2018 ASEE Annual Conference & Exposition
June 24–27, 2018
Salt Palace Convention Center
Salt Lake City, UT

Paper ID #21181

Use of Active Learning and the Design Thinking Process to Drive Creative Sustainable Engineering Design Solutions

Dr. Renee M. Clark, University of Pittsburgh

Renee M. Clark serves as research assistant professor focusing on assessment and evaluation within the University of Pittsburgh's Swanson School of Engineering and its Engineering Education Research Center (EERC), where her interests center on active and experiential learning as well as learner-centered instruction. She has 25 years of experience as an engineer and analyst, having worked most recently for Walgreens and General Motors/Delphi Automotive in the areas of data analysis, IT, and manufacturing. She received her PhD in Industrial Engineering from the University of Pittsburgh and her MS in Mechanical Engineering from Case Western while working for Delphi. She completed her postdoctoral studies in engineering education at the University of Pittsburgh.

Ms. Lisa Marie Stabryla, University of Pittsburgh

Lisa Stabryla is a mid-career PhD student, a 2017 National Defense Science and Engineering Graduate (NDSEG) fellow, and an aspiring faculty member. In the Civil and Environmental Engineering Department at the University of Pittsburgh, she is pursuing research questions related to the sustainable design of nanomaterials. She is also enrolled in the teacher-training program through the NSF-funded Center for the Integration of Research, Teaching, and Learning (CIRTL) Network to gain the knowledge and skills to be an effective teacher and implement research-based best practices in different learning environments.

Dr. Leanne M. Gilbertson, University of Pittsburgh

Use of Active Learning and the Design Thinking Process to Drive Creative Sustainable Engineering Design Solutions

Abstract

In a *Design for the Environment* upper-level undergraduate engineering course, the design thinking process for creative problem solving as well as a host of in-class, active-learning design sessions were implemented, with the objective of enhancing the creativity of design solutions to real-world sustainability challenges. The literature indicates the need for enhanced engineering curricula that fosters students' creative skills, since development of this skillset, and divergent thinking skills in particular, are often missing from engineering courses. The instructor implemented this approach during the fall 2017 after attending Stanford's *d.school* Teaching and Learning Studio, a workshop that engages higher education instructors in the design thinking process and supports them in developing associated active learning exercises. Design thinking is a five-stage process that guides students in empathizing with the user's needs, defining the problem, brainstorming solutions, creating simple solution prototypes, and testing the prototypes, iteratively ideating, prototyping, and testing to reach the best solution. This paper describes the development of the course enhancements to infuse design thinking throughout, including new in-class design activities. This paper also describes the associated assessment plan for evaluating students' creativity and execution of the design thinking process, perceptions of the active learning and their own creativity, practice of sustainability in their design solutions, oral presentation skills, and other developmental outcomes related to their engineering careers. Some initial results are presented, including the very preliminary result that the use of design thinking may be associated with increased performance on the semester-long design solutions, including a boost in novelty.

The course enhancements included new group, in-class design exercises related to the sustainability concepts of toxicity and risk, life cycle assessment, systems thinking, and design for disassembly, which were added to modules on biomimicry and design for the developing world from the previous year. The instructor promoted the use of various maker spaces within the engineering school for prototyping of solutions. The design sessions were preceded by primers on the content areas, which were also conducted using active-learning techniques such as think-pair-share. The assessment analyst utilized the COPUS observation protocol to observe the classroom and quantify the degree of active learning and other interactive practices.

The assessment plan consists of a host of methods, including 1) pre, midterm, and post-course surveys, 2) an end-of-term focus group, 3) a project presentation with a panel of judges, and 4) midterm and end-of-term student written reflections on their application of the design thinking process. The post-course survey included questions from the StRIP (Student Response to Instructional Practices) survey, a new rigorously-developed survey for measuring students' perspectives on and responses to active learning. Rubrics and measurement matrices from the literature were adapted to guide assessment of the students' presentations and design solutions, including the Oral Communications VALUE rubric, Watson et al.'s sustainable design rubric, Nagel et al.'s design process rubric, and the creativity-measurement rubrics and matrices of Genco et al. and Moss.

1. Background and Relevant Literature

Design for the Environment is a class of approximately 30 undergraduate engineering students and is comprised of juniors and seniors from all disciplines. The class size is maintained at a maximum of 30, in part so the school's maker spaces can be utilized for in-class activities and prototyping. The course covers fundamental concepts, including sustainability design frameworks, the design process and the role of innovation, life cycle assessment, and toxicity and risk, as well as focused case studies on topics such as energy, water, agriculture, and nanotechnology.

Significant enhancements were made to the course in the fall 2017 semester. Modifications were motivated by (i) student feedback that highlighted the success of three active-learning modules and the demand for more hands-on innovation and design activities and (ii) the instructor's experience at Stanford's *d-school* Teaching and Learning Studio during the summer of 2017. Formative feedback was collected from a student focus group at the end of the fall 2016 semester. When students were asked during the focus group what would aid their learning process in the course, they overwhelming responded with more in-class activities in the Makerspace. Specific student comments included, "more time spent in the Makerspace lab doing hands-on activities," "more interactive lectures, as they are fun and good for the learning process," "incorporation of more small design challenges in mixed groups," and "more examples of current products to help show what we're learning." A student stated, "I loved the group activities, especially in the Makerspace lab! It allowed us to try things out, which was helpful and engaging. It was helpful because we were able to apply the design process by gathering needed information, work in groups, brainstorm, etc." Another student stated, "Presenting information through multiple mediums like videos, readings, discussions, and Power Point slides made the information more interesting and memorable rather than all through lecturing."

In addition, students were asked during the focus group to compare and contrast their understanding of two groups of concepts covered in the class. Group 1 included the topics of innovation and the design process, Biomimicry, and design for the developing world, all of which involved an integrated content and active-learning module. Group 2 included the topics of toxicity and risk, life cycle assessment, and waste management and design for disassembly, which included content modules only. *Students were not primed with the information distinguishing these two groups* (i.e., inclusion or not of an active learning component). The majority of respondents reported having a better understanding of the group 1 topics, noting that they enjoyed the activities and videos associated with the topics in group 1 that reinforced the lecture content. Regarding group 2, one student described that "lecture was 'it' on these topics," and many reported difficulties in paying attention to the slides for the full class time. Another student explained, "With the group 1 topics, we did more activities in the Makerspace lab and during class. All topics had activities. The group 2 topics were covered through the homework assignments; however, we did not have good examples to follow for this. I would have liked an in-class activity on design for disassembly." Another student had similar comments - "The life cycle assessment readings were detailed and dry. An LCA in-class activity would be better than the readings." Similar comments were made for toxicity and risk, with students requesting more examples to replace some of the readings and lecture.

Integration of the *design thinking process* to the course was intended to serve as a mechanism for enhancing student learning and creativity in the course, and it also aligned with the students' comments during the focus group. The design thinking process is a five-stage, iterative needs-driven process consisting of the steps of empathizing with the customer, defining the problem, ideating or brainstorming solutions, low-resolution prototyping, and testing of the prototype (Hasso Plattner Institute of Design at Stanford). Designers typically iterate on the latter steps to improve upon the solution. Design thinking is therefore a human-centered approach to innovation that integrates human and societal needs with technological and economic feasibility (Design Thinking Thoughts by Tim Brown). Design thinking has become a learning model to develop creativity and innovation in students and to teach creative problem solving with the goal of enhancing creative confidence (Royalty et al., 2014).

With this addition of design thinking to the course in 2017, active learning was incorporated to a greater degree throughout the course, in particular during class time. After mini-lectures, students participated in group-based design sessions and subsequent class discussions in support of developing creative solutions to sustainability design problems using the design thinking process. The theory and experimental research on active learning has established its benefits and effectiveness in regards to problem solving and skills application, conceptual gains, in-class engagement, and exam performance (Chi, 2009; Hake, 1998, Freeman et al., 2014; Wieman, 2014).

In addition to the desirability of active learning, the literature also indicates the need for enhanced engineering curricula that fosters students' creative skills, since development of this skillset, and divergent thinking skills in particular, is often missing from engineering courses (Daly et al., 2014). To assess students' creative skills, we defined creativity as a combination of novelty/originality as well as usefulness/value/feasibility. Multiple other researchers working in the area of education or design, including engineering education, apply this same definition for creativity or innovation, or acknowledge its commonality (Oman et al., 2013; Genco et al., 2012; Chulvi et al., 2012; Sarkar & Chakrabarti, 2011; Moss, 1966). However, some consider a third dimension for creativity – that of wholeness, which involves aesthetics and elegance (O'Quin & Besemer, 1989; Mishra et al., 2013; Henriksen et al., 2015). Although we could appreciate this third dimension, it was not a specific requirement for our students' designs, and so novelty and usefulness were the final requirements for our students' designs of their sustainable solutions.

The importance of educating designers early on sustainability is emphasized by proponents of the circular economy, which reduces supply risk by keeping materials in circulation via recycling and disassembly (Andrews, 2015). The literature has highlighted the promise inherent in applying design thinking to complex environmental and social problems (Westley et al., 2011; Brown & Wyatt, 2010). Indeed, design thinking can transform societies, in particular related to sustainability challenges, and it is increasingly being applied in new arenas, including social, societal, and environmental problem solving (Chick & Micklethwaite, 2011). Businesses were first to embrace design thinking; however, nonprofits are starting to use design thinking for better solutions to social problems (Brown & Wyatt, 2010). For example, design thinking was applied by the Positive Deviance Initiative to decrease malnutrition among children in Vietnamese villages (Brown & Wyatt, 2010). Tim Brown, CEO of IDEO and high-profile advocate of design thinking, has called for the application of design thinking to some of the world's greatest challenges, including serving the needs of the poor and designing healthy and profitable food systems (Design Thinking Thoughts by Tim Brown).

2. Methods

The learning and performance objectives related to the course enhancements were as follows: 1) enhance students' creativity and innovation, 2) enhance their practice of sustainable engineering, including for their future careers, and 3) enhance oral presentation skills. The instructional strategies and objectives were as follows: 1) increase the use of active learning in class, and 2) introduce design thinking for creative and innovative solutions to the sustainability design challenges. These challenges were semester-long projects in which student teams were expected to incorporate the design thinking process as well as course content. We next discuss implementation of the instructional strategies – active learning and design thinking– and will later discuss the assessment methods.

Methods: Re-Design of Class Time

Table 1 outlines the use of class time for the first and second year in which the instructor taught the course. As shown here, several active-learning exercises that consisted of group-based, in-class design sessions were added, and these related to the topics of design thinking, toxicity and risk, product life cycle and systems thinking, life cycle assessment, end-of-life management and design for disassembly, and energy in relation to sustainability. This increased the amount of in-class active learning in the course, which was motivated by the feedback from the student focus group the previous year. By way of example, we will later provide development details on two of these modules – toxicity and risk and design for disassembly.

Typically, two days were spent on each topic, with a mix of content delivery via traditional methods, active learning components, and a reading or other assignment completed at home. This diversity of instruction gave students the chance to experience multiple learning modalities and learn through different senses to better retain information. In addition to shifts in how the content was packaged and delivered, the classroom space changed. The classroom was moved from a stadium-style room that was designed for didactic lecture-style teaching to a more collaborative, flexible classroom that included movable tables and whiteboards on all walls of the room.

Table 1. Use of Class Time (2016 vs. 2017)

Topic	2016			2017		
	In-Class Discussion of Reading	Lecture	Active Learning Component	In-Class Discussion of Reading[a]	Lecture	Active Learning Component
Innovation and the Design Process	✓	✓	✓			
Human Centered Design	✓	✓				
Introduction to Design Thinking (5 stages)				✓	✓	✓
Sustainability Design Frameworks	✓	✓			✓	
Biomimicry	✓	✓	✓		✓	✓
Toxicity and Risk	✓	✓			✓	✓
Product Life Cycle, Systems Thinking	✓	✓		✓	✓	✓
Life Cycle Assessment	✓	✓			✓	✓
Multi-Criteria Decision Analysis		✓			✓	
Durability, Waste Management, End-of-Life, Design for Disassembly	✓	✓			✓	✓
Design for the Developing World	✓	✓	✓	✓	✓	✓
Sustainability Case Study: Water	✓	✓		✓	✓	
Sustainability Case Study: Energy	✓	✓		✓	✓	✓
Sustainability Case Study: Agriculture		✓	✓		✓	✓
Sustainability Case Study: Nanotechnology	✓	✓		✓	✓	
Project Feedback Opportunities						
Prototyping work days	✓			✓		
One-on-one meeting with instructor and TA	✓			✓		
Interim presentation	✓			✓		
Practice presentation	✓			✓		
Final presentation	✓			✓		

[a]Many of the readings were shifted to out-of-class assignments in 2017. [b]The topics of Innovation, the Design Process and Human Centered Design were combined into a 2-week Design Thinking module in 2017.

Class time was also allotted for students to work in their project groups to apply relevant concepts to the development of a sustainable solution to the semester-long engineering design challenge. The project topics during both the 2016 and 2017 semesters included the following: 1) Built environment (i.e., space transformation and integration of physical structures and the environment), 2) Agriculture (i.e., water use, food waste, and friendly fertilizers), 3) Natural disaster relief, and 4) Recycling.

The instructors provided formative feedback on this project development, including on four written deliverables at progressive stages of development as well as during a one-on-one group meeting, an interim presentation, a practice final presentation, and a formal final presentation to an external panel of judges, as outlined in Table 1. An additional teaching assistant in the fall 2017 semester (for a total of two) allowed for more formative feedback for students on their design projects as compared to 2016. More timely and structured feedback was provided from the teaching assistant and the instructor. Expectations were also more clearly communicated up front, a result of the second time of teaching the course.

Methods: Examples of New Active Learning Modules and Exercises

The instructor and teaching assistant developed new sustainability-based modules containing interactive, hands-on exercises, in which the students could actively apply the design thinking process and/or engage with course content during class. The instructor had received both internal and external grants for the development of these modules. After returning from Stanford's *d.school* Teaching and Learning Studio, she also designed a new module to introduce the design thinking process to students during the first two weeks of the course. This design thinking module allowed students to experience or "live" the five stages of the design thinking process first-hand.

Design Thinking Process Module

Instruction on design thinking could be a course on its own. However, the instructor had a limited amount of time to lay the foundation for the application of design thinking to students' sustainable design solutions. Given time constraints (of the 75-minute class periods) and the understanding that each design-thinking stage builds upon the others, she knew this foundational instruction had to be both well planned and well executed. This foundational instruction occurred over the course of two weeks (i.e., four class sessions) and focused on fieldwork and debriefing those experiences. Traditional lecture was limited to ten minutes per session, and videos, in-class activities, and discussion augmented the experiences.

The students were informed that the focus was on learning the design thinking process *by doing* (versus lecture) and hence, they might feel uncomfortable at first. For example, their first field work assignment involved working in groups of three to interview at least four people outside the classroom about a particular topic related to life-long learning. This was a twenty-five minute exercise during class time. Upon returning to class, students debriefed on their experiences. Then, during the next class session, they "unpacked" two of their interviews using a POV (point-of-view) statement to frame a design opportunity for the define stage. This led to in-class brainstorming activities for rapid generation of solution ideas in the ideate stage. The third and fourth class session were held in a maker space so students could perform low-tech prototyping and testing with a minimum of three people outside the classroom to receive feedback. After testing, students debriefed on their experiences with this stage and discussed next steps, including the important iterative aspect of the design thinking process and the need to revisit previous stages for design improvements. Laying this design thinking process foundation, the instructor prepared students for the upcoming in-class design sessions as well as their semester sustainability design challenge. This hands-on experience with the process set the stage for the remainder of the semester.

Design for Disassembly Design Exercise

The design-for-disassembly exercise was a 45-minute in-class activity in which groups disassembled obsolete electronic products, including a phone, DVD player, laptop, headphones, and a camera, using a household toolkit. The groups tracked their steps as they disassembled the product, using a stop watch to time each step, ultimately making a brief presentation to the class and submitting their disassembly notes. One of the objectives was for students to think about end-of-life considerations with respect to the initial design of a product. Students categorized the types and recyclability of the materials encountered when disassembling the product, including the sub-materials used for initial assembly, such as adhesives. Timing the process enabled a consideration of both the economic and environmental feasibility of the disassembly process for a given product. During the preceding class session, the activity was situated within the frameworks of the 12 Principles of Green Engineering and Design for Disassembly.

Toxicity and Risk Design Exercise

The idea for the toxicity and risk design activity was inspired by a workshop at the 2017 ACS Green Chemistry and Engineering Conference. The goal of this in-class activity was for students to evaluate the environmental health and safety of two hand lotions to determine which was "greener" based on the hazard level of the ingredients. After an introduction to the activity, students worked in groups to evaluate the physical hazards, human health toxicity, and environmental toxicity of all ingredients in both lotions. They used environmental health and safety data that was compiled by the teaching assistant using the material safety data sheet (MSDS) for each ingredient. In addition to ingredient hazards, students were also prompted to consider other factors in evaluating the products, including cost, quality, and performance. Students defended their choice of the greener product in a presentation to the class.

Methods: Assessment of Student Performance

The assessment plan aligned with the main learning, performance, and instructional objectives associated with the course changes. The students' solution to the semester-long sustainability design challenge was evaluated by the instructor and teaching assistant based on novelty/innovativeness, usefulness, sustainability practices, and use of the design thinking process. To assess these outcomes, a series of rubrics were used, including 1) Creativity-measurement rubrics and matrices of Genco et al. and Moss, 2) Watson et al.'s sustainable design rubric, and 3) Nagel et al.'s design process rubric (Genco et al., 2012; Moss, 1966; Watson et al., 2017; Nagel et al., 2013). Genco et al. and Moss assess creativity on two dimensions – novelty and usefulness/value. The instructor and teaching assistant used these various rubrics to independently grade the design challenge solutions from the fall 2017 course. The average of their scores was used as the final score for each dimension being measured. At this same time, the design solutions from the fall 2016 semester (i.e., before the course changes) were also evaluated using the same rubrics. The order in which the projects were evaluated was randomized, enabling a fair comparison between the two semesters. The instructor taught this course in the fall 2016 without the use of design thinking and associated active-learning activities.

At the end of the semester, students presented their sustainability design solution to a panel of judges. The judges included faculty members with expertise in sustainability as well as other engineering areas, industry professionals, and environmental engineering PhD students/teaching assistants. The judges used a scoring sheet with survey questions to assess the groups based on creativity, sustainable practices, and presentation skills. Since the enhancement of oral presentation skills was a key objective, multiple questions were adapted from the AACU's Oral Communications VALUE rubric (Finley, 2011) for the scoring sheet. The presentation dimensions from the VALUE rubric were transformed into questions on a 1-5 scale.

A written reflective prompt posed at both the midpoint and end of the semester was used to further assess students' execution of the design thinking process. Specifically, the following question was posed to the students: Describe how you have applied or executed the 5-step *Design Thinking Process* (i.e., Empathize, Define, Ideate, Prototype, and Test) in developing a creative solution to the sustainability design challenge in this course. A content analysis of the reflections will be completed by two analysts for reliability (Neuendorf, 2002). Although we are considering the students' reflections as a measurement of performance, we note the fact that the reflections contained self-reported activities.

Methods: Assessment of Student Perspectives

The assessment plan also contained methods to indirectly assess students' achievement of the learning objectives and their perspectives on the course. These methods included pre, midterm, and post-course surveys as well as an end-of-term focus group. The pre-survey was intended to obtain baseline data on students' perceptions of creativity, including their definition of creativity. Students were also asked to provide their definition of creativity on the post-course survey. The project's two analysts independently content-analyzed these creativity definitions; thus, all definitions were double-coded, and consensus was reached on the codes assigned. The first-time inter-rater reliability for this coding, which indicated good agreement beyond chance, was Cohen's $\kappa = 0.73$ (Norusis, 2005).

The midterm survey was primarily intended to elicit formative feedback for the instructor. For example, two of the midterm questions were as follows:

> 1. List the in-class activities, assignments, lectures, projects, etc. that are most positively impacting your use or application of the *design thinking process* and a short description as to why.
>
> 2. Are there any elements missing from the course that you think would benefit your application of the *design thinking process*? Please discuss so your instructor can potentially include them.

Several of the survey questions, including the above midterm questions, were adapted from questions asked by Daly and colleagues in their work on creativity in engineering courses (Daly et al., 2014). The post-course survey included questions from the StRIP (Student Response to Instructional Practices) survey, a new rigorous survey for measuring students' perspectives on and responses to active learning (DeMonbrun et al., 2017). The StRIP measures four factors or dimensions of the students' responses - Value, Positivity, Participation, and Distraction. The students used an instructor-assigned numerical code when completing the surveys and written reflections so their responses could be linked and remain anonymous to the analysts. The focus group questions are shown in the Appendix in Table 6, and various open-ended survey questions aligned with these for triangulation of the data.

Methods: Classroom Observation

To assess the amount of active learning and student-instructor interactions during class time, the assessment analyst observed multiple class sessions using the COPUS, or Classroom Observation Protocol for Undergraduate STEM (Smith et al., 2013). Four (i.e., two sets of) class sessions were observed. Each set consisted of one session in which lecture/video content was presented, with simple active learning and whole-class discussion. The other session in the set involved active group work in small teams to generate ideas or solutions to a sustainability problem related to the class topic. With the COPUS, the total class period was divided into a series of two-minute observation segments. For example, this 75-minute class had 38 observation segments. In each segment, the activities of the students and instructor (listed in the protocol) were recorded when observed. Thus, the percentage of segments with activities such as student questions or responses, lecture, active group work, and instructor circulation among the students to coach and assist could be calculated. The assessment analyst had used the COPUS protocol in previous research and evaluation activities and achieved inter-rater reliability scores of $\kappa = 0.83$ and $\kappa = 0.96$ with other analysts, indicating her reliability in terms of strong agreement with other analysts (Norusis, 2005).

3. Preliminary Results

Results: Pre and Post Surveys: Student Perspectives

We achieved an approximate 80% response rate on each of the pre and post course surveys. The pre-survey enabled baseline data on students' perceptions of creativity, including their definitions of creativity and beliefs about their ability to "learn" to be creative. In defining creativity on the pre-survey, 80% of the respondents (n=20) identified the concept of novelty, or originality or newness, as part of their definitions. Only 15% included usefulness (i.e., value, feasibility, good solution) as part of their definition. Twenty-five percent (25%) associated "independent thought or action" with creativity, and 25% mentioned a product or output of some type as part of their definitions. Interestingly, on the post survey, the distribution of responses was approximately the same for the respondents (n=20) when defining creativity – 75% identified novelty, 10% identified usefulness, 30% identified independent thought or action, and 15% mentioned a product or output in their definition. For these percentages, we included only those students who provided both pre and post responses. Thus, the students overwhelmingly associated novelty/originality with creativity and to a much lesser extent usefulness, although both are part of the definition of creativity used by many educators.

Sixty-seven percent (67%) of pre-survey respondents agreed or strongly agreed that a person could learn to be creative. However, on the post-survey, this percentage jumped to 81%, possibly suggesting the impact of the course on students' assessment of their creativity and ability with creativity. A paired-sample *t* test showed a statistically significant difference between the pre and post responses ($p = 0.035$), and the non-parametric test version (i.e., related-samples Wilcoxon signed rank test) corroborated this result ($p = 0.038$). The effect size, which is a measure of practical significance, was medium with Glass' delta = 0.50 (Lakens, 2013). One of the students on the post-survey said, "*I would define creativity as something that can be learned now. I didn't think I was creative before I came into this class and now I know by going through the design steps that I can think of anything and create anything.*"

Additional indirect assessment results from the post-survey are shown in Table 2. All scales are from 1 to 5, corresponding to very small, small, medium, large, and very large. Notable percentages of students rated their development related to design thinking and future career skills as occurring to a large to very large degree (i.e., 75% and 67%, respectively) as a result of the course. The majority of students (58%) felt this way about their creative functioning as a result of the course. Students' assessment of the development of their oral presentation skills was a surprising outcome, given the many opportunities they had to present their work throughout the semester. In analyzing this, the instructor may incorporate an evaluation and feedback mechanism into the various presentations throughout the semester to enhance this outcome.

Table 2: Post-Course Survey Results

Rate the degree to which… (n=24)	Large to Very Large Degree	Very Small to Medium Degree
Your use of the design thinking process improved or developed as a result of this course.	75%	25%
Your ability to function creatively increased or developed as a result of this course.	58%	42%
You believe the content and skills you learned in this course will be applicable to your future career.	67%	33%
You believe your oral presentation skills improved or developed as a result of your work in this course	13%	87%

Results: StRIP Survey

The favorable results in Table 2 coincided with favorable results from the StRIP survey, in which students frequently valued, felt positive towards, participated in, and remained focused (i.e., did not become distracted) during the in-class active learning exercises. The average results by dimension or factor are shown in Table 3. On the 1-5 frequency scale, with a score of 1 corresponding to almost never, 4 corresponding to often and 5 corresponding to very often, the students frequently perceived value in the in-class activities, with average scores of approximately 4.00 for the three questions comprising the Value (*Val*) dimension. The Positivity dimension (*Pos*), with average scores between 4.04 and 4.71, demonstrated frequent positive feelings towards the instructor and the in-class activities. Students reported frequently participating seriously in the activities, as evident in the average scores for the questions in the

Participation (*Par*) dimension. Finally, students reported being infrequently distracted during the activities, with average scores between 1.22 and 2.42 for the Distraction (*Dis*) dimension. The StRIP results were useful because they demonstrated that the active learning was very well accepted by the students, given the many item averages well above the middle scale value of 3.00 (for positively worded items) and the many averages well below 3.00 (for negatively-worded items). In summary, students' responses to the in-class activities were highly favorable. These results are encouraging to faculty considering this type of instruction with design thinking.

Table 3: StRIP Survey: Student Responses

In this course, when the instructor asked you to do an in-class activity (e.g., solve problems in a group during class or discuss concepts with classmates), how often did you react in the following ways?	**Dim**	**Average**	**S**	**n**
I felt the effort it took to do the activity was worthwhile.	Val	4.04	0.75	24
I saw the value in the activity.		4.04	0.62	24
I felt the time used for the activity was beneficial.		4.00	0.78	24
I felt positively towards the instructor.	Pos	4.54	0.59	24
I felt the instructor had my best interests in mind.		4.71	0.46	24
I enjoyed the activity.		4.04	0.81	24
I did not actually participate in the activity.	Par	1.13	0.45	24
I gave the activity minimal effort.		1.46	0.72	24
I tried my hardest to do a good job.		4.29	0.81	24
I participated actively (or attempted to).		4.46	0.83	24
I distracted my peers during the activity.	Dis	1.50	0.88	24
I pretended to participate in the activity.		1.22	0.42	23
I talked with classmates about other topics besides the activity.		2.42	1.18	24
I surfed the internet, checked social media, or did something else instead of doing the activity.		1.58	0.88	24
I rushed through the activity.		1.88	0.85	24

Response Scale: 1 = almost never (<10% of the time); 2 = seldom (~30% of the time); 3 = sometimes (~50% of the time); 4 = often (~70% of the time); 5 = very often (>90% of the time).

Results: Project Scores

The group-based sustainability design projects were evaluated by the instructor and teaching assistant based on four dimensions - novelty/innovativeness, usefulness, sustainability practices, and use of design thinking. Each dimension had a different number of possible points given its particular rubric. Each dimension score was therefore normalized to one by dividing it by the number of possible points. Combining the dimensions, the maximum project score for each group was four. In comparing the results of the projects before the use of design thinking (2016) and with the use of design thinking (2017), the 2017 semester had the higher average adjusted scores, as shown in Table 4. Given the small sample sizes, the non-parametric version of ANCOVA (i.e., Quade's test) was used, with the group's average pre-course GPA serving as the covariate, or control, variable (Quade, 1967; Lawson, 1983). Adjusted means are calculated during an ANCOVA to control for the covariates (Norusis, 2005). As shown in Table 4, the difference was statistically significant ($p = 0.049$) when considering all four dimensions (i.e., novelty/ innovativeness, usefulness, sustainability practices, and use of design thinking). In addition, the effect size, a measure of practical significance, was large in this case, with Hedge's g=0.95 (Lakens, 2013). Hedge's g is often used when the sample sizes are small. This suggests (very preliminarily) that the use of design thinking may be associated with enhanced overall performance on these sustainability design solutions (both practically and statistically). We also examined the results of just the novelty and usefulness dimensions, which relate to creativity. Although non-significant, there was a rise in the novelty score during the semester with design thinking, with a medium effect size (g=0.75). This rise occurred without negatively impacting usefulness or feasibility, which had a small effect size (g=0.40) in favor of design thinking. Assessing creativity in this manner (i.e., separately analyzing novelty and usefulness) has been done by others working in the field of engineering education (Genco et al., 2012). Additional future data will enable us to draw more definitive conclusions regarding the association of design thinking with novelty, usefulness, and all dimensions being measured within these sustainability design challenges. We plan to continue data collection in future semesters of the course.

Table 4: Project Comparison: Before vs. With Design Thinking

Adjusted Means	**Before Design Thinking (n=7)**	**With Design Thinking (n=8)**	**Quade's Test p**	**Hedge's g**
All four rubric dimensions (/4)	2.30 *(0.57)*	2.86 *(0.57)*	0.049	0.95
Novelty dimension (/1)	0.58 *(0.13)*	0.67 *(0.13)*	0.173	0.75
Usefulness dimension (/1)	0.73 *(0.23)*	0.82 *(0.23)*	0.695	0.40

Note: standard deviations are shown in parentheses.

Results: Classroom Observation

Upon combining the COPUS observation data from the four 75-minute class sessions, the classroom could be characterized as a mixture of 1) lecture/video-based instruction with simple, individual active learning (11% of segments), whole-class discussion (6%), and question & answer interaction, and 2) small-group work (25% of segments) to address a sustainability problem, as shown in Table 5. The instructor circulated and had one-on-one discussions with students during the group work (18%-24% of segments). This was a good use of instructional time because of the personalized interaction with students in support of their creative problem-solving. In general, the classroom environment was very interactive and responsive, characterized by frequent instructor-initiated questions, including questions to check for progress or issues (36% of segments), as well as students' responses to content-related questions (24% of segments). Thus, the class sessions were both active and interactive, with discussions occurring among students as well as between the students and instructor. The observed percentages of the relevant activities from the COPUS protocol are summarized in Table 5.

Table 5: Observed COPUS Percentages

COPUS Code	Percentage of Observation Segments	COPUS Code	Percentage of Observation Segments
Student Practices		***Instructor Practices***	
L – Listening	51%	Lec – Lecture	23%
Ind – Individual active work	11%	PQ – Poses question	36%
OG – Group active work	25%	MG – Moves throughout room	24%
AnQ – Answers question	24%	1to1 – One-on-one discussion with students	18%
SQ – Asks question	11%	D/V – Video instruction	18%
WC – Whole class discussion	6%		
SP – Presentation	7%		

4. Discussion and Conclusions

In this paper, we have described enhancements to a *Design for the Environment* undergraduate course. The associated learning and performance objectives were to enhance students' creativity and innovation, their practice of sustainable engineering, and their oral presentation skills. The instructional objectives and strategies were to increase the use of active learning during class and introduce design thinking for creative and innovative solutions to the sustainability challenges. As part of these enhancements, new sustainability-based modules with design exercises were implemented, in which the students actively applied the design thinking process during class. This paper also described the assessment plan aligned with these new objectives. It consisted of pre, midterm, and post-course surveys; an end-of-term focus group; and midterm and end-of-term written reflections on students' application of the design thinking process. The post-course survey also included questions from the StRIP survey to assess students' responses to the active learning. A series of rubrics was adapted from the literature to enable the instructor and teaching assistant to assess sustainability practices, creativity, and use of design thinking in the students' semester design projects. Based on the preliminary assessment results presented, the active learning was very well accepted by the students. Notable percentages of students also assessed their development related to design thinking, creativity, and future career skills highly. There was also a statistically significant increase from the start to the end of the course in students' beliefs that they could learn to be creative. Observation of the classroom revealed a highly active and interactive environment. Although the sustainability design solution results are very preliminary at this point given the small sample sizes (thereby leading to a small limitation of this paper), the use of design thinking may be associated with increased performance on these semester-long design projects, including from a creativity perspective. The collection of future data in the course, which is planned for fall 2018, will enable us to draw more definitive conclusions regarding the association of design thinking with novelty, usefulness, and all dimensions being measured. Our future publications will also more fully describe our assessment results.

From the instructor and teaching assistant's perspective, the initial hands-on experience with the design thinking process during the first two weeks set the stage for the remainder of the semester. The instructor observed a comfortable environment and culture in the class, with participation much improved in 2017 versus in 2016 in terms of responses to questions and ready completion of in-class activities. The classroom space, which consisted of movable group tables and seats and whiteboard walls, was very important to the success of the in-class activities. The instructor plans to deliver the course going forward using the design thinking process and the in-class design activities. She noticed a positive shift in the quality and professionalism of the sustainability design challenge presentations in 2017 (versus 2016).

The instructor's thoughts for enhancements going forward include opening the course to graduate students, in part to infuse professional or more experienced/mature perspectives into the group activities and designs. In addition, she would like to enhance the diversity of the students' majors in the course to include engineering as well as non-engineering majors. The instructor would also like to obtain more projects from companies or outside sources, such as local farmers. This would provide a real-life context and purpose for the work and enable students to obtain guidance from professionals. Several of the groups had the advantage of working with a community advocate who connected the groups with the particular neighborhoods where they worked on their sustainable solutions.

Appendix

Table 6: Focus Group Questions

Describe any changes in your perceived creativity that you feel are a direct result of this course.
Can you tell me about a specific experience in this course where your *design-thinking process* skills improved?
What have you learned or been exposed to in this course that will enhance how you practice sustainable engineering in your future career?
To what extent do you believe you will apply or practice the knowledge and skills gained from this course in your future engineering careers?
What impact did the in-class activities in this course have on your learning or development, and what is your perspective on their use?
What changes could be made to enhance the use of activities or active learning in this course? (Note: active learning is anything students are asked to do in class besides listening to lecture and taking notes).
What do you think helped most in this course to develop your *design-thinking process* skills?
Consider yourselves as advisors to the next group of students who will take this course. How would you describe or characterize this course to the next group of students?
What are your suggestions for items that the instructor could do differently to enhance learning in this course?

References

Andrews, D. (2015). The circular economy, design thinking and education for sustainability. *Local Economy*, *30*(3), 305-315.

Brown, T., & Wyatt, J. (2010). Design thinking for social innovation. *Stanford Social Innovation Review,* 31-35.

Chi, M. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science*, *1*(1), 73-105.

Chick, A., & Micklethwaite, P. (2011). *Design for sustainable change: how design and designers can drive the sustainability agenda*. Lausanne, Switzerland: AVA publishing SA, 6-7, 37.

Chulvi, V., Mulet, E., Chakrabarti, A., López-Mesa, B., & González-Cruz, C. (2012). Comparison of the degree of creativity in the design outcomes using different design methods. *Journal of Engineering Design*, *23*(4), 241-269.

Daly, S., Mosyjowski, E., & Seifert, C. (2014). Teaching creativity in engineering courses. *Journal of Engineering Education*, *103*(3), 417-449.

DeMonbrun, M., Finelli, C., Prince, M., Borrego, M., Shekhar, P., Henderson, C., & Waters, C. (2017). Creating an instrument to measure student response to instructional practices. *Journal of Engineering Education*, *106*(2), 273-298.

Design Thinking Thoughts by Tim Brown. Retrieved from https://designthinking.ideo.com on October 9, 2017.

Finley, A. (2011). How reliable are the VALUE rubrics? *Peer Review*, *13*(4), 31-33.

Freeman, S., Eddy, S., McDonough, M., Smith, M., Okoroafor, N., Jordt, H., & Wenderoth, M. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of National Academy of Science*, *111*(23), 1-6.

Genco, N., Hölttä-Otto, K., & Seepersad, C. (2012). An experimental investigation of the innovation capabilities of undergraduate engineering students. *Journal of Engineering Education*, *101*(1), 60-81.

Hake, R. (1998). Interactive engagement vs. traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64-74.

Henriksen, D., Mishra, P., & Mehta, R. (2015). Novel, effective, whole: Toward a NEW framework for evaluations of creative products. *Journal of Technology and Teacher Education*, *23*(3), 455-478.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*, 1-12.

Lawson, A. (1983). Rank analysis of covariance: alternative approaches. *The Statistician*, *32*(3), 331-337.

Mishra, P., & Henriksen, D., & the Deep-Play Research Group. (2013). A NEW approach to defining and measuring creativity: Rethinking technology & creativity in the 21st century. *TechTrends*, 57(5), 10-13.

Moss Jr, J. (1966). Measuring Creative Abilities in Junior High School Industrial Arts. Washington, DC: *American Council on Industrial Arts Teacher Education*.

Nagel, R., Pierrakos, O., & Nagel, J. (2013). A versatile guide and rubric to scaffold and assess engineering design projects. *Proceedings of the American Society for Engineering Education Annual Conference & Exposition, Atlanta, Georgia*.

Neuendorf, K. (2002). *The content analysis guidebook*. Thousand Oaks, CA: Sage Publications.

Norusis, M. (2005). *SPSS 14.0 statistical procedures companion*. Upper Saddle River, NJ: Prentice Hall, 152, 183.

Oman, S., Tumer, I., Wood, K., & Seepersad, C. (2013). A comparison of creativity and innovation metrics and sample validation through in-class design projects. *Research in Engineering Design*, *24*(1), 65-92.

O'Quin, K., & Besemer, S. (1989). The development, reliability, and validity of the revised creative product semantic scale. *Creativity Research Journal*, *2*(4), 267-278.

Quade, D. (1967). Rank analysis of covariance. *Journal of the American Statistical Association*, *62*(320), 1187-1200.

Royalty, A., Oishi, L., & Roth, B. (2014). Acting with creative confidence: developing a creative agency assessment tool. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design Thinking Research*. Switzerland: Springer International, pp. 79-96.

Sarkar, P., & Chakrabarti, A. (2011). Assessing design creativity. *Design Studies*, *32*(4), 348-383.

Smith, M., Jones, F., Gilbert, S., & Wieman, C. (2013). The classroom observation protocol for undergraduate STEM (COPUS): A new instrument to characterize university STEM classroom practices. *CBE-Life Sci. Educ.*, *12*(4), 618-627.

Hasso Plattner Institute of Design at Stanford. “An Introduction to Design Thinking Process Guide.”

Watson, M., Barrella, E., Wall, T., Noyes, C., & Rodgers, M. (2017). A rubric to analyze student abilities to engage in sustainable design. *Advances in Engineering Education*, *6*(2).

Westley, F., Olsson, P., Folke, C., Homer-Dixon, T., Vredenburg, H., Loorbach, D., Thompson, J., Nilsson, M., Lambin, E., Sendzimir, J., Banerjee, B., Galaz, V., van der Leeuw, S. (2011). Tipping toward sustainability: emerging pathways of transformation. *AMBIO: A Journal of the Human Environment*, *40*(7), 762-780.

Wieman, C. (2014). Large-scale comparison of science teaching methods sends clear message. *Proceedings of National Academy of Science*, *111*(23), 8319-8320.