Evaluation of teaching approach and student learning in a multidisciplinary sustainable engineering course

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ABSTRACT

Teaching sustainability concepts to multidisciplinary classes of engineering students is challenging due to their diverse background and discipline-specific skill set and the interdisciplinary nature of the sustainability issues at stake. The present study was conducted to understand the challenges and identify opportunities for improving teaching and learning of sustainability in higher education institutions. The case study used for data collection was the Sustainable Engineering and International Development course taught at Iowa State University since 2005. We assessed the students' course content knowledge before and after the course and their perceptions about the overall course, content, and instruction methods. A mixed methods approach consisting of qualitative (focus groups) and quantitative (survey and pre- and post-assessment) techniques was used for the study. Quantitative data were analyzed using descriptive statistics, explanatory analysis, and multinomial logistic regression. Thematic analysis was used to evaluate the qualitative data. The difficulty level of the pre- and post-assessment was low. Application-based questions could be included in the assessment to test beyond the levels of mere comprehension and memorization. Student perceptions about module usefulness exhibited year-to-year variation, which was attributed to the diversity of students enrolled in the course each year. Barriers to learning in a multidisciplinary engineering course included student difficulties working in multidisciplinary teams, course organization, and limited student engagement in

SEID: Sustainable Engineering and International Development; ISU: Iowa State University; SB: Sustainability Background; ST: Sustainability Tools; WWS: Waste and Water Systems; ES: Energy Systems; AFS: Agricultural and Food Systems; BIS: Building and Infrastructure Systems; TEA: Techno Economic Analysis; LEED: Leadership in Energy and Environmental Design; AE: Agricultural Engineering; BSE: Biological Systems Engineering; CE: Civil Engineering; CHE: Chemical Engineering; CPRE: Electrical & Computer Engineering; EE: Electrical Engineering; ENGRS: Engineering; ME: Mechanical Engineering; MATE: Materials Engineering; IE: Industrial Engineering; SE: Software Engineering; CONE: Construction Engineering

projects. The assessment techniques were complementary, aiding in the identification of strategies to improve teaching and learning in multidisciplinary engineering environment.

Keywords: Multidisciplinary; Sustainability; Assessment; Engineering; Student Learning, Teaching Approach

1. Introduction

Higher education institutions have acknowledged their responsibility to achieve sustainability goals, as they play a major role in preparing future professionals (Filho, 2002; Woodruff, 2006). Therefore, academic institutions are focusing on campus sustainability as well as promoting sustainability research and education (Alshuwaikhat and Abubakar, 2008; Rose et al., 2015; Zwickle et al., 2013). Engineering students were introduced to the concept of sustainability after a common consensus was reached among professional engineering associations on the importance of sustainability in this field. Sustainability has also become an important component for professional engineer accreditation (Boyle, 1999). Initially, sustainability education was integrated into civil engineering and later into environmental and chemical engineering programs. With increasing environmental concerns, the recognition of the need for sustainability in other engineering disciplines has grown steadily (Glavič, 2006).

Sustainability science is generally not recognized as an autonomous field or discipline; however, it brings together disciplines and their scholarship, practice, global and local perspectives. Therefore, a goal of sustainability education is to create awareness and understanding about sustainability, issues, challenges and solutions (Kajikawa, 2008). Each institution and faculty has their own view and interpretation of sustainability engineering and its application in their educational program (Velazquez et al., 2006; Allenby et al., 2009). Sustainability engineering courses cover different topics relating sustainability to environment, biodiversity, water, urban and regional planning, energy, infrastructure, food security, economic development, and climate change.

There is increased pressure on institutions with engineering and environmental related subjects across UK, New Zealand and US to fulfil accreditation requirements related to sustainability (Zhan et al., 2015). Sustainability education consists of three dimensions: social, economic and environmental. Because of this multidisciplinary nature, finding effective ways to educate students about sustainability in relation to engineering is still an ongoing conceptual and practical challenge for several reasons (Zwickle et al., 2013; Allenby et al., 2009). First, sustainability is a broad concept, making it difficult to determine which sustainability topics to include in courses to best serve the students (Zhan et al., 2015). Secondly, colleges and institutions already have very full engineering curricula with little room to add courses, and incorporating sustainability topics would require substantial curricular changes (Shephard, 2008). Thirdly, sustainability science has many qualitative aspects, and the social dimension of sustainability may make engineering faculty uncomfortable to teach these topics (Allenby et al., 2009). Therefore, successful implementation of courses with sustainability foci usually requires collaboration of faculty from several different departments to develop and modify curricula to educate students about the social,

environmental and economic realms of sustainability (Glavič, 2006).

A major barrier to sustainability education is bringing together skills and knowledge from different disciplines. The interdisciplinary content and structure of sustainable engineering courses often results in student enrollment from different engineering majors. Disseminating sustainable engineering knowledge to a multidisciplinary group of students is challenging. Instructors often seek to provide relevant information to the multidisciplinary class with multiple modes of instruction (Clayton, et al, 2010).

Because of these challenges, the purpose of this study was to understand student perceptions of a multidisciplinary sustainability course as well as measure their knowledge and understanding of sustainability. The specific objectives of this study were to:

1. Evaluate students' perceptions about an example multidisciplinary sustainability engineering course and the teaching methods employed in it, and
2. Assess students' knowledge about sustainability and its implementation across various engineering systems.

2. Methods

2.1 Case study

To help engineering students learn about sustainability and engineering in developing world contexts, the Sustainable Engineering and International Development (SEID) course was developed and first offered to engineering majors at Iowa State University (ISU) in 2005. It has been taught every fall semester since 2005. The course is an elective for engineering juniors and seniors, with an average class size of 40 students. The course consists of six learning modules and a team project. The six learning modules are: Sustainability Background (SB); Sustainability Tools (ST); Waste and Water Systems (WWS); Energy Systems (ES); Agricultural and Food Systems (AFS), and Building and Infrastructure Systems (BIS). Team projects are focused on the application of sustainable engineering principles in the context of developed/developing world scenarios and constitute sixty percent of the course grade. The remaining forty percent of the course grade is derived from assignments and quizzes associated with the six learning modules. In several modules, guest lectures from topic experts are organized. Each week, the three-credit class meets twice for 50-minute lecture sessions and once a week for a 110 minutes laboratory session. Bhandari et al. (2011) described the course in detail as well as the learning outcomes, module topics and evaluation methods. The SEID course was selected for this study because of its unique challenges: (a) it addresses sustainability in the global context (b) it is composed of students from a diversity of engineering majors, and (c) its structure consists of multiple independent learning modules.

2.2. Survey, focus groups and pre-and post- assessment

A mixed methods approach consisting of qualitative (focus groups) and quantitative (survey and pre- and post-assessment) techniques was used for data collection. Two of the five course learning objectives were evaluated using pre- and post-assessment. Those learning objectives were to: a) describe, discuss and compare key concepts of sustainability, sustainable development and sustainable engineering, and b) describe, discuss, and evaluate the use of sustainable engineering principles in the design and

implementation of water and waste systems, energy systems, agricultural and food systems, and building and infrastructure systems. Other course learning outcomes are addressed using guest lectures, team exercises, team projects, exams and quizzes (Bhandari et al., 2011). However, evaluations of these course learning objectives were out of scope of the present study and were not analyzed.

The focus group approach is a qualitative research method with “a carefully planned series of discussions designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment” (Krueger and Casey, 2009). The open and interactive setting of the focus group provides good understanding of the students’ beliefs and experiences (Morgan and Krueger, 1998). In addition, focus groups provide opportunities to evoke more specific responses and gather ‘rich data’ which is not possible through the use of surveys (Weight and Hendershott, 1992). The small number of participants in focus groups provide opportunity for in-depth discussion. However, the small number of participants may not be representative of students enrolled in a course. Integrating a qualitative research approach such as focus groups with a quantitative instrument such as a survey improves the quality and enhances the validity of the results (Wolff and Sittitrai, 1993). These two approaches complement each other and strengthen the likelihood of researchers drawing conclusions from the study. Therefore, focus groups with surveys were used to get detailed feedback from students and to better understand student perceptions about the methods of instruction, course content, and their overall course experience.

Pre- and post-assessments are widely accepted as a viable method to quantify the knowledge attained by the students with diverse learning styles and educational backgrounds in a course (Newton, 1999). By comparing the results from pre- and post-assessments, the success of a course in increasing participant knowledge and understanding of the course content can be measured (International Training and Education Center of Health, 2010). Pre- and post-assessment was used to assess students’ achievement of two course learning objectives.

Focus groups and pre-and post-assessments were conducted in Fall 2014 term and survey data was collected for the years 2010, 2011, 2013 and 2014 for the fall term (Table 1). The survey was administered in the class; therefore, most of the students enrolled in the course each year participated in the survey. The survey questions provided feedback on the usefulness of course content, instruction methods, and students’ self-assessment. The survey consisted of two sections: the first section consists of ranking the usefulness of the individual learning modules using a five point Likert-type scale (1 = not useful, 2 = somewhat useful, 3 = useful, 4 = very useful, and 5 = critical). The second section involved students indicating their agreement with statements about perceptions about the overall course, instructional methods, and individual learning using a five point Likert-type scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). The comments section in the survey was added to obtain additional information about topics to be included, excluded, or taught differently in the future. The data collected for the first section of the survey for the years 2010, 2011, 2013 and 2014 were analyzed to evaluate usefulness of the six learning modules using multinomial logistic regression.

Table 1

Summary of the methods and time for conducting the intervention for quantitative and qualitative data collection

Measure students' perceptions	
<i>Methods</i>	<i>Time during term</i>
Survey	End of the term (Fall: 2010, 2011, 2013, 2014)
Focus groups	Near end of the term (Fall: 2014)
Measure knowledge attained	
<i>Methods</i>	<i>Time during term</i>
Pre-assessment	Beginning of the term (Fall: 2014)
Post-assessment	End of the term (Fall: 2014)

Near the end of the Fall 2014 term, focus group discussions were conducted to understand students' perceptions about the course. The focus group planning kit was used to design the focus group discussions (Morgan and Krueger, 1998). Two focus groups were formed with eight participants (20 % of those enrolled in the course) from five engineering majors composed of one junior, six seniors and one graduate student. An experienced moderator and assistant moderator facilitated the discussion and took notes, respectively. The focus group discussion was recorded and transcribed. Focus group questions were developed after having conversations with instructors of the course. The second section of the survey which included the ranking of overall course, instructional method, and self-assessment for the year 2014 was supplemented with focus group discussions data to understand student's perceptions about the course.

Single group, pre and post-assessments (Bishop-Clark et al., 2012) were conducted at the beginning and end of the Fall 2014 term to measure student learning in the SEID course. The assessment consisted of 20 multiple-choice questions and was moderated through the online learning management system. The questions span topics covered in the six learning modules of the course. An incentive of a 1% increase in quiz grade was given to the students who completed both pre- and post-assessments.

Validated evaluation instruments were not available to be used for this particular study therefore all interventions were designed by instructors for the course. Institutional Review Board (IRB) approval was sought, and the study qualified as exempt. Student participation in these assessments was voluntary.

2.3. Data analysis

The first section of the survey explained student perception of individual learning module usefulness for the years 2010, 2011, 2013 and 2014. These data were analyzed using multinomial logistic regression with standard statistical software (SAS Version [9.3], Cary, NC, US). Survey data was not collected for the year 2012 due to an instructor being on leave. Logistic regression resulted in an odds ratio which was used to interpret the survey data results on usefulness of each course module. An odds ratio is the measure association between the two groups/variables (McHugh, 2009; Szumilas, 2010). The odds ratio of one, greater than one, and less than one indicates that both groups have same odds, the control group is better than intervention, and the intervention is better than control, respectively. In the present study, the odds ratio enabled comparison between the usefulness of learning module pairs. Within each year, all possible learning module combinations were analyzed.

Transcribed data from the focus group discussions were reviewed by two

researchers independently, and themes were identified. After individual review, researchers discussed and agreed upon theme and sub-theme categories. In addition to manual coding, qualitative data analysis was done using qualitative data analysis software (NVivo, QSR International, Doncaster, Australia) to identify the important themes and visualize relationship between the themes. Word frequency was analyzed to determine the most frequent words used by the participants. Explanatory analysis was used to identify and discuss patterns in focus group data and the second section of the 2014 survey (ranking of overall course, instruction method, and self-assessment).

The difficulty level of the pre- and post- assessment was measured by finding the percentage of students who get each question correct (ranging from zero if no one answered the question correctly to one if everyone answered correctly). A difficulty level of 0.5 is considered ideal but may vary depending on the subject area (Maloney et al., 2001). The data were analyzed using the paired t-test in a statistical analysis software (SAS Version [9.3], Cary, NC, US)

3. Results and discussion

3.1. Survey (Years: 2010, 2011, 2013, and 2014)

Using the survey data, the odds ratio indicated if the student perceptions of module usefulness was the same or different for learning module pairs. For example, when comparing the usefulness of the Sustainability Background (SB) and Energy systems (ES) modules in the year 2010, the odds ratio of 0.47 indicated that the odds of SB module being less useful were 0.47 times the odds of the ES module being less useful (Table 2). This result indicated that students found the SB module more useful than the ES module in 2010. Additionally, an odds ratio of 1.98 was obtained in the year 2010 when comparing the usefulness of the Sustainability Background (SB) and Water and Waste Systems (WWS) modules (Table 2). This result meant that the odds of the SB module being less useful were 1.98 times the odds of WWS module being less useful. Therefore, statistical evidence may show students found the WWS module more useful compared to the SB module. The 95% confidence intervals on the odds ratios were also calculated. If the 95% confidence interval does not contain one, it indicates that the odds ratio is significantly different than one, and the odds are that one module is less useful than the other at the 5% significance level.

Overall, there were 19 learning module pairs in which the usefulness of one module was significantly different than that of the other module (Table 3). Examining the results by individual years, eight, five, six and zero learning module pairs had significant differences in usefulness for the years 2010, 2011, 2013, and 2014, respectively. While this result does not indicate an overall increase in perceived usefulness by the students, it may indicate that the odds of similar usefulness across the module were increasing. A possible explanation is that the course structure may have become more coherent across multiple instructors and guest lecturers, something that the instructors indicated was a challenge.

Examining the Sustainability Tools (ST) module more closely, it was less useful than three, five, and four other modules, in 2010, 2011, and 2013, respectively. There are a couple possible reasons for the relatively low perceived usefulness of the ST module. First, during these years, there was a transition in the instructors of this module. In 2010, it was taught by the course instructors. In 2011 and after, the module was taught

by a guest lecturer who was a new faculty member. Thus, this module may have been perceived as less useful as an instructional transition was taking place. Another reason could be the order in which this module was taught. After 2010, a guest lecturer, depending on his availability, the ST module was taught usually near midterm. In the focus group discussions conducted in 2014, students suggested re-ordering the module sequence. They specifically mentioned that the ST module should be the second module after the SB module for improved conceptual flow. The sequence of modules is important to enhance student learning, and having the ST module taught later in the semester could have contributed to student perceptions of it being less useful compared to other modules.

These perceptions are consistent with the literature. Generally, a course should proceed from teaching simple and familiar topics to complex and unfamiliar topics (Mysels and Copeland, 1951). Topic sequencing should enable students to integrate new topics with those that proceed so that topics build on one another (Fink, 2003). Specifically, in a multidisciplinary course, it may be challenging for students with different backgrounds to make meaningful connections to the previously taught content as they proceed in the course. Thus, topic sequencing should be carefully considered as a part of course development.

In the year 2014, there was no evidence of any module being less useful than another at the 5% significance level. A possible explanation is that the course structure became more coherent and consistent over time. Another reason could be that the students were more diverse in 2014. The students were from ten engineering majors (Fig. 1), and their perceptions about individual modules could differ from each other because of the diversity of academic backgrounds.

Apart from these notable patterns, student perceptions about module usefulness exhibited more year-to-year variation than consistent patterns. This variability was attributed to varying students in the class each year with diverse majors and pre-existing knowledge. In addition, student classification (junior or senior), gender, and race/ethnicity could impact their perceptions about usefulness of topics related to sustainability (Cech, 2014). Also, over the five years associated with the study, there was natural progression in course improvements that may have contributed to differences in student perceptions.

Table 2

Results of the logistic regression model for comparison of learning modules over the years.

Module	2010	95% CI	2011	95% CI	2013	95% CI	2014	95% CI
SB - ES	0.47^a	0.22-0.97	0.97^a	*0.65-1.45	1.57 ^b	1.03-2.39	1.49 ^b	*1.03-2.17
SB - WWS	1.98 ^b	*0.91-4.31	1.36 ^b	*0.90-2.05	1.20 ^b	*0.81-1.80	1.37 ^b	*0.94-1.98
SB - AFS	2.15 ^b	*0.67-6.93	1.59 ^b	*0.85-3.00	1.30 ^b	*0.69-2.42	1.13 ^b	*0.65-1.99
SB - BIS	0.54^a	*0.24-1.23	1.12 ^b	*0.70-1.81	0.76^a	*0.48-1.22	1.11 ^b	*0.72-1.70
SB - ST	0.32^a	0.11-0.96	0.34^a	0.21-0.55	0.57^a	0.36-0.91	1.47 ^b	*0.96-2.27
ES - WWS	4.25 ^b	1.70-10.67	1.40 ^b	*0.87-2.26	0.77^a	*0.47-1.25	0.91^a	*0.59-1.42
ES - AFS	4.64 ^b	1.31-16.43	1.64 ^b	*0.83-3.24	0.82^a	*0.42-1.63	0.76^a	*0.41-1.40
ES - BIS	1.16 ^b	*0.45-2.99	1.16 ^b	*0.68-1.98	0.49^a	0.28-0.84	0.74^a	*0.45-1.22
ES - ST	0.69^a	*0.21-2.24	0.35^a	0.20-0.60	0.36^a	0.21-0.63	0.99^a	*0.60-1.62
WWS - AF	1.09 ^b	*0.30-3.94	1.17 ^b	*0.59-2.32	1.08 ^b	*0.55-2.11	0.83^a	*0.45-1.53
WWS - BIS	0.27^a	0.10-0.74	0.83^a	*0.48-1.42	0.63^a	*0.37-1.08	0.81^a	*0.50-1.33

WWS - ST	0.16^a	0.05-0.55	0.25^a	0.14-0.43	0.47^a	0.28-0.81	1.08 ^b	*0.66-1.77
AFS - BIS	0.25^a	0.07-0.94	0.71^a	*0.34-1.46	0.59^a	*0.29-1.20	0.98^a	*0.51-1.87
AFS - ST	0.15^a	0.03-0.67	0.21^a	0.10-0.44	0.44^a	0.21-0.90	1.30^a	*0.68-2.48
BIS - ST	0.59^a	*0.17-2.06	0.30^a	0.16-0.55	0.75^a	*0.42-1.34	1.33^a	*0.78-2.28

Note: Learning Modules: **SB**: Sustainability Background; **ES**: Energy Systems; **WWS**: Water and Waste Systems; **AFS**: Agricultural and Food Systems; **BIS**: Building and Infrastructure Systems; **ST**: Sustainability Tools. *shows the modules comparison in which the 95% confidence interval for odds ratio that contains value one. ^a indicates the cases in which the module in first position is more useful than module in second position. ^b indicates the cases in which the module in first position is less useful than module in second position

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Table 3

Results of the logistic regression model for number of significant differences in usefulness of learning modules pairs by year

Learning Module	2010	2011	2013	2014
Sustainability Background (SB)	2	1	1	0
Energy Systems (ES)	0	1	3	0
Water and Waste Systems (WWS)	3	1	1	0
Agricultural and Food Systems (AFS)	3	1	1	0
Building and Infrastructure Systems (BIS)	0	1	0	0
Sustainability Tools (ST)	0	0	0	0

Fig. 1. Number of students enrolled in SEID course by majors over the years.

Note: N= Total number of students enrolled in the course. N=23 (2010); N= 31 (2011); N= 38 (2013); N= 46 (2014)

Note: **AE**: Agricultural Engineering; **BSE**: Biological Systems Engineering; **CE**: Civil Engineering; **CHE**:

Chemical Engineering; **CPRE**: Electrical & Computer Engineering; **E E**: Electrical Engineering; **ENGRS**: Engineering; **ME**: Mechanical Engineering; **MATE**: Materials Engineering; **IE**: Industrial Engineering; **SE**: Software Engineering; **CONE**: Construction Engineering

Use of the odds ratio to quantify student's perceptions in this study was a novel approach to understand how students perceived usefulness of modules relative to one another and how those perceptions changed over time. Other studies of student perceptions using survey questions answered with Likert scale responses have reported results in terms of frequencies, percentages, and chi-squared and Kruskal-Wallis test statistics (Kagawa, 2007, Bhandari et al, 2011, Miller et al., 2005, Emanuel and Adams, 2011, Lake, 2001). Frequencies and percentages indicate the relative occurrence of particular Likert scale responses relative to total number of responses. Bhandari et al. (2011), for example, presented response frequencies in pie charts to report student perceptions if a sustainability engineering course improved their ability to consider key aspects of sustainability in engineering design. Percentages and frequencies can show response patterns; however, they alone do not offer a means to assess statistical significance in those patterns. The chi-squared and Kruskal-Wallis test assess whether categorical variables are statistically associated with each other. Emanuel and Adams (2011) found that majority of respondents agreed or strongly agreed that universities should make sustainability a priority in planning operations and found statistically significant differences between the categorical response variables. The odds ratio measures the association with a means to assess statistical significance (Lovelace, and Brickman, 2013).

3.2. Focus group and survey (Year: 2014)

Focus group data were classified into themes and sub-themes through an inductive approach by reviewing the transcripts and identifying repetitions and transitions. Three major themes were identified: course organization, content knowledge, and skill development. Within these major themes, there were nine sub-themes (Table 4).

Chart document coding analysis showed that 33% of the focus group discussions time was spent on the course organization theme (sub-themes: expectations, enrollment, format, and components). Qualitative (focus groups) as well as quantitative (survey) data showed that the overall student expectations from the course were met. However, students wanted to learn more about sustainability in the context of developed countries and sustainability quantification (Table 4). Student interest in sustainability, the international aspect of the course, the multidisciplinary nature of the course, and major/minor requirements were some of the reasons students enrolled in the SEID course. Students embraced the modular format of the course, and this format worked well to enhance their understanding of the subject matter (Fig. 2, Table 4). However, students suggested re-ordering of modules to fit the flow of the course content (sustainability tool module moved to second position instead of being the fourth module taught in class). Students appreciated guest lectures from topic experts because they provided different points of view and were perceived to effectively facilitate student learning. The project component of the course was also well received by the students because it provided the students an opportunity to apply the sustainability concepts taught in class to different engineering systems. Richter and Paretti (2009) also found

providing students with opportunities to apply interdisciplinary subject knowledge to solve complex problems enhances their interest and involvement.

Students also suggested providing supplementary material and additional lectures on agricultural system topics. In 2014, the course had several team projects that focused on agricultural topics, so background information about agricultural technologies would have been helpful for students from non-agricultural majors. Students also suggested that smaller projects rather than a semester long project would be more effective for students to apply concepts learned in the course.

About 12% of the focus group discussions focused on the content knowledge theme. Students were largely able to make the connection between sustainability and engineering. They attributed the group projects as the main component helping them understand this connection. They suggested incorporating frameworks for quantitative evaluation of sustainability for various engineering systems discussed in learning modules such as life cycle assessment (LCA) for other systems. Students found the LCA component of the sustainability tool module to be most useful for their understanding of sustainability and its application. Students were of the view that sustainability is an integral part in any design process. They liked the triple bottom line concept presenting environmental, economic and social aspects of sustainability. In addition, they also found working in multidisciplinary teams to be extremely beneficial. It helped them improve communication and time management skills.

Table 4

Focus group themes and illustrative quotations for students' perceptions about the course.

Themes	Sub-Themes	Illustrative Quotations
Organization	Expectations	"So I would say, more or less, ya, my expectations were met..."
		"Okay. Well, being in electrical engineering, I definitely thought of sustainability as conserving energy, turning out the lights, finding/using LED lights, everything under the sun that would reduce energy inputs. Of course, after being in the class for almost a whole semester, I realized it's not just energy. it's definitely changed to a lot larger."
		"It, going in, I kind of expected, again, a little bit more in the ... along the lines of showing us examples of sustainability and talking about a little bit more modern stuff, stuff that we'll see in in the U.S. and around here"
	Enrollment	"But I think it would have been nicer to actually dig into some of those developed world as we dug into the third world country examples"
		"I needed to fulfill a tech elective and looking at tech electives, like what I am actually interested in. And I saw sustainability and sustainability's something that's always been of interest to me"
		"And just wanted to learn more about it (sustainability)"
	Format	"I thought it sounded like a really interesting course just from the description"
		"I like having the separation between the different units"
		"we adjusted the LCA module and that might have been helpful to know as we worked through the previous modules in our projects"
		"Just a little bit more in depth... some of the stuff we went over seemed very basic and kind of obvious which, I mean, it's good to go over that, to like make sure that everyone understands it but, I mean, for one of the homework assignments, it was like just plugging in the numbers into a calculator and then you get the results and like ."

Content knowledge	Components	<p>"I like the guest lecturers"</p> <p>"I definitely like the combination of the two, the guest lecturers and the projects"</p> <p>"Just more information on agriculture side. And a lot of the projects have been ag-based that lot of students doesn't get in their normal curriculum, especially EE..."</p> <p>"I would rather do like two smaller projects than one giant"</p>
	Sustainability in context of engineering	<p>"The group projects have helped most in kind of engineering sustainability cause we're like looking at a problem, applying it"</p> <p>"I mean, I still think that's cool but I was looking for more of an engineering thing"</p> <p>"And especially in an engineering course, all of us are going in with the background and the expectation of problem solving so, when it's mostly fact based memorization"</p>
	Learning modules	<p>"feel like the LCA was probably the most critical part of this class"</p> <p>"LCA was the most useful piece of information from the class"</p> <p>"Energy systems module: This was needed greatly as our group project relied heavily on green energy and our group was all civil engineering. We had little previous exposure. It would have been nice to learn more to help us with project."</p>
	Sustainability in context of design	<p>"Ya, I would say it should be considered but I don't think it's always possible to apply it"</p>
	New concepts	<p>"As we were going into the class, I just thought it was strictly environmental which I feel like is a very common misunderstanding among most people so I really enjoyed it and understand there's a social aspect to that too."</p> <p>"Before, I'd think of sustainability as just being green, a general thought so like having a method to kind of define what it means for each situation and look at the triple bottom line like in different ways that we can measure and attain it"</p>
	Teamwork	<p>"It helps us develop deadlines and just work on your communications skills with others"</p> <p>"I have learned how to interlink my knowledge with what other people know and get to appreciate that doing the project"</p>

Fig. 2. Student evaluation responses (percent students) to the question: The modular format for this course was appropriate and worked effectively.

3.3. Pre- and post-assessment (Year: 2014)

The overall response rate for pre- and post- assessment was 61%. The difficulty level of pre- and post-assessment was low with 77.3% of the questions answered correctly in the pre-assessment and 87.3% in the post-assessment. The percentage of questions answered correctly was significantly higher ($P=0.0365$) in the post-assessment than in the pre-assessment which indicated that there was a learning gain associated with the course.

Examining the results on a question-wise basis was fruitful (Fig. 3). For example, three questions were answered correctly in both the assessments. In the case of three other questions, the average percent correct response in the post-assessment compared to pre-assessment was lower; however, the average decrease was only 2.13%. However, for thirteen questions, there was an increase in the post-assessment scores compared to the pre-assessment. On an average, the increase was 19%. Examples of pre and post-assessment questions were provided in the supplementary materials.

Fig. 3. Students' response to pre-and post-assessment by question and module type. **Note:** Learning Modules: **SB**: Sustainability Background; **ES**: Energy Systems; **AFS**: Agricultural and Food Systems; **ST**: Sustainability Tools; **WWS**: Water and Waste Systems; **BIS**: Building and Infrastructure Systems.

Through evaluation of student responses to the specific questions from the Sustainability Background (SB) module, it was found that 43% and 32% of the students in the pre- and post-assessment, respectively, were not aware of the percentage of world resources consumed by the U.S (Question 4, Fig. 3). On average, 92% of the students in the pre and post-assessment correctly answered questions related to steps

involved in the engineering design process (Question 1), meaning of sustainability engineering (Question 2), and the federal agency in the U.S. that oversees environmental regulations (Question 3).

Three out of the four questions from the Energy Systems (ES) module were answered correctly by all students in the pre- and post- assessment. Students demonstrated knowledge about types of renewable energy sources (Question 6), energy resources most widely used for electricity generation in the U.S. (Question 8), and transportation fuel made from corn (Question 9). The pre- and post-assessments results for questions about the primary reason for rise in oil prices (Question 5, Fig. 3) and which country is the biggest emitter of the greenhouse gas carbon dioxide (Question 7, Fig. 3) showed an increase in students' knowledge. In their responses, 79% of students in the post-assessment knew that China is biggest emitter of carbon dioxide (Question 7, Fig. 3).

The results from the Agricultural and Food Systems (AFS module) questions revealed that students knew about sustainable agriculture practices (Question 10) and understood that GMO stands for Genetically Modified Organisms (Question 11, Fig. 3). The pre-assessment showed that students were not aware of the goal of the Green Revolution as only 43% of students answered the question correctly and 28% opted for choice E (don't know) (Question 12, Fig. 3). In the post-assessment, 82.14% of students knew that an increase in agricultural output was the main goal while none of the students opted for choice E (Don't know) and 17.85% of the students selected other options (To decrease population growth in developing countries; Establishment of economic equality; Introduce western culture and values in the developing countries).

The TEA (Techno Economic Analysis) question (Question 15, Fig. 3) from the Sustainability Tools (ST) module was correctly answered by 40% and 85.71% of students in pre-and post-assessment, respectively. The response of students to the Water and Waste Systems (WWS) module questions indicates improvement in understanding of the concepts taught in the module (Question 16, 17, 18, Fig. 3). Pre and post-assessments results showed changes from 51% to 68%, respectively, of students knowing the primary reason for hypoxic areas in the Gulf of Mexico and 72% to 92%, respectively, knowing the causes for turbidity in water and 60% to 86%, respectively, knowing that the agriculture sector consumes the largest amount of water. For the Building and Infrastructure (BIS) systems questions (Question 19, 20, Fig. 3), on average, 96% of the students understood what a Leadership in Energy and Environmental Design (LEED) rating reflects and a shift was seen from 65% to 93% of students knowing that the State Gym at Iowa State University is LEED certified in the pre-and post-assessment, respectively.

Pre- and post-assessments directly measure student background knowledge and student learning (Newton, 1999, Delucchi. M., 2014). In this study, the results from the pre-and post-assessments showed that students performed well in answering the fundamental/foundational questions about sustainability and showed student learning in the course. However, weak performance was mainly observed in questions bounded by time, which indicated students lacked knowledge about current sustainability issues.

The results also indicated that the assessment had a low difficulty level as evidenced by relatively high pre-test scores. The design of the assessment is crucial and should consider questions such as why the evaluation is conducted and what is

being evaluated. A balanced set of questions, varying in difficulty level should be developed after taking input from experts, conducting focus group discussions, and pilot testing (Zwickle et al., 2013).

3.4 Barriers in multidisciplinary engineering courses

There is an increasing demand for engineers who can successfully work in interdisciplinary contexts (Richter & Paretti. 2009). Sustainability is a broad, global issue so engineers along with experts from multiple disciplines from all over the world must collaborate to develop better solutions. Teaching effective ways for students to communicate, function in diverse teams, and embrace other ideas are key competencies engineers need to create successful sustainable solutions (Savage et al, 2007, Gruba and Al-Mahmood, 2004). Mainstream academics recognize the demand for these competencies and actively seek pedagogical practices to prepare students for the real world. Today's engineers must work in a complex global context. However, they are generally trained in a narrow disciplinary focus (Amadei, 2014). There is need for educational models which include both depth in technical knowledge and breadth in general education (Grasso and Burkins, 2009).

Multidisciplinary courses have potential to achieve some of these goals of providing a broader engineering education and better prepare students for current and future real-world contexts (Altringer, and Habbal, 2015). However, multidisciplinary courses pose some additional challenges related to course content, preparation and organization, structure, and delivery (Hatipkarasulu, et al., 2012). Essential components of multidisciplinary courses are team projects and in-class active learning activities that promote student learning and prepare engineers to solve real-world problems (Bielefeldt, A.R., 2013, Desjardins, et. Al., 2010). The SEID course had these components from the instructor's perspective, but the student perceived challenges to effective learning in the multidisciplinary course. Three challenges became apparent from the assessments.

First, the multidisciplinary nature of the project teams was perceived as a barrier to learning instead of enhancement to learning. Reasons for this barrier included difficulties in communicating between team members of different disciplines. The project teams consisted of five to six students chosen by the course instructors to ensure interdisciplinary diversity within the teams.

Additionally, the students had limited project and time management skills thus creating difficulties in managing their open-ended team projects. Engineers must have a solid understanding of project management concepts as project success in the workplace depends on effective and efficient proper management. Therefore, emphasizing project management in engineering curricula is crucial (Panuwatwanich et al., 2011).

The students also had limited capability to make connections between their own disciplinary background and the knowledge required for the project or the background knowledge of their team members from other disciplines. Richter & Paretti (2009) describe this effect as negative relatedness, and it reflects the tendency to narrowly train engineers to be experts in their disciplinary topics with little emphasis on topics outside their discipline.

Second, course organization was perceived to be a barrier to learning because some modules were not in a sequence that enabled the multidisciplinary students to

build on their knowledge. In a multidisciplinary course, it may be challenging for students with different backgrounds to make meaningful connections to the previously taught content as they proceed in the course. Thus, topic sequencing should be carefully considered as a part of course development.

Third, the teams did not deeply engage with the projects, which limited their learning from the experience. This lack of engagement may be due to a limited motivation to self-learn and self-manage their projects. Additionally, the student recommended more accountability from instructors for project implementation. Limited time and project management skills may also be a factor that hindered project engagement.

4. Conclusions

Assessing the nature of teaching and learning in a multidisciplinary sustainable engineering class can be a challenge. Through this study the following conclusions were drawn:

1. The use of multiple assessment techniques provide a means for gaining deeper understanding of student perceptions and learning, which is particularly helpful in the case of a multidisciplinary class. Multiple assessments that are complementary in nature are particularly valuable. In the case of this study, surveys and focus groups provided both quantitative and qualitative measures of student perceptions of the course. The pre- and post- assessment provided a direct measure of student learning. Measuring student learning answered questions about what type of learning took place in the course, while uncovering student perceptions often answered questions about how learning occurred.
2. Multidisciplinary courses have good potential to train engineers to bring a sustainability perspective into their practice; in fact, we cannot envision training engineers in sustainability in a strictly disciplinary context. Nevertheless, because of the narrowly focused nature of engineering education, a multidisciplinary course presented several barriers or challenges of which an instructor should be aware. These barriers included students having limited project management and communication skills, students with low capability to connect with others outside their disciplines and course organization leading to students having difficulty in connecting to the course topics. We believe effective multidisciplinary course design can overcome many of these barriers.

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