenges and Opportunities." *Journal of Educational Technology & Society* 17 (1). International Forum of Educational Technology & Society: 1–2. https://doi.org/10.2307/jeductechsoci.17.1.1.

Bodnar, C. A., and R. M. Clark. 2017. "Can Game-Based Learning Enhance Engineering Communication Skills?" *IEEE Transactions on Professional Communication* 60 (1). ieeexplore.ieee.org: 24–41. https://doi.org/10.1109/TPC.2016.2632838.

Bodnar, Cheryl A., Daniel Anastasio, Joshua A. Enszer, and Daniel D. Burkey. 2016. "Engineers at Play: Games as Teaching Tools for Undergraduate Engineering Students." *Journal of Engineering Education* 105 (1). Wiley Online Library: 147–200. https://doi.org/10.1002/jee.20106.

Bodnar, Cheryl A., and Renee M. Clark. 2014. "Exploring the Impact Game-Based Learning Has on Classroom Environment and Student Engagement within an Engineering Product Design Class." In *Proceedings of the Second International Conference on Technological Ecosystems for Enhancing Multiculturality*, 191–96. ACM. https://doi.org/10.1145/2669711.2669899.

Bonwell, C. C., and J. A. Eison. 1991. "Active Learning: Creating Excitement in the Classroom." George Washington University. http://eric.ed.gov/?id=ED336049.

Clancey, William J. 1992. "Representations of Knowing: In Defense of Cognitive Apprenticeship." *Journal of Artificial Intelligence in Education* 3 (2): 139–68. http://cogprints.org/291.

Collins, Allan, and Manu Kapur. 2014. "Cognitive Apprenticeship." In *The Cambridge Handbook of the Learning Sciences*, edited by R. Keith Sawyer and R. Keith Sawyer, 2nd ed., 109–27. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139519526.008.

Creswell, John W. 2012. *Qualitative Inquiry and Research Design: Choosing among Five Approaches*. Sage. https://books.google.com/books?hl=en&lr=&id=Ykruxor10cYC&oi=fnd&pg=PR1&dq=qualitative+inquiry+and+research+design&ots=4bl6oDj1Di&sig=EiKCJBgmGK3-2iBqxKLMJpBv-vE.

———. 2013. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. Sage publications. https://books.google.com/books?hl=en&lr=&id=EbogAQAAQBAJ&oi=fnd&pg=PR1&dq=mixed+methods&ots=caeQsPPBz6&sig=-9LnLIn-LpgEY44cC9hx4vrus0k.

Cross, K. Patricia. 1987. "Teaching for Learning." *AAHE Bulletin* 39 (8). ERIC: n8. http://eric.ed.gov/?id=ED283446.

Dennen, Vanessa Paz. 2004. "Cognitive Apprenticeship in Educational Practice: Research on Scaffolding, Modeling, Mentoring, and Coaching as Instructional Strategies." *Handbook of Research on Educational Communications and Technology* 2. Lawrence Erlbaum Associates Mahwah, NJ: 813–28. http://faculty.weber.edu/eamsel/Classes/Projects%20and%20Research%20(4800)/Teaching%20and%20Learning/Dennen%20(2004).pdf.

Duval-Couetil, Nathalie, Teri Reed-Rhoads, and Shiva Haghighi. 2011. "The Engineering Entrepreneurship Survey: An Assessment Instrument to Examine Engineering Student Involvement in Entrepreneurship Education." *The Journal of Engineering Entrepreneurship* 2 (2): 35–56. http://www.ingentaconnect.com/content/jeen/jeen/2011/00000002/00000002/art00003.

———. 2012. "Engineering Students and Entrepreneurship Education: Involvement, Attitudes and Outcomes." *International Journal of Engineering Education* 28 (2): 425. https://pathways.epicenterusa.org/resources/41/download/Engeering_Students_and_EShip_Education_-_Involvement_Attitudes_and_Outcomes.pdf.

"Education for the 21st Century." n.d. UNESCO. Accessed July 2015. http://en.unesco.org/.

Emmerson, G. S. 1973. *Engineering Education: A Social History*. David & Charles. https://books.google.com/books?id=2olRAAAAMAAJ.

Erickson, S. C. 1984. "The Essence of Good Teaching: Helping Students Learn and Remember What They Learn." San Francisco: Jossey-Bass.

Ernst, E. W. 1996. "Workplace Changes and Engineering Education Reform." In *Frontiers in Education Conference, 1996. FIE '96. 26th Annual Conference., Proceedings of*, 2:882–85 vol.2. ieeexplore.ieee.org. https://doi.org/10.1109/FIE.1996.573092.

Fulcher, Keston H. 2008. "Curiosity: A Link to Assessing Lifelong Learning." *Assessment Update* 20 (2). Jossey Bass. Available from John Wiley & Sons, Inc. 111 River Street, Hoboken, NJ 07030-5774. Tel: 800-825-7550; Tel: 201-748-6645; Fax: 201-748-6021; e-mail: subinfo@wiley.com; Web site: http://www3.interscience.wiley.com/jhome/86511121: 5–7. https://doi.org/10.1002/au.202.

Fulcher, K. H. 2004. "Towards Measuring Lifelong Learning: The Curiosity Index." https://books.google.com/books?id=XQMUtwAACAAJ.

Gross, David, Evava S. Pietri, Gordon Anderson, Karin Moyano-Camihort, and Mark J. Graham. 2015. "Increased Preclass Preparation Underlies Student Outcome Improvement in the Flipped Classroom." *CBE Life Sciences Education* 14 (4). https://doi.org/10.1187/cbe.15-02-0040.

Hennessy, Sara. 1993. "Situated Cognition and Cognitive Apprenticeship: Implications for Classroom Learning." *Studies in Science Education* 22 (1): 1–41. https://doi.org/10.1080/03057269308560019.

Kriewall, Timothy J., and Kristen Mekemson. 2010. "Instilling the Entrepreneurial Mindset into Engineering Undergraduates." *The Journal of Engineering Entrepreneurship* 1 (1): 5–19.

Matthew, Victoria, Thema Monroe-White, Ari Turrentine, Angela Shartrand, and Amit Jariwala. n.d. "Integrating Entrepreneurship into Capstone Design: An Exploration of Faculty Perceptions and Practices." In *2015 ASEE Annual Conference and Exposition Proceedings*, 26.990.1–26.990.30. ASEE Conferences. https://doi.org/10.18260/p.24327.

McGivern, J. G. 1960. *First Hundred Years of Engineering Education in the United States (1807-1907)*. Gonzaga University Press. https://books.google.com/books?id=APvvAAAAIAAJ.

Mitterer, John, and Mitterer John. 2006. "Cognitive Apprenticeship, Hybrid Learning, and Large Class Instruction." *PsycEXTRA Dataset*. https://doi.org/10.1037/e669362012-017.

Nodoushan, S., and M. Ali. 2009. "The Shaffer–Gee Perspective: Can Epistemic Games Serve Education?" *Teaching and Teacher Education* 25 (6): 897–901. https://doi.org/10.1016/j.tate.2009.01.013.

Oman, Sarah K., Irem Y. Tumer, Kris Wood, and Carolyn Seepersad. 2012. "A Comparison of Creativity and Innovation Metrics and Sample Validation through in-Class Design Projects." *Research in Engineering Design* 24 (1). Springer-Verlag: 65–92. https://doi.org/10.1007/s00163-012-0138-9.

Pieters, Jules M., and Henneke F. M. de Bruijn. 1992. "Learning Environments for Cognitive Apprenticeship: From Experience to Expertise." In *Cognitive Tools for Learning*, 241–48. NATO ASI Series. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-77222-1_19.

Poitras, Gérard, and Eric Poitras. 2011. "A Cognitive Apprenticeship Approach to Engineering Education: The Role of Learning Styles." *Engineering Education* 6 (1). Routledge: 62–72. https://doi.org/10.11120/ened.2011.06010062.

Prince, Michael. 2004. "Does Active Learning Work? A Review of the Research." *Journal of Engineering Education-Washington-* 93. American Society for Engineering Education: 223–32. http://www.rlillo.educsalud.cl/Capac_Docente_BecadosAPS/Metodologias/Aprendizaje%20Activo%20Prince_2004.pdf.

Saavedra, Anna Rosefsky, and V. D. Opfer. 2012. "Learning 21st-Century Skills Requires 21st-Century Teaching." *Phi Delta Kappan*.

Shuman, Larry J., Mary Besterfield-Sacre, and Jack McGourty. 2005. "The ABET 'professional skills'—Can They Be Taught? Can They Be Assessed?" *Journal of Engineering Education* 94 (1). Wiley Online Library: 41–55. http://onlinelibrary.wiley.com.libproxy.clemson.edu/doi/10.1002/j.2168-9830.2005.tb00828.x/abstract.

Stalmeijer, Renée E. 2015. "When I Say … Cognitive Apprenticeship." *Medical Education* 49 (4): 355–56. https://doi.org/10.1111/medu.12630.

Walker, Erica B. 2016. "Opportunities for Innovation: Game-Based Learning in an Engineering Senior Design Course." PhD, Clemson University. http://tigerprints.clemson.edu/all_dissertations/1805/.

Wheatley, Walter J. 1999. "Enhancing the Effectiveness and Excitement of Management Education: A Collection of Experiential Exercises Derived from Children's Games." *Simulation & Gaming* 30 (2). Sage Publications: 181–98. http://sag.sagepub.com/content/30/2/181.short.

Williams, Julia. 2015. "KEEN Webinar: The Curiosity Index | KEEN Blog." Online, March 2. http://keennetwork.org/blog/?p=2458.

AUTHORS

Erica Walker has a diverse background in visual communications that includes feature film production, web design and development, print buying, marketing, and graphic design for print. As a faculty member in the Department of Graphic Communications at Clemson University, Walker teaches courses in Photography, Video, Web Development, and Entrepreneurship. She received her PhD in Curriculum and Instruction from Clemson and has since developed and co-developed eight new courses, including several cross-disciplinary courses. Walker is interested in many areas of research including curriculum development, the entrepreneurial mindset, Game-Based Learning, applications of artificial intelligence, and color management for brands.

John DesJardins is the Hambright Leadership associate professor in Bioengineering at Clemson University and the director of the Frank H. Stelling and C. Dayton Riddle Orthopaedic Education and Research Laboratory at CUBEInC. He has co-authored over 300 peer-reviewed conference or journal publications in the areas of biomechanics, tribology, engineering education and implant design. He actively engages in many professional societies and review panels, including BMES, ASEE, VentureWell, ORS, NIH and NSF. He has contributed or led multidisciplinary research teams that have been funded through NASA, DoT, NIH, DoD, NSF, the Gates Foundation, and numerous biomedical industry contracts. His work has been featured on TEDx and The Academic Minute on NPR. He directs the bioengineering senior capstone design program, leads a bioengineering study abroad program in bioethics to Spain each summer, and he directs the NIH funded Clemson-GHS summer needs-finding experience for bioengineering students called DeFINE.

Bre Przestrzelski is a new post-doctoral research associate at the University of San Diego (USD), where she innovatively integrates social justice into the traditional engineering curriculum. Before joining USD in August 2017, Bre spent nine years at Clemson University, where she was a three-time graduate of the bioengineering program (BS, MS, and PhD), founder of The Design & Entrepreneurship Network (DEN), and Division I rower. In her spare time, Bre coaches a global community of learners through IDEO U, loves her Hemingway cat, and fails miserably at cooking.