Introducing Sustainability into Engineering Design: a First Year Course

Dr. Courtney Pfluger, Northeastern University

Dr. Courtney Pfluger received her Bachelor's degree from Northeastern University in 2004. She then went to work in the Biotechnology Industry, where she worked on process development of recombinant proteins from mammalian cell cultures. In 2006, Dr. Pfluger enrolled into the Chemical Engineering PhD program at Northeastern University. In the spring of 2011, she successfully defended her PhD dissertation entitled "Biomimetic Replication of Intestinal Basement Membrane Topography". In the fall 2011 semester, she started a new position as Assistant Academic Specialist in the College of Engineering as a Gateway Faculty with a focus on chemical engineering. As part of her appointment she teaches freshman engineering courses, Engineering Design and Computations and Problem Solving, as well as undergraduate chemical engineering Process Controls. She has also been appointed at the faculty advisor for the undergraduate student chapter of the American Institute of Chemical Engineers.

Dr. Kathryn Schulte Grahame, Northeastern University

Dr. Kathryn Schulte Grahame is an Assistant Academic Specialist at Northeastern University. She is a member of the Gateway Faculty Team who's focus is to provide a consistent, comprehensive, and constructive educational experience in engineering that endorses the students centered and professionally oriented mission of the University. As a member of the Gateway Teams she dedicated to the development and instruction of first-year engineering courses as well specialty courses for undergraduates in the Civil and Environmental Engineering Department at Northeastern University.

Introducing Sustainability into Engineering Design: A First Year Course

Abstract

Engineering Design is a project-based first-year student course that introduces systematic engineering design methods. Using the engineering design cycle, students are walked through each phase of the cycle using real world examples. Two faculty members introduced a sustainability theme into the existing project-based course to around 180 students (approximately one third of the incoming freshman). With the university's mission to become a more sustainably aware campus, this piloted theme synchronized well with long term goals. Thematic sustainability lessons that focused on water, materials, and alternative energy technologies were introduced throughout the course alongside traditional methods used to teach the engineering design cycle and culminated with a themed group final project to design a sustainable home in an assigned global location. Compared to past iterations of the course done in a traditional style, students produced stronger projects that were more technical and realistic. The improved quality of design projects was a result of the additional thematic lessons aimed at creating a more focused classroom experience. Pre and Post course assessments indicated that the thematic inclusion of sustainability resulted in both gained knowledge on sustainable designs and practices and more confidence in student's abilities to be successful engineers.

Institutional and Program Background

In recent years, Northeastern University undertook the initiative to focus on global challenges in health, security, and sustainability. The campus has undergone many changes to make it more environmentally sustainable; including the erection of new LEED certified buildings and the inclusion of several recycling, composting, and sustainability initiatives. In 2011, Northeastern was awarded one of the highest ratings in North America from the Sustainable Endowments Institute for having a sustainable campus. Adding a sustainable focus to the first-year engineering course, Engineering Design, seemed fitting to the university's mission, as well as introducing students to global awareness.

The Northeastern University College of Engineering begins the first-year engineering students' first semester with the traditional foundational courses of mathematics, sciences and English; and accompanies these courses with Engineering Design. Engineering Design is a four-credit, project-based design course taught by the Gateway Team at Northeastern University; they are faculty dedicated to teaching the introductory design courses to all first-year students and specialty courses in their department of expertise.

Curriculum Evolution

Engineering Design: Traditional

Engineering Design is a project-based first-year student course that introduces systematic engineering design methods. *Engineering by Design* by Voland is the text used for the course, which outlines the 6 stages of the engineering design cycle shown in the graphic in Figure 1[1]. The engineering design cycle's 6 stages are:

1. Needs Assessment - Assesses the objective, reason or goal for the design of a solution to a problem. Looks at what the problem is, who would need this solution, and how will they benefit from it.
2. Problem formulation - Determines what the real problem is by looking at the design goals that are to be achieved by any viable solution.Teaches multiple problem formulation techniques to identify the real problem, i.e. Dunker Diagrams, Kepner-Tregoe, Why-why diagrams and Statement & Restatement techniques.
3. Abstraction and Synthesis - Come up with general concepts or approaches to solve the problem and develop detailed alternative solutions or designs for the problem.
4. Analysis (of alternatives) - Evaluation of the pros and cons of each alternative design are compared. An analysis of engineering ethics, hazards, and failures are considered for health and safety concerns.
5. Implementation - Develop the final solution and fabricate, test, and evaluate design.
6. Reflection and Iteration - Contemplates final design, reviews the failures, and redesigns the product accordingly.

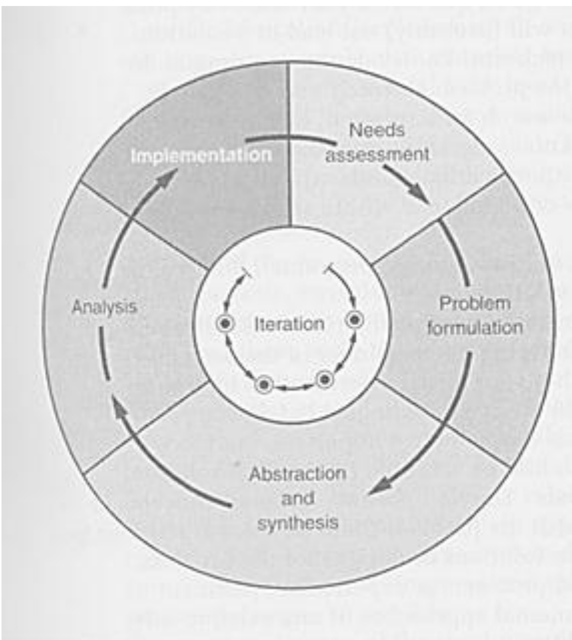

Figure 1: Graphical Representation of the Engineering Design Cycle, from Voland 2004

Following the engineering design cycle, students are walked through each phase of the cycle using real world examples. Lectures and homeworks are given for each of the cycle phases using different examples in world needs and engineering.

This course also includes two group projects: a smaller, minor, hands-on project where the students build, test, and redesign an engineering system and a larger, major project, which is more theoretical with extensive research and design to solve an engineering problem. The groups consist of 3-4 students. Both projects follow the students through the engineering design cycle but with different goals and lessons in mind. The minor design project is more hands on and the students get to test their designs and realize their mistakes, which is detailed in a paper by Jaeger, et. al[2]. This project is given mid-way through the semester and the students have 2 weeks to work on it. Conversely, the major design project focuses more on research and development of a design for a specific engineering problem and students usually have 3-4 weeks to complete the project. There are a variety of projects from which the groups get to pick from, sometimes not in the area of engineering that they are interested in. Also, many of the projects are tailored to a professor's area of expertise and do not encompass all different engineering disciplines.

Engineering Design: Sustainability Theme

Similar to the original course, the engineering design cycle is also used as a guide for this project-based design course. Notable changes to the course were the sustainability-themed major design projects and sustainable technology lectures that were included throughout the semester, providing a robust foundation for the final projects. Figure 2 compares the traditional course timeline to the thematic timeline. In order to accommodate the added lectures, the timing of lectures was shifted and several traditional, but dated, activities were eliminated. The main items to note are that the themed course was more accelerated and the students were now responsible for learning additional lecture material related to the theme.

	Week 1		Week 2		Week 3		Week 4	
Traditional	Introductory class	Like/Dislike Presentations	Ch. 1 and 2 - Engineering Design Intro and Needs Assessment	Wright Brothers Movie	Case study Presentations	Ch. 3 - Problem Formulation	Ch. 6 - Engineering Graphics	Ch. 4 Design goals
Themed	Introductory class	Ch. 1 - Engineering Design Intro	Sustainability: Intro and Major Design Overview	Ch. 6 - Engineering Graphics	Susatainability: Energy and Heat Transfer	Ch. 2 + 3: Needs Assessment + Problem Formulation	Sustainability: Water and Ch. 4 - Design Goals	Appliance Activity

	Week 5		Week 6		Week 7		Week 8	
Traditional	Saw it in the movies presentations	Tower of Straws	Minor Design Tests	Minor Design Tests	Major Project overview	Ch. 5 - Patents	Patent Search Presentations	Ch. 7 - Synthesis
Themed	Sustainable System Presentations	Minor Design Practice Test	Minor Design Tests	Minor Design Tests	Ch. 5 - Patents	Ch. 7 - Synthesis	Exam Review	Midterm

	Week 9		Week 10		Week 11		Week 12	
Traditional	Exam Review	Midterm	Ch. 8 + 9 - Ethics and Hazards & Failure Analysis	Engineering Disasters Movie	Ch. 10 - Analytical decision making	Ch. 11 - Implementation	Deconstruction Poster Day!	Exam Review
Themed	Ch. 8 - Ethics	Ch. 9 - Hazard & Failure Analysis	Ch. 10 - Analytical decision making	Ch. 11 - Implementation	Tower of Straws	Deconstruction Work Day	Deconstruction Poster Day!	Final Project Work Day

	Week 13	Week 14
Traditional	MAJOR Project Presentations	Final Exam Week
Themed	MAJOR Project Presentations	Final Exam Week

Figure 2: A comparison of the timelines for traditional and the sustainably themed Engineering Design courses

A motivating factor to change the course came after reading a paper entitled "Successful students: smart or tough" by Jaeger et al[3]. The paper discusses how the focus on design should be more on the process required for achieving success and less on having a predetermined set of skills. The paper defines a student's grit as perseverance and passion for long-term goals and entails working strenuously toward challenges, maintaining effort and interest over time, despite failure, adversity, and plateaus in progress. We hypothesized that by presenting the major design project early we provided them with a seemingly difficult and large challenge. To prevent them from being overwhelmed by this challenge, the project was then presented to the students in small, easier to manage sub-challenges throughout the whole semester. We believed that teaching them how to tackle a large challenge through sub-challenges would make success viewable in easily achievable chunks, as it would be in a well-managed project in the real working world. This major project was designed to set students up for future grit by giving the students the ability to successfully accomplish large challenges through planning.

Sustainability Lectures

Sustainability was first introduced to the students by having them take an ecological footprint quiz as part of their first homework assignment[4]. The results were submitted for homework and discussed in the classroom. From this assignment, the students gained an appreciation for their actions and how they affect the environment. An awareness of their actions on the environment helped the students realize that as engineers they will play a role in the future of this world. In the class following this assignment, the first thematic lecture looked at the results and discussed how sustainability can only be feasible at the intersections of economics, environment, and society. A graphical representation (presented in Figure 3) of this concept was presented to the students in the form of a Venn diagram and they were asked to keep this representation in the back of their minds as they developed their designs. In this lecture we also discuss what the students thought sustainability was and we provide them with a working definition as provided by the US EPA: "Meeting the needs of today without diminishing the ability of future generations to meet their needs"[5].

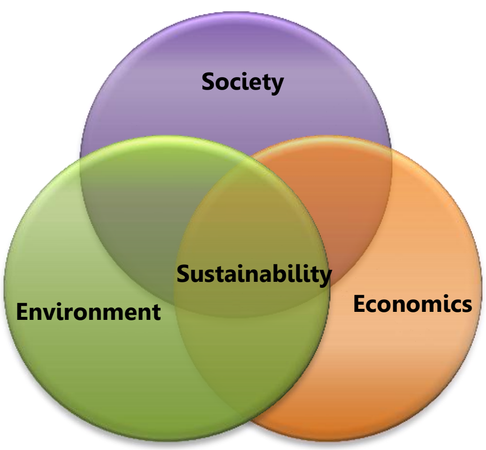

Figure 3: Venn Diagram representing the 3 aspects of sustainability

A lecture on needs assessment was given to the students, specifically looking at the needs of a modern home. In this lecture, types of energy, how it is generated and converted into electricity and converting units of energy was discussed. Type of heat transfer and how they relate to heating and cooling of a home was also examined. An in class assignment where the students had to calculate the heat flux through different insulation materials was performed, which promoted a conversation on different insulating materials for varying climates. This lecture helped students understand how they can use the sun and better home building material choices to save energy, and therefore money, on heating and cooling in their sustainable home.

After the lecture and homework assignment on what their client's needs are and what natural resources they have from their location, a subsequent lecture was given on problem formulation techniques. This was given to help students choose the best sustainable energy generation technologies, energy and water conservation techniques, and sustainable material options for their clients. This was supplemented with an in class assignment where they had to calculate how much energy is required to heat well water for use in a shower. Then they had to calculate how much energy and money would be saved if the water was preheated using the sun. This demonstrated to the students that by using free energy from the sun, it can benefit their clients by saving them energy and money.

Lastly, a lecture was given on the sustainable manufacturing and design processes. This lecture highlighted how materials, manufacturing processes, transportation of goods, and the end of use of products can negatively affect the environment. The students were given a project where they had to design a water bottle in SolidWorks and, using Sustainability package in that software, they had to determine the environmental effects of the materials, manufacture, and end of use of their water bottle design. The software lets the user determine what materials to use for the design, along with where they plan on manufacturing and selling the product. It then gives the students quantifiable results of how their design affects the environment by looking at the Carbon Footprint (amount of CO_2 released), Energy Consumption (amount of Mega Joules used), Air Acidification (amount of SO_2 given off), and Water Eutrophication (amount of PO_4 produced). This small project gave the students an appreciation for assessing something they designed and analyzing generated data on how their product would affect the environment. The students were then asked to change their design and materials to have their water bottle designs have less of a negative impact on the environment. This allows students to see how changing certain parameters in their designs, they can decrease the negative impacts they have on the environment. All these lectures were given to guide students to realize the importance and impact they can have an engineers on the world. The lectures also helped the students follow the engineering design cycle, as they designed their major design projects.

Major Project Overview

While the logic for the thematic course redesign stems from the synchronization of this course to the university's mission, it should be noted that the inspiration for the major project redesign was inspired by Dr.Andrew Lau's 2012 ASEE paper and presentation on the "Design of a Zero Energy Home as a First-Year Design Project"[6]. The sustainably themed major design project problem statement given to the students was: *Design a sustainable home: minimize or completely eliminate the use of energy and water from outside sources and identify how you can utilize local and/or sustainably harvested/produced materials.*

Each group of 3-4 students were given one of eight cities in the United States, which were: Burlington, Vermont; Anchorage, Alaska; Hilo, Hawaii; Miami, Florida; Seattle, Washington; Boulder, Colorado; Tucson, Arizona; St. Louis, Missouri. They were asked to do research on your region looking at the culture, climate, appropriate sources of alternative energies, and local resources and materials. They were to do a cost analysis in Excel on their house.
The students were tasked with looking at three major components: energy, water, and materials.

For energy, students needed to determine how they were going to provide energy to their home, how they could utilize the natural environment sustainably to minimize energy needed, and calculate the energy intake with the energy output of the home and get it as close to zero as possible. For the water requirement, they had to figure out how to supply water throughout their home, what they were going to do with the waste water, and how they would recycle the water in their home. They had to determine what local materials (within 500 miles as per LEED standards[7]) could be used in their home, how they could minimize the carbon footprint of the materials they use to make their home, and how they were going to insulate their house. Each group had a property sizes have a maximum footprint of 1 acre for a family of 4 and final construction and design budgets are capped at $500,000 USD(not including land).

The students were introduced to the major design project in first week of classes and were put into their design groups by the second week. This allowed the students to work on their major design projects for the whole semester. After each lecture on a particular part of the engineering design cycle, the students had a homework assignment that pertained to their sustainable home final project and that part of the engineering design cycle. In addition to the lectures and homework assignments, some in class assignments were added to teach them about energy units and how to calculate heat flux for insulation using different materials. An explanation of how the homework assignments correlated with lectures on the engineering design process will now be described in detail.

After a lecture on needs assessment and problem assessment, the students had a homework assignment where they had to research the culture and climate in the region in which they were to build their sustainable home to investigate what resources were available in that region, such as rainfall and sun. Then they had to determine their energy usage in their home by cataloging and calculate the amounts of energy that is needed to supply the appliances and systems in the home in kilowatt hours. They also calculated the peak energy demand for their home and how much energy they need to generate to meet the client's needs.

The next homework assignment, given in the middle of the semester, was a 5 minute group presentation to the class about the research about the climate and resources in their design home location and the results of utilizing a problem formulation technique to determine the best energy generation technology for their location. They were also asked to present on rainwater collection and waste water patent research and they had to make a Gantt chart to catalog a plan to finish their design projects.

After the abstraction and synthesis lecture, the students were given a homework assignment to perform brainstorming techniques to come up with creative ideas on how to design for energy, water, and materials for the home designs. They were then asked to come up with three alternative designs in detail for the design of their sustainable homes, discussing the pros and cons of each alternative design, specifically looking at the effects on the economics, environment, and society of each alternative.

Their last homework assignment that went along with their major sustainable home design projects was after a lecture on analysis of alternatives. They were asked to perform a decision analysis to select your preferred alternative for each component for their home (energy, water, materials). They were asked to put this information into a table using Excel and to write a paragraph discussing which alternative was chosen as their preferred alternative and why. These homework assignments given in conjunction with lectures on the engineering design cycle provided the students with the implementation of the engineering design cycle throughout the course and helped guide them in designing their sustainable home project.

The Results

Survey Assessment 1: PRE and POST learning
At the beginning and end of the second year of offering this thematic approach to Engineering Design, students were assessed with a short survey looking at their ability to define sustainability, determine the traits of a good engineer, identify renewable energies, and gage their ability to succeed further in the engineering program. The results from the identical PRE and POST surveys were tabulated and indicated very positive results that support a beneficial learning experience.

<u>Question 1: Define Sustainability.</u>
The first question in our assessment asked students to define sustainability. We had hoped to ascertain from this question any preconceived notions they initially harbored and how the definition changed as the course completed. The responses were compiled in a word document and the number of instances of each word counted. To better visualize what "buzzwords" were utilized the most, the free web program Wordle was used. Wordle displays the size of a word in a visualization proportionally to the number of times the word appears in the input text. The results of the Wordle visualization are shown in Figures 4a and 4b. As shown, the students had many diverse ideas to define sustainability before the course - ranging from themes of long lasting to energy to recycling with large themes of resources and the environment. The resultant definition as the students exited the class was more simplistic and uniform with large themes focusing on future generations' needs and variations minimal as indicated by the noticeable less small text in the word cloud. This indicated that many students were framing their definitions in the context of the first step of the engineering design cycle (Needs Assessment) as had been presented to them in the class.

Figure 4a: Question 1 Assessment Results: Wordle Visualization – PRE Assessment Results

Figure 4b: Question 1 Assessment Results: Wordle Visualization – POST Assessment Results

<u>Question 2: Which of the following items best describe an engineer?</u>

The second question looked to see what stereotypes about engineers the students initially believed and more importantly, how these stereotypes changed after their first course in engineering. To keep the responses slightly more streamlined, a list of words was supplied and students were asked to select all that applied. The percentage of students selecting each item was tabulated and analyzed for significant (greater than 10%) changes. The most significant changes in answers noted between the PRE and POST Assessments were increases in the selection of “highly ethical” (24% gain), “honest and impartial” (13% gain), and “concern for safety” (18% gain). A graphical representation of the data collected is shown in Figure 5.

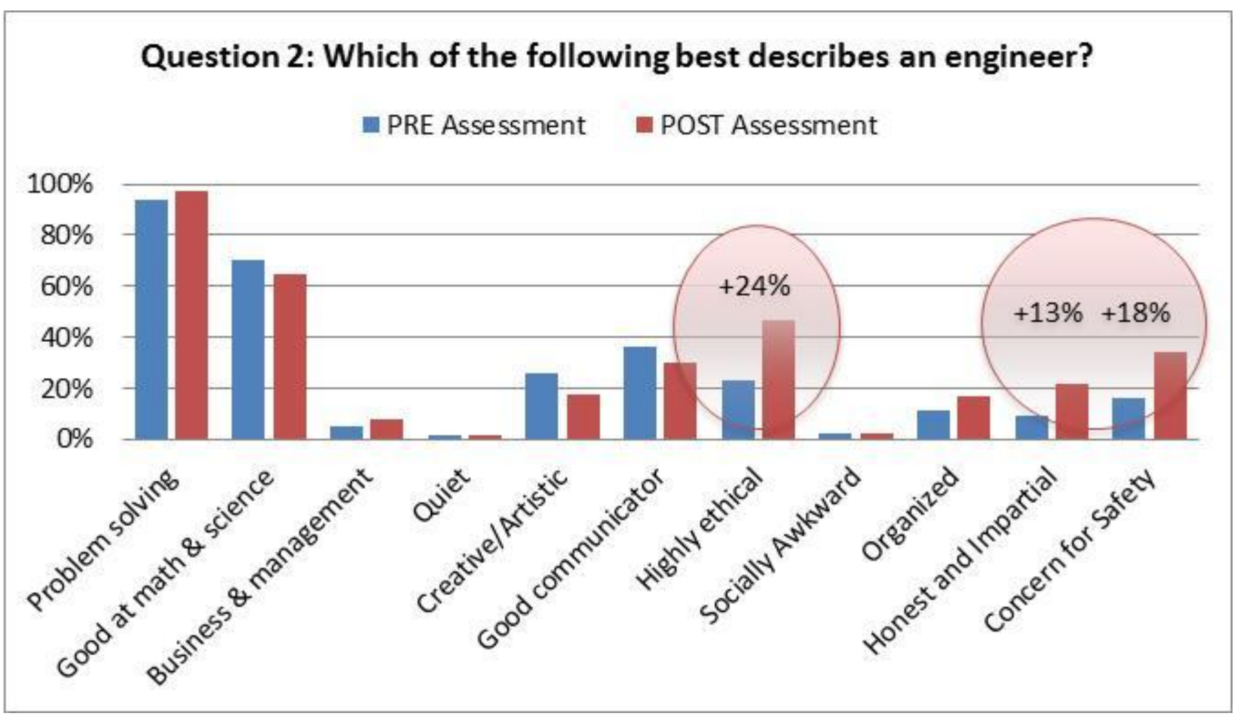

Figure 5: Question 2 Assessment Results

Question 3: Which of the following are renewable energies?

This particular question aimed at identifying the student's general knowledge of renewable energies before the course and seeing what clarifications they gained over the course. The media-popular technologies of wind and solar energy remained top choices for students in both evaluations but it should be noted that hydro-electric, sugar cane, and geo-thermal made significant gains between the PRE and POST assessment surveys. We postulate that the students may not have originally chosen these technologies for a lack of knowledge about what they were. Further, the research required in our design course required them to learn more about these technologies and familiarize them with the technologies enabling them to make more informed choices in the POST assessment survey. While this was helpful for this project and for the clarification of renewable energy misconceptions, the overall benefit of gaining this technical knowledge will have longer term benefits. The ability of students to familiarize themselves with current technical advances through research will be a valuable tool moving forward in any engineering career. Figure 6 provides a graphical visualization of the results from Question 3.

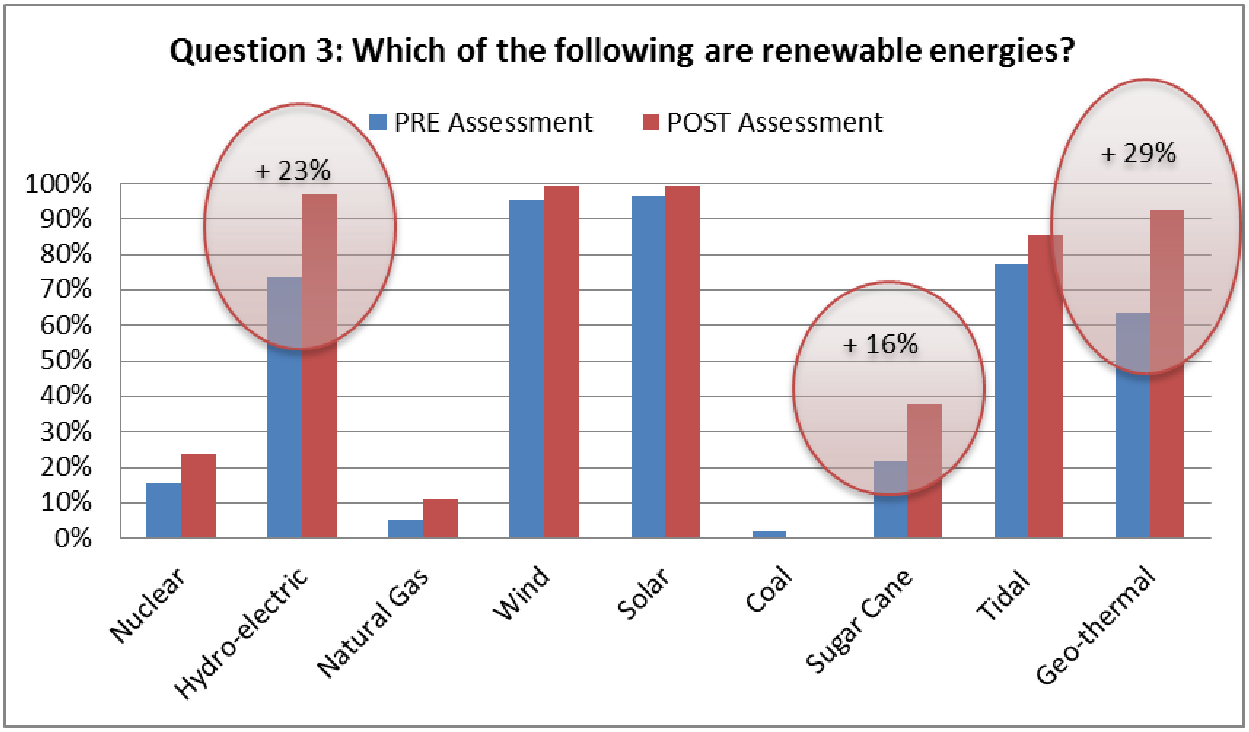

Figure 6: Question 3 Assessment Results

Question 4: Based on your experiences so far, do you think you have the ability to become an engineer?

The goal of this lone first-year engineering course was to introduce students to engineering design and how it utilizes talents from all aspects of a student's academic repertoire. Many students come in apprehensive about their abilities to succeed and this question aimed to identify if this sustainably themed engineering course inspired students to believe they could be successful. The compiled results are presented in Figure 7. These results present a great success story for this course. A very significant gain of 22% of students reported that they were confident that they had what it took to be an engineer. Additionally, categories of lower confidence all decreased with the second highest confidence category showing the most significance of -13%, indicating that many students received a boost in confidence in their ability to thrive in engineering after taking this course. This increase in confidence demonstrates that the changes made in this course helped the students gain a small amount of grit, which will benefit them greatly as they continue on the undergraduate studies and future endeavors.

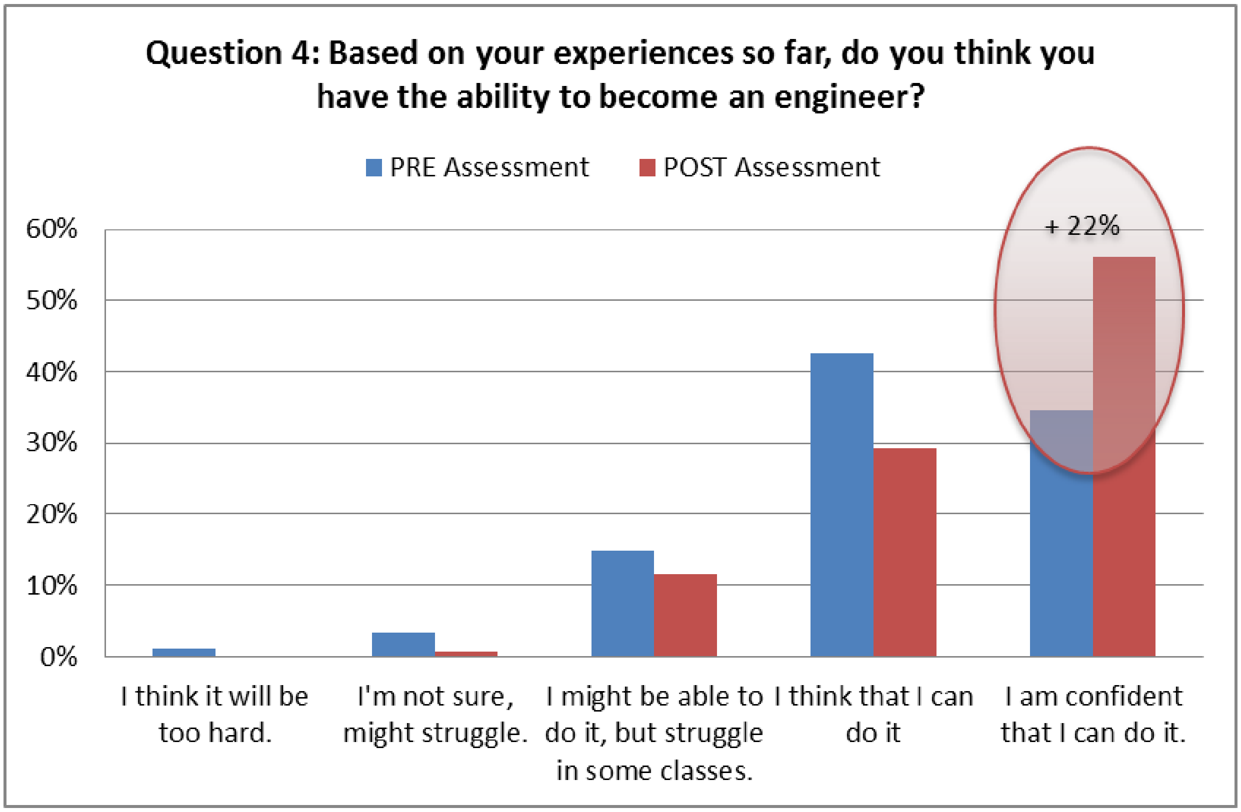

Figure 7: Question 4 Assessment Results

Survey Assessment 2: Peer and self-assessment of final projects
In addition to the PRE and POST Assessment Survey, students were asked to assess themselves and their peers' work on the final project. This data was collected with respect to the final projects to assess how each student felt they grew as an individual, how well their group functioned, and if project grades should be altered due to a lack of effort by certain individuals. Students were asked a series of reflective questions on the final project and to assess their team mates' work on the final project. This is done to get the students to honestly think about their experiences from the semester and how they functioned in a group while teasing out individual's embellishments through their peer's evaluations.

- Please rate your contribution, choosing from the following options:
  - Excellent - Consistently went above and beyond, helped team-mates, carried more than his/her fair share of the load.
  - Very Good - Consistently did what he/she was supposed to do, very well prepared and cooperative.
  - Satisfactory - Usually did what he/she was supposed to do, acceptably prepared and cooperative.

  - Ordinary - Often did what he/she was supposed to do, minimally prepared and cooperative.
  - Marginal - Sometimes failed to show up or complete assignments, rarely prepared.
  - Deficient - Often failed to show up or complete assignments, un-prepared.
  - Unsatisfactory - Consistently failed to show up or complete assignments, often unprepared.
  - Superficial - Practically no participation.
  - No Show - No participation at all.
- My major contribution(s) were:
- Something I did not know before this project that I learned was:
- Next time I will be a better team member by:
- How would you rate your team member's contribution(s)?
- Please comment on why they deserve this rating.

This 360^o evaluation proved very important at settling disputes and provided a reasonable checks and balances system to students knowing they would be evaluated to pull their weight on the major projects. It was also very helpful to the evaluation team to see what they enjoyed learning through the course and how we could improve aspects in the future. The question of greatest relevance to this paper was: "Something I did not know before this project that I learned was…" While there were a variety of responses, major themes to this response included: the importance of project management and communication, sustainable design is complex, exciting and largely misunderstood, and a greater appreciation in the student's own capabilities. A selection of the students' responses:

The importance of project management and communication

- Group cooperation is key. Knowing the strengths and weaknesses of your group can be the difference between success and failure. Besides everything I learned about sustainability and house design and research, I learned how to evaluate my own abilities as well as my group mates and cooperate efficiently while getting the work done well.
- Teamwork is truly essential to get work done. Leave personal issues at the door and get the work done.
- That working with a group can be extremely frustrating. It's tough when we are not all on the same wavelength and we don't work together well. This was something I never had to deal with in high school, so it was very different and sometimes difficult to struggle with it in college.
- How to deal with differing opinions in a group, how to deliver messages that others do not want to hear, and how to resolve conflict
- I need to be better at communicating with other team members on what I feel we should be doing instead of waiting til the last minute and getting mad at the other team members.
- Working in groups allows a lot more of ideas to be generated and allows for a better final product. I also learned a lot about time management.
- Teamwork is very important, but if there is no talking between group members there won't be any confidence therefore no excellent job will come out.

- It is important to have a well-functioning group. Having several people filling the same job is not useful, it is therefore important to have a group with individuals with unique skills applicable to the task ahead.
- Communication skills definitely improved through this group. Also, scheduling and planning for bigger projects improved through the many projects our group went through.

<u>Sustainable design is complex, exciting, and largely misunderstood.</u>

- Alternate Energies are really not as economically feasible as one would think. Solar panels do not save money and are, in fact, extremely more expensive than the cost of the energy they generate over their short 25-year lifespan. It seems that, at this point in time, alternate energy ""savings"" can only come from government grants and subsidies.
- How much energy is actually required to run a house and how much water is actually wasted by an average American family. They are actually both fairly high numbers. However, I also learned that is it possible to run a home entirely off of reusable energy sources.
- I didn't know how effective alternative energies could be. I thought that it was impractical to run a home completely off the grid, but after looking into it, and given the right area, it is actually a feasible, economical, and sustainable way of generating energy.
- Previously, I had heard of the different alternative energy designs, like solar power and wind power, but I never knew how they worked. It was really interesting to research the different alternative energy designs and to find out how they work. I feel like I learned a lot by doing this project.
- The most important thing that I learned after doing the project is really to what extent is using sustainable energy resources important to us especially in this time. Our planet's resources are running out and specialists expect the earth to run out of resources in just 40-50 years from now. I didn't actually know this fact before I did research on this topic. Hence, I realized that it is vitally important for humans to start looking for renewable energy resources and using them for generating energy to save the future generations.
- I actually didn’t know that water from sinks and showers could be recycled and used for toilets. I also was unaware of all of the amazing energy conserving technologies like the solar panel windows and the Eco-drain (harnessing energy from warm shower water).

<u>Greater confidence in the student’s own capabilities</u>

- We had a considerably larger amount of work to do for our projects compared to other Engineering Design classes but I felt like it was more reflective of how much time we would put in when we become engineers working at our respective jobs. I learned a lot.
- That I greatly enjoyed taking this class this past semester. The skills I learned are so practical and will likely be used and refined through my entire career. I looked forward to working on projects for this class, regardless of the intense time commitment--I was driven to create a good end project, rather than to simply make a good grade.
- Self-sustaining one's own house does seem like a very feasible option for many people, but it seemed daunting and hypothetical at first.
- That designing a completely sustainable home was possible. Through our research, design, and implementation it's clear that the technology is here for homes to be completely green. This [sustainable housing] project made me want to design a completely sustainable home for myself in the future.

- I was unaware of how much thought goes into building a house. There are several aspects of designing a home and the entire process is much more complicated that I thought before. In addition, I was unaware of how easy it is to cut back on water and energy usage by installing sustainable systems within the home.

Conclusions

The final sustainable home design project provided the students with an opportunity to learn about many factors that go into engineering design and that emphasized the importance of collaboration between students of various engineering disciplines. The students also learned design engineering that emphasized environmental, economic, and social responsibility. The project was initiated at the beginning of the semester; subsequent homework assignments enabled students to integrate the design cycle into their sustainable homes. This integrated, collaborative, semester-length project format resulted in final products that were developed with greater depth and provided a better understanding of sustainable engineering design.

As evidenced from the PRE Assessment survey data, students entered the university with many preconceived notions as to what sustainability was. Media and society provide many definitions to the public and the generalized wide confusion was evident. Similarly, the students also entered into our classroom with many narrow stereotypes as to what qualities an engineer should have. The result of a sustainably themed design course led to the reverse of the majority of original thought; the students now can:

- identify the qualities of an engineer more broadly with more emphasis on ethicality,
- define sustainability more uniformly while recognizing that it is a complex process to identify needs at the intersection of society, environment and economics.

In hindsight, the result of increased ethical awareness should not have been a surprise when incorporating a theme of sustainability. For design engineers, the complexity of sustainably meeting a client's needs is not easy. In a first-year engineering course we might want to make project solutions more black and white but this is not what they will encounter in industry. Sustainable design is not simple if done correctly - an ethical dilemma for future engineers.

The first-year design course themed in sustainability was more work for the students than the traditional course and left more open questions. These questions had to be answered as a team in an effort to simulate real-world experiences. There was no right answer to the design project and the complexity of the design was as deep as the students dared to venture. The students found that without good group communication the project was difficult. They learned about their own capabilities to function as a group more deeply than they had in high school experiences and they learned how hard they could push themselves to design something sustainably. The result of the sustainable design process appears to be clear: the sustainability themed format of the class driven through group projects lead to an improved understanding of engineering and sustainable design, subsequently improving self confidence in the students' ability to become engineers. Also, by introducing the major design project in the beginning of the semester and breaking it down into sub-challenges throughout the semester it showed an increase in the confidence of the students to tackle these challenges. This boost in confidence can be attributed to an increase in grit, which will allow these students to tackle more difficult challenges in their future careers as engineers.

Reflections and Improvements

Just like many engineering designs, our course can always be improved in an nth generation iteration. Through final project reflections and student evaluations we have identified many minor items that can be improved in our expectations on calculations and graphics in the final projects.

Conversely, there is one larger aspect which needs to be addressed; group work remains one of the most difficult skills to regulate in a project based course. Further tools to resolve student issues will be incorporated early in the semester. Planned improvements may include a communication and conflict resolution homework assignment; a mid-semester peer evaluation; more periodic self-assessments; and a scheduled project meeting with the professor for each team.

References

1. G. Voland, *Engineering by Design, 2nd Edition.* New Jersey: Prentice Hall, 2004.
2. B.K. Jaeger, S.F. Freeman, R. Whalen, "Successful Students: Smart or Tough?" *Proceedings of American Society of Engineering Education*, San Antonio, Texas, 2010.
3. B.K. Jaeger, S.F. Freeman, J.C. Brougham, "No rockets, no robots: Teaching low-tech engineering design with credibility and success," *Proceedings of American Society of Engineering Education*, Nashville,Tennessee, 2004.
4. The Nature Conservancy. (2013). *What's my Carbon Footprint?* [Online]. Available: http://www.nature.org/greenliving/carboncalculator/index.htm
5. United States Environmental Protection Agency. (2013). *What is sustainability?* [Online]. Available: http://www.epa.gov/sustainability/basicinfo.htm#sustainability
6. A. Lau, T.L.Sulewski, "Design of a Zero Energy Home as a First-Year Design Project," *Proceedings of American Society of Engineering Education*, San Antonio, TX, 2012.
7. United States Green Building Council. (2013). *LEED Rating Systems* [Online]. Available: http://www.usgbc.org/leed