122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Seattle Making Value for Society
Paper ID #12954

Incorporating Sustainable Engineering Design Principles into Senior Design Proposals

Dr. Ding Yuan, Colorado State University, Pueblo

Ding Yuan received the Bachelor of Engineering degree in industrial automation from Dalian University of Technology, Dalian, Liaoning, China, in 1998 and the Ph.D degree in Electrical Engineering from New Jersey Institute of Technology, Newark, NJ, in 2006. She is currently an Associate Professor of Engineering at Colorado State University-Pueblo.

Dr. Jane M. Fraser, Colorado State University, Pueblo

Jane M. Fraser is chair of the Department of Engineering at Colorado State University-Pueblo. She was formerly on the faculty at the Ohio State University and Purdue University. She has a BA in mathematics from Swarthmore College and MS and PhD in industrial engineering and operations research from the University of California-Berkeley.

Dr. Ananda Mani Paudel, Colorado State University, Pueblo

Ananda Mani Paudel is Assistant Professor of Engineering at Colorado State University, Pueblo. He was formerly on the faculty at the University of Wisconsin-Platteville. He has a B.S in mechanical engineering from Tribhuvan University, Nepal, a M.S. in Mechatronics from Gwangju Institute of Science and Technology, South Korea, and a Ph.D. in industrial engineering from Western Michigan University.

Incorporating Sustainable Engineering Design Principles into Senior Design Proposals

Abstract

Sustainability as a multidisciplinary concept has been introduced and developed for over twenty years, and its principles have been well recognized by engineering professionals, especially in environmental-related fields. However, it remains challenging for most engineering educators to engage students with such a concept in their traditional technical courses. It is even more challenging to prepare students for integrating the sustainability principles into their engineering design process since it requires knowledge, training and practice. In our engineering program, senior engineering students are required to prepare their senior design proposals in a fall semester and complete the project in the following spring semester. The topics of senior design projects are chosen by students, not professors. Since last year, each team is required to evaluate the project from a sustainability point of view in the final report. Accordingly, a new approach is proposed in this paper to enhance students' understanding of sustainable engineering design principles and to help them synthesize sustainability concepts already introduced in previous courses. This new process starts right after the students select the project topic and form in teams. A six-factor table proposed by Pawley *et al*. is introduced to the students. This framework is used to evaluate an engineering project at the early stage on six factors, i.e. systems, time, energy, modeling, people and scale. Each team uses the framework as an anchor to identify the sustainability related opportunities and potential issues with the topic the team selects. Then an integrated sustainable engineering design process is adopted which includes eight more tasks in addition to the thirteen tasks required in a traditional engineering design process. Consequently, each team is required to develop a sustainable engineering design flowchart that specifically ties to the team project. For an assessment purpose, pre- and post- anonymous student surveys are developed and implemented. The results on Likert-scale and multiple choice questions are analyzed and discussed.

Introduction

Sustainability is an important topic to everyone. Its relevance is acute to engineers who are directly involved in enabling the built environment. Accordingly, the well-known ABET engineering accreditation criteria[1] requires engineering graduates should be able to "*design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*." Engineering educators have been making every effort to educate the future engineers in sustainability and to prepare them with solid knowledge to deal with the sustainability challenges[2-6]. The related topics have been taught both as core engineering and general education[2]. In certain engineering disciplines, such as civil and environmental engineering, more emphasis has been placed on sustainability than others since sustainability is considered as one of the most dominant course objectives[3].

The implementations of sustainability in academia are various, either strategically or through many ongoing academic activities. Typically, in an educational institution, it could be implemented in four levels: university-level with a strategic plan, school- or college- levels, departmental-levels or individual-levels. Various pedagogies and approaches are used in teaching sustainability in different engineering disciplines, e.g., creating an interdisciplinary seminar as a summer research program[5], or integrating sustainability into all engineering courses incrementally[6, 7], etc. In general, it is agreed that integrating sustainability into existing courses might be a better way[8, 9]. However, predefined course content requires additional preparations on the instructor's side and supplementary resources may be a challenge as well.

Capstone design as a showcase for students' development before their graduation has been chosen[18-24] to engage students in sustainable engineering design experience, especially in civil and environmental engineering areas. Burian[18] proposed to use a specific professional rating system as a tool to enhance the civil engineering students' understanding of sustainability concepts, but the preliminary results indicates the lack of deeper learning of general sustainability knowledge. El-Sayed *et al.*[19] suggested a flexible structure for engineering capstone courses so as to include environmental sustainability activities, however, a reliable set of performance indicators were required to accurately identify the performance gap for each team. Several studies expanded sustainable engineering design to multiple engineering disciplines by using sustainability focused capstone projects[20-21], or increasing the capstone design experience duration[22].

These previous studies are helpful, but we did not find that they provided us with sufficient guidance for integrating sustainability into engineering design in the types of programs we have. The goal of this paper was to describe the design and the implementation of a new sustainable engineering design module in a Senior Seminar course for students in our engineering with specialization in mechatronics program and industrial engineering program. It was intent on improving students' understanding on sustainable engineering design, and helping them to integrate it into their two-semester-long senior design projects. The changes on students' perception of sustainable engineering design before and after the module were assessed by an anonymous survey (attached in Appendix A). The discussion on these survey results focused on the questions related to their senior design while the answers on the open-ended questions in the survey will be addressed in another paper.

Background

The Department of Engineering offers two BS programs, the BS in Industrial Engineering and the BS in Engineering with specialization in mechatronics. Through funding from the US Department of Education, all STEM departments at our university have been working to integrate sustainability throughout the curricula as reported at previous ASEE conferences[6-9, 17].

Students from both BS programs are required to complete a senior design sequence, consisting of a two-credit senior seminar in fall semester and a three-credit design project course in spring semester. Since spring semester 2013, the requirements for the senior design project reports have included this statement: "The report must include a section on **sustainability aspects** of the project. Topics may include optimization of resources, product life cycle, benefits to the current and future generations, etc." It was found that the material students included in 2013 and 2014 was adequate but did not show the depth of understanding of sustainability as desired. This gap caused the initiation of the work reported in this paper.

Project Approach and Observations

Traditionally, a good engineering design should be sustainable. As described in the Obligation of the Order of the Engineer[10] in 1970s, engineers should "uphold devotion to the standards and the dignity" of the profession; this pledge carries "with it the obligation to serve humanity by making the best use of Earth's precious wealth." Hence, sustainable engineering design was not something new or only related to certain types of projects; instead, it has been what good engineers do in a daily practice and it has been involved in every stage of an engineering design process.

However, such an understanding may not be well accepted by all the engineering students according to our observation. For example, some students thought only the projects related to renewable energy need to address sustainability. So, it becomes our goal to help students clarify such a misconception and enhance their sustainable engineering design skills. Moreover, the students can practice and demonstrate their capability on sustainable engineering design through their capstone senior design experience. Typically, our engineering students select project ideas and work in teams to prepare their senior design proposals in a fall Senior Seminar course and complete them in the following spring semester. Hence, this new module was designed to be implemented in fall, right after each team was formed and selected a senior design topic.

This new module included lectures, group discussions, in-class activities, team assignments, and survey. It started with an in-class discussion about the relationship of sustainability to engineering. Then, a six-factor table was introduced as a tool to broaden the students' view of sustainable engineering design. The students worked in teams to evaluate their senior design projects ideas from a sustainability point of view. In the next step, an integrated sustainable engineering design process was introduced and discussed in the class. The students learned to integrate sustainability into their senior design process by including sustainability related tasks into their engineering design flowcharts. Finally, the module was completed with a brief introduction and discussion on decision making. An anonymous survey was administrated before and after the module. About 25 senior-level engineering students accomplished the model, and completed the surveys in this pilot run. The following paragraphs detailed each part of the module and the related observations from the instructor. The pre- and post- survey results were discussed in the next section.

At the beginning of the module, a series of questions were brought to the class. For example, what kind of role does engineering play in sustainability? Is sustainable engineering design a normalized requirement by industry or a "soft" option? The purpose of these questions was not to draw a universal agreement, but to encourage the students to think deeply as future engineers. During the discussion, it was observed that not everybody was on the same page. Some of them advocated sustainable engineering design and thought it should be a part of all engineering design projects while the others were less sure if it would be applicable in every case.

The discussion then became central to which kind of engineering projects would be applicable. The students started to give the examples that they thought sustainable engineering design would fit in. And some of the keywords were found quickly: renewable/green energy, recyclability and safety, etc. These listed terms showed that the students realized engineers should be socially responsible in general. For example, safety was no doubt on everyone's list. However, compared to the three pillars in sustainability, i.e. people, plant and profit, it was found that the last one was not in the list. This may be due to its apparentness, like one student commented in class "Who will fund a project if it is not profitable?" On the other hand, this also implied that some of the students thought sustainable engineering design was costly and its solution might not be cost effective.

Another concern about the keyword list came from an obvious energy theme in examples. For instance, when discussing if a certain project can be designed sustainably, one student made a comment (paraphrased) as "My senior project is to design a low-powered device in a lab setting which can't use green energy, so sustainable engineering design is not necessary for my project." In other words, at least some of the students circumscribed sustainable engineering design in energy-related projects. Such an observation was coherent with the findings by other educators[11]. It became critical to broaden their views of sustainability and sustainable engineering design first.

Pawley *et al*. proposed to use six factors to evaluate an engineering project at the early stage[12]. These six factors were systems, time, energy, modeling, people and scale. They could be used separately, or in pairs to assess the sustainability related opportunities/concerns in a project. So, a 6x6 table could be formed (see Table 1 attached as Appendix B) and an engineering design idea should be questioned with respect to the factors labeled in the corresponding row and column[12]. It would be ideal to fill in all cells (except the shaded ones) with some questions to ensure a completed consideration. The shaded area was blocked due to its redundancy.

During the class, the students learned to use such a table as a general approach to evaluate a project idea. Each of the six factors was explained by using some demonstration examples only. The sample questions proposed by Pawley *et al*. were not revealed to the students at this point so as to avoid imposing some potential restraints in the students' discussion. Then an assignment was left to each senior design team to build a six-factor table for their project idea. It was not an easy task for them to fill all blank cells in the table with good questions on a specific project idea.

Due to the different project topics, the questions proposed were various and the team-preferred factors were different too. For example, one team with a modeling-type IE project showed good considerations using the Modeling factor while another team that planned to automate a lab size equipment examined sustainability related opportunities well by using the Scale factor. It was also noticeable that some teams extended their understanding of sustainable engineering design. For example, together with his/her team, the student whose comments were paraphrased before posed some good questions by using the People factor. It implied energy was no longer the only factor the student took into consideration. On the other hand, it was observed that there existed a misunderstanding on a span of a project. For example, more than one team confined their questions in the span of the course, especially when using the Time and People factors. Such a misperception was clarified later as an integrated sustainable engineering design flowchart was introduced to the class. Some sample questions from different teams were shown in Table 1 as Appendix B.

It was worth clarifying that not all of the questions in the tables were coherent. Some questions might be posed in different cells for a better match on factors. However, in consideration of the purpose of the module, more focus was placed on broadening the students' view of sustainable engineering design, instead of correcting which cell a question should belong to.

Up to this stage, each team should be able to connect their senior design idea with at least one sustainability related opportunity/concern. The next step was to embed this connection through their design process.

The conceptions of engineering design processes have been described in different ways, but typically can be represented as a flowchart which has been well accepted by both engineering educators and practicing engineers[13]. Through our engineering curriculum, the students may learn different types of engineering design flowcharts in different courses. For example, a general engineering design process[14] was introduced in the first-year Introduction to Engineering course while a DMAIC (Define, Measure, Analyze, Improve and Control) process was covered in the required course in quality improvement to address some design features specifically in the industrial engineering field. In other words, our senior-level students should be familiar with conventional engineering design processes. It was reasonable to modify a conventional engineering design process to fit in a sustainability framework. Therefore, an integrated sustainable engineering design process[15] was adopted in this module. In this approach, Gagnon *et al*. recommended to add eight more tasks to the thirteen tasks required in a traditional engineering design process (as shown in the top part of Figure 1), so as to address the possible ways to assess sustainability related issues. These eight new tasks were associated with all four phases in the design process, from forming a multidisciplinary team in as the first task in Phase I to generating sustainability indicators for a monitoring purpose as Phase IV.

The life-cycle analysis stage was kept in Figure 1 and presented to the students although the detailed analysis method with potential tools was not covered due to the time limit. However, it was still valuable to remind the students the life span of a project and to enhance their understanding of the six factors, especially the Time and People factors. As a result, more students started to give comments with the 5 r's (i.e., reduce, reuse, recycle, replace and reinvent) in the class discussion.

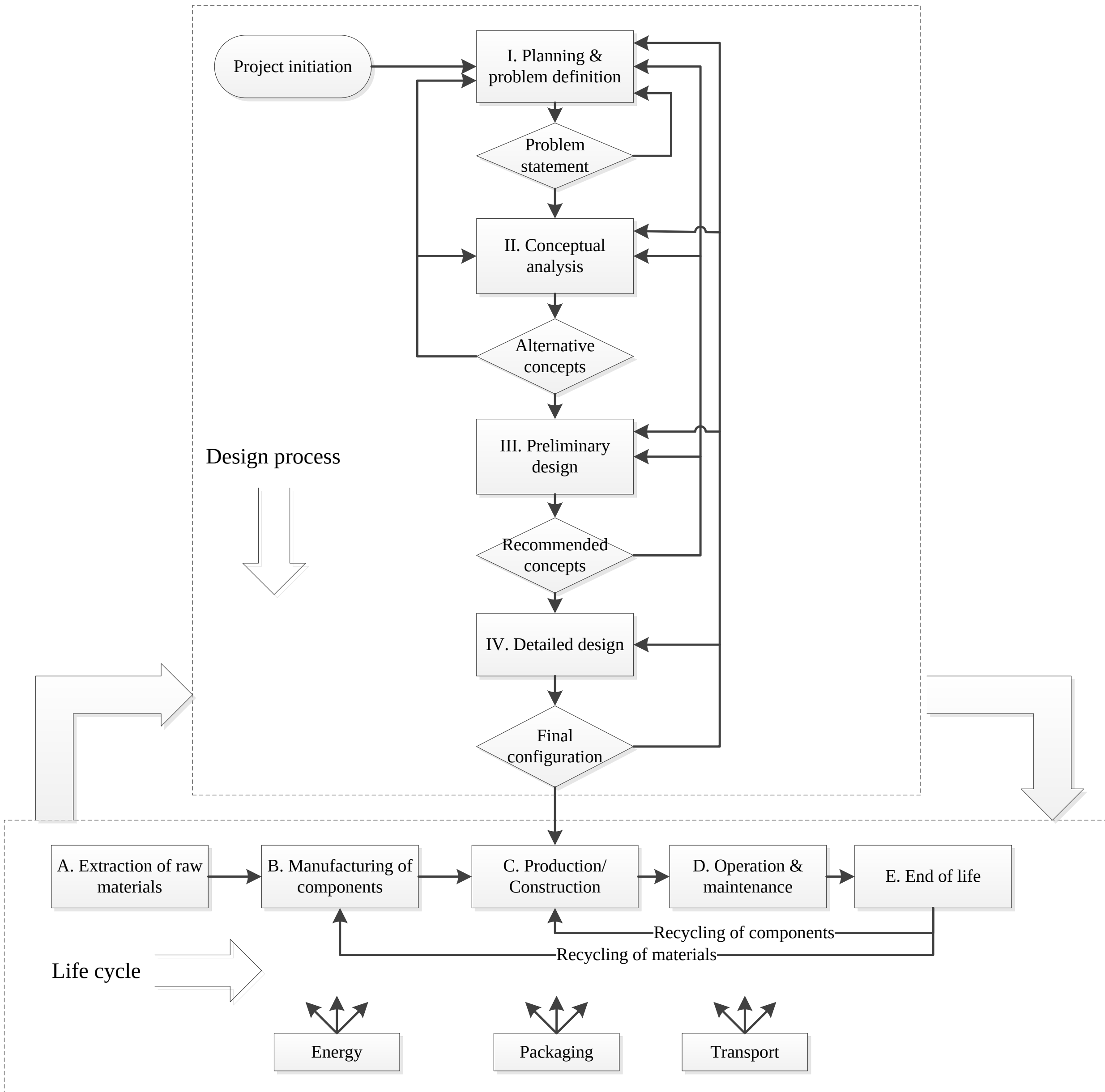

Figure 1: The integrated sustainable engineering design flowchart adapted from the study by Gagnon *et al*. [15]

As a generalized integrated process, some of these 21 tasks may be more rational in an industrial setting for a complex project. In this class, the students were encouraged to use the 21 tasks as a check list or stimulus as they developed a flowchart of their senior design project in teams. However, not all of the teams showed enough efforts in this assignment since some of the flowcharts were still too vague within the scope of a certain project. Some teams didn't include the sustainability related issues identified in the 6-factor table into their flowcharts. This may be due to a time constraint or a misunderstanding of the requirements on flowcharts.

Positive findings were also observed in these flowcharts. For instance, more than one team included generating one alternative concept according to the sustainability criteria or indicators in their senior design flowcharts. Sometimes, it was difficult to differentiate if the tasks given by the students came from a sustainability concern or a technical one. For example, one team added easily upgradeable as one of the functionalities, which could involve both a conventional engineering thinking and a sustainability mind set. Another example in this case was related to the concerns on operation and maintenance.

Decision making was critical in engineering design and needs to be addressed in this module. The inclusion of the sustainability criteria or indicators was valuable, but the corresponding decision making became more challenging. The related multi-criteria decision analysis (MCDA) method for various engineering applications was still an active research area due to its multidisciplinary nature[15]. Our goal of including the MCDA section in the module was to emphasis the importance of selecting and weighting different kinds of criteria in a sustainability framework. During this ending section of the sustainable engineering design module, the MCDA material included an example of choice of manufacturing process for stainless steel knives, in which tradeoffs were made among economic, environmental, and social factors including effects on the worker and local community[16]. It was desired to provide the students with first experience of MCDA methods so as to help them be more cautious when comparing alternatives in their senior projects.

Survey Results and Discussions

An anonymous survey was developed to assess the students' perception of sustainable engineering design. It was administrated to the students at the beginning and at the end of the new module. The questions in the post- survey were the same as the ones in the pre-survey, except that there was one additional question in the post-survey. A copy of the survey is attached as Appendix A. Except for the first question, the ones in the survey asked the students about their understanding of sustainable engineering design by Likert-scale, multiple-choice and open-ended questions.

All 25 students in the course completed both pre- and post- surveys. In this paper, only the survey results related to Likert-scale and multiple-choice questions would be discussed (shown in Figure 2 - 4) while the analysis of the rest questions will be held until such a survey is administrated again in the Spring 2015 semester. It is our goal to survey the same group of students one more time on these questions after they complete the capstone senior design project and then compare the difference in the students' answers on open-ended questions.

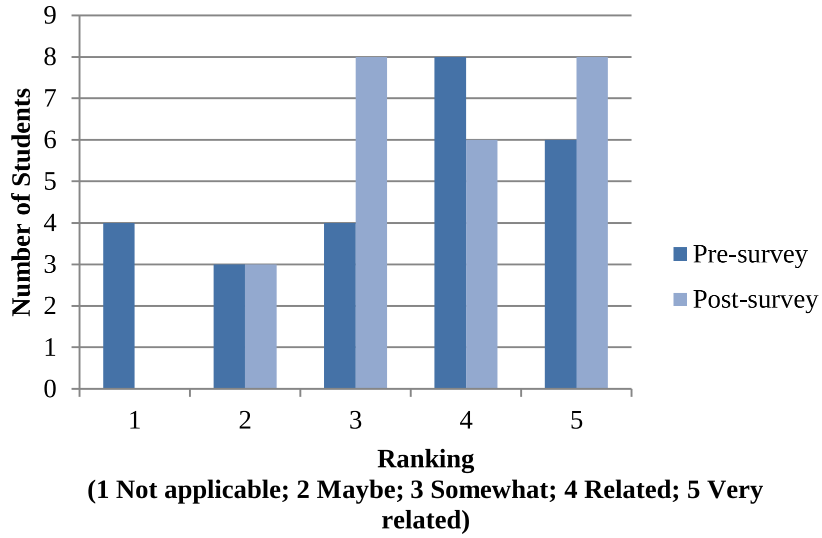

Figure 2: Survey results on “To what extent do you feel the senior design topic you chose is related to sustainability?"

The two Likert-scale questions in the survey were related to the students’ perception of whether sustainability would be a factor of their senior projects. Figure 2 showed the students’ ranking on a scale of 1 to 5, 1 being least related and 5 being most related when they were asked if they thought their senior design idea would be related to sustainability.

The data indicated more students thought their project ideas at least “somewhat” related to sustainability in the post-survey (about 88%) than they did the pre-survey (which was about 72%). In both survey results, more than 50% of the students were positive on the relationship between their project ideas and sustainability. It was good to observe that the four students who believed sustainability had nothing to do with their projects in the pre-survey changed their mind in the post-survey. On the other hand, about 12% of the students still had doubts about connecting their project with sustainability in the post-survey.

Another Likert-scale question was intended for revealing if sustainability would impact the students’ design process. Similarly, the question was asked on a 5-point scale, 1 being least affected and 5 being most affected. The answers to this question (shown in Figure 3) indicated that over 90% of the students in the post-survey agreed their design would be at least “somewhat” sustainable compared to 80% in the pre-survey. No students thought sustainability had no effect on the design process anymore.

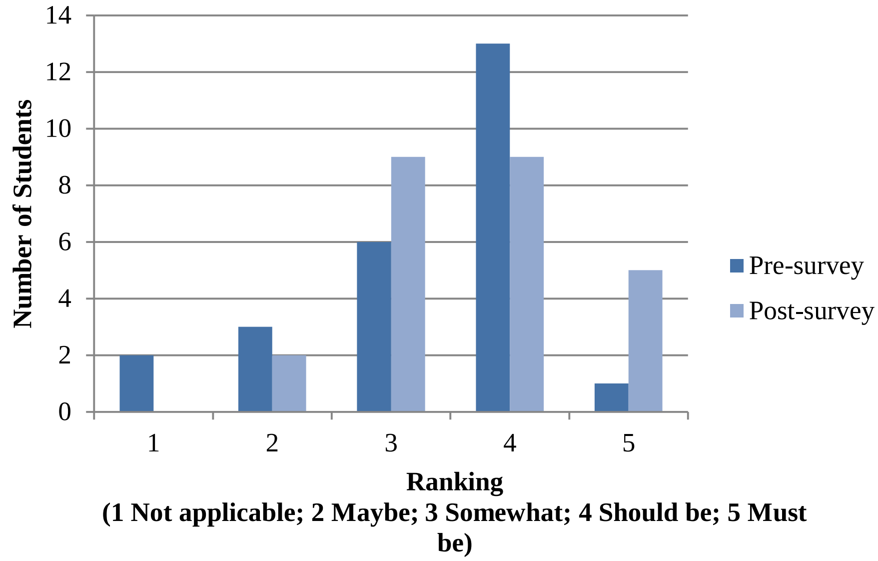

Figure 3: Survey results on "To what extent do you think your senior design project will be sustainable?"

In a multiple-choice question in the survey, participants were asked to select, as many as they wanted, the terms which matched their thought on sustainable engineering design best. These choices were listed in Figure 4. On average, two out of the total eight choices were circled by the students in pre- and post- surveys. Consistently, the top two answers in both surveys were *An approach that more and more engineers use* (48% in both surveys) and *A mind set* (44% in the pre-survey and 48% in the post-survey). This implied that the student realized the demand of sustainable engineering design by our society. The third popular choice (i.e., *Something critical to a successful project*) also remained the same in both surveys, but the percentage dropped for 44% in the pre-survey to 36% in the post-survey. More students agreed that sustainable engineering was conceptual and required a skill set in the post-survey. No more students treated sustainable engineering design just as a fancy term to use in the post-survey although some of them persisted about its potentially high cost. The expense concern in the survey results also agreed with the instructor's observation in the class.

Overall, some changes were found in the comparison of the pre- and post- survey results, but in a limited scale. This was likely due to two primary factors:

1. The new module started right after the students chose a project idea and lasted less than three weeks, which may not be enough for the students to well digest the new materials. For example, the six-factor evaluation was done when some teams were still trying to collect some information from the clients. Another related concern was in the flowchart section. The students seemed not as thorough as they should when they had midterm exams for other courses.
2. The survey was newly designed and may need to be polished. According to the students' explanation of their rankings, some of them couldn't differentiate the two Likert-scale questions and gave the similar or even the same answers.

According to our plan, during spring semester 2015, the material from the fall semester discussion will be reviewed with the teams in order to remind them of the types of factors they should consider in their assessment of the sustainability of their projects. The survey will be administrated once again when the students complete their senior projects in spring 2015. Deliberately, all the questions in the survey will remain the same to keep the consistency.

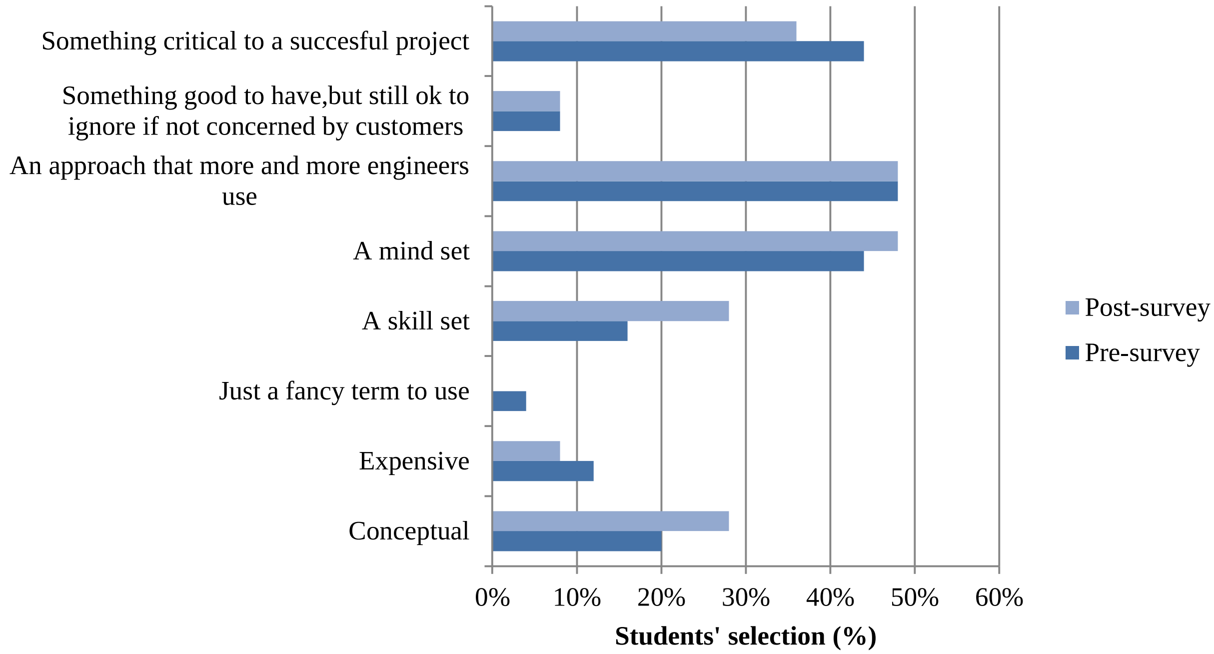

Figure 4: Survey results on " In your opinion, sustainable engineering design is …"

Conclusions

A new sustainable engineering design module was developed and implemented in fall 2014. The senior-level students learned to evaluate their senior design ideas by using the six-factor table. An integrated sustainable engineering design process was adapted to the class to help the students embedding sustainability into their senior design process. Moreover, an introduction on MCDA methods was included in the module to enforce their understanding on sustainable engineering design. An anonymous survey was developed and conducted at the beginning and the end of the module. A discussion of the survey results focused on the Likert-scale and multiple-choice types of questions in this paper. Changes in the students' perception of sustainable engineering design were found, but in a relatively small degree. Future work is planned and will be reported after the same group of students accomplishes their senior design projects.

Bibliography
1. http://www.abet.org/eac-criteria-2015-2016/, retrieved on 2/1/2015.

2. Vanderburg, W. H., “On the measurement and integration of sustainability in engineering education,” *Journal of Engineering Education-Washington-*, vol. 88, pp. 231-236, 1999.
3. Othman, M. R., Hady, L., Repke, J. U. and Wozny, G., “Introducing sustainability assessment and selection(SAS) into chemical engineering education,” *Education for Chemical Engineers*, vol. 7, pp. e118-e124, Aug. 2012.
4. Legg, R. et al., “Solving multidimensional problems through a new perspective: the integration of design for sustainability and engineering education,” *Proceedings of the 2005 ASEE Annual Conference& Exposition*.
5. Grimberg, S. J., Langen, T. A., Compeau, L. D. and Powers, S. E., “A theme-based seminar on environmental sustainability improves participant satisfaction in an undergraduate summer research program,” *Journal of Engineering Education-Washington-*, vol. 97, p. 95, 2008.
6. Fraser, J. M., et al, “Community Outreach and Engagement through Sustainability,” *Proceedings of 2013 ASEE Annual Conference & Exposition*, Paper ID #7429.
7. Paudel, A. M., “Teaching sustainability – an increment into the engineering courses or a paradigm shift in engineering education?” *Proceedings of the 2013ASEE Rocky Mountain Section Conference*, pp 121-126.
8. Paudel, A. M. and Fraser, J. M., “Teaching Sustainability in an Engineering Graphics Class with Solid Modeling Tool,” *Proceedings of the 2013ASEE Annual Conference & Exposition*, Paper ID #7532.
9. Bedoya-Valencia, L., Yuan, D. and Fraser, J. M., “Incorporating a Sustainability Module into an Introduction to Engineering Course,” *Proceedings of the 2013 ASEE Annual Conference & Exposition*, Paper ID 7872.
10. http://www.order-of-the-engineer.org/?page_id=6, retrieved on 2/1/2015.
11. Blevins, M. D. and Burian, S. J., “Analysis of the sustainability culture in civil and environmental engineering and mechanical engineering program,” *Proceedings of the 2012 ASEE Annual Conference & Exposition*, Paper ID #4337.
12. Pawley, A. L. et al., “Assessing sustainability knowledge: a framework of concepts.” *Proceedings of the 2014 ASEE Annual Conference & Exposition*, Paper ID #9967.
13. Mosborg, S., et al, “Conceptions of the engineering design process: an expert study of advanced practicing professionals,” *Proceedings of the 2005 ASEE Annual Conference & Exposition*, 2005.
14. Landis, R. B., *Studying Engineering: A Road Map to a Rewarding Career*, 4th ed., Discovery Press, pp. 38-39, 2013.
15. Gagnon, B., Leduc, R. and Savard, L., “From a conventional to a sustainable engineering design process: different shades of sustainability,” *Journal of Engineering Design*, Vol. 23, No.1, pp 49-74, 2012.
16. Zhang, H., and Haapala, K. R., “Integrating sustainable manufacturing assessment into decision making for a production work cell.” *Journal of Cleaner Production.* 2014.
17. Fraser, J. M. et al, “Integration of Sustainability in a Multidisciplinary Engineering Department,” *Proceedings of the 2014 ASEE Annual Conference & Exposition*, Paper ID #9551.
18. Burian, S. J., “Using a sustainable infrastructure rating system in the civil Engineering capstone design course,” *Proceedings of the 2014 ASEE Annual Conference & Exposition*, Paper ID #10410.
19. El-Sayed, M. E., and El-Sayed, J. A., “Integration of environmental sustainability with capstone experience,” *Proceedings of the 2013 ASEE Annual Conference & Exposition*, Paper ID #8110.
20. Bormann, N. E., *et al*., “Understanding the system: sustainability projects increase student interest and learning,” *Proceedings of the 2012 ASEE Annual Conference & Exposition*, Paper ID #5102.
21. Sattler, M. L. *et al*., “Integrating sustainability across the curriculum: engineering sustainable engineers,” *Proceedings of the 2012 ASEE Annual Conference & Exposition*, Paper ID #4152.
22. Pierrakos, O., *et al*., “An innovative two-year engineering design capstone experience at James Madison University,” *Proceedings of the 2013 ASEE Annual Conference & Exposition*, Paper ID #7464.
23. Watson, M. K., Barrella, E. M., Wall, T. A., Noyes, C. R., and Rodgers, M. O., “Development and application of a sustainable design rubric to evaluate student ability to incorporate sustainability into capstone design projects,” *Proceedings of the 2013 ASEE Annual Conference & Exposition*, Paper ID #5882.
24. Watson, M. K., Pelkey, J., Noyes, C. R., and Rodgers, M. O., “Use of concept maps to assess student sustainability knowledge,” *Proceedings of the 2014 ASEE Annual Conference & Exposition*, Paper ID #10382.

APPENDIX A.

EN486 Pre/Post-Survey on Sustainable Engineering Design

Please circle the appropriate one: My major is IE Mechatronics

What is sustainability? Please use your own words to define it.

What is a sustainable engineering design?

To what extent do you feel the senior design topic you chose is related to sustainability?

1 Not applicable 2 Maybe 3 Somewhat 4 Related 5 Very related

Please explain your ranking briefly.

To what extent do you think your senior design will be sustainable?

1 Not applicable 2 Maybe 3 Somewhat 4 Should be 5 Must be

Please explain your ranking briefly.

In your opinion, sustainable engineering design is

Conceptual Expensive Just a fancy term to use

A skill set A mind set An approach that more and more engineers use

Something good to have, but still ok to ignore if not concerned by customers

Something critical to a successful project

(Other) ____

What is the major sustainability factor you will use to evaluate your senior design project? (*Post-survey only*)

APPENDIX B.

Table 1: Sample questions proposed by the students using a six-factor approach (continued on the next page)

Factors	System	Time	Energy	Modeling	People	Scale
System	How does our robotic system interact with the IEEE maze systems? Will your system be compatible across other platforms?	What is the system lifespan? How long is it intended to operate?	How much energy does our system require to complete the task? What kind of energy will the system consume?	What necessary data do we need to collect to make sure our simulation model is a good representation of the real-life system? Is our maze consistent with IEEE?	What is the intended user? How are the people in the system affected?	How many buildings will we look at? How do we make sure that the scope of our project does not get too broad or too minimal?
Time		Is there a time constraint? How do we manage time on tasks and make sure to not spend unnecessary time on little tasks?	How long will the energy supply last? Can we limit the amount of time appliances being used, thus reducing the energy consumed?	Does the model give an accurate representation of the time involved in the Sabbatier process? How long will it take us to get an analysis (of) one building and model?	How long will the machine be able to operate without human intervention? How long will the machine be able to sustain people?	Do we have enough time to do a successful project for all 27 buildings? How does scaling the machine affect the time scale?
Energy			Does the energy that is already in place work for the new requirements that are going to be added to the system? Will IEEE provide an energy source to replenish our energy resource?	Can we model the system/component energy usage? What program will be used to model the energy consumption?	Will the machine produce enough energy required by the people in the context of the space grant? Depending on the day, economy, and the number of people around the building, what will the differences in the energy calculations be?	What are the energy requirement for a full size machine? Do we have enough energy produced by solar power to move the dome?

Table 1 (continued)

Factors	System	Time	Energy	Modeling	People	Scale
Modeling				How does our model of one building compare to another model of another building? Are the modeling systems that we are currently familiar with going to work for what we need to model?	How will the robot be modeled; user friendly? How do we incorporate the necessary people into our simulation model?	How detailed should be go into our simulation model? How can we model scalability since we will not be able to build a full size Sabbatier?
People					How do we keep people involved in our project and make sure to given up to date and accurate accomplishments of the project? How will users interact with this machine?	How will scalability affect use, and environmental consequence, for people? What scale of people with will this system effect?
Scale						Is the scale of which we will test our system relatable with the scale of the actual dome? How big of a scale of model should we make so that our project is applicable to different scale problems?