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A New Multidisciplinary Course in Sustainability using a Combination of Traditional Lecture and Self-Directed Study Modules

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Abstract

Not only are energy and sustainability important topics in industry and in the public sector, they are topics of interest to engineering students as well. As a result, it is important to find innovative ways to incorporate energy and sustainability into the various curricula for all disciplines of engineering. This contribution will describe the development and implementation of a new, multidisciplinary elective course called Concepts, Assessment Tools and Methods in Sustainable Power and Energy at the University of Kentucky. This course utilizes a combination of traditional lecture and self-directed study modules to deliver course content to students in any engineering discipline. Additionally, the use of an interactive television connection to allow students at the University of Kentucky main campus in Lexington, the Extended Campus in Paducah, off campus graduate students and students at other in-state universities enrolled in the course to attend lecture and participate in classroom discussions will be described.

Background

What is Sustainability?

The impacts of energy use and production on the environment and the economy are of increasing concern to the general public, the energy manufacturing sector and educators. Ensuring that the natural resources required to produce the energy and fuels needed by society are utilized in a way that ensures their availability for future generations is the core of the broad field of sustainability. In *Our Common Future*, the U.N. World Commission on Environment and Development, also commonly called the Bruntland Commission, defined sustainable development as follows:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Bruntland, 1987)

Although there is no single accepted definition, the Bruntland Commission's concept of sustainable development points to the general goals. For engineers in particular, sustainability has come to mean designing, operating and maintaining products and processes in a manner that is economically viable, environmentally benign, and beneficial to society. In other words, a sustainable product or process is designed, operated and maintained to meet the "triple bottom line" of economics, environment and society, both now and in the future.

Sustainability Education

Students transitioning into the workforce after receiving an undergraduate or graduate degree in engineering will increasingly be entering careers that require understanding both sustainability and renewable energy. Therefore, it is more important than ever that students be introduced to these challenges as part of their engineering education. The National Academy of Engineers stated this need in its *The Engineer of 2020: Visions of Engineering in the New Century*:

"It is our aspiration that engineers will continue to be leaders in the movement toward the use of wise, informed, and economical sustainable development. This should begin in our educational institutions and be founded in the basic tenets of the engineering profession and its actions" (NAE, 2004).

Sustainability has become a key topic for accreditation for engineering departments. ABET Criteria 3, defines specific student outcomes both directly and indirectly related to sustainability:

(c) an ability 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,
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,
(f) an understanding of professional and ethical responsibility,
(j) a knowledge of contemporary issues,
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Unfortunately, exactly how to incorporate sustainability in engineering education remains a challenge to the academic community (Davidson, *et al.*, 2010),(Allen, *et al.*, 2006). However, because of the ambiguity in defining the term sustainable engineering, there is little consensus in the education community as to how it should be taught (Allenby, *et al.*, 2009). Furthermore, there is no clear consensus as to what educational outcomes define student competency in sustainable engineering. Based on this, courses that provide sustainability related content and needed more than ever. The multidisciplinary course at the University of Kentucky described herein is an attempt to meet this need.

Making the Case for Sustainable Power and Energy

Recent data underscores the growing importance of considering sustainability principles in engineered systems. World consumption of energy has been growing for decades and continuing to be able to supply this energy in a cost effective way is an ongoing challenge. Recent data published as part of the British Petroleum World Energy Report (BP, 2012) illustrate the growth of world energy usage. See Figures 1 and 2.

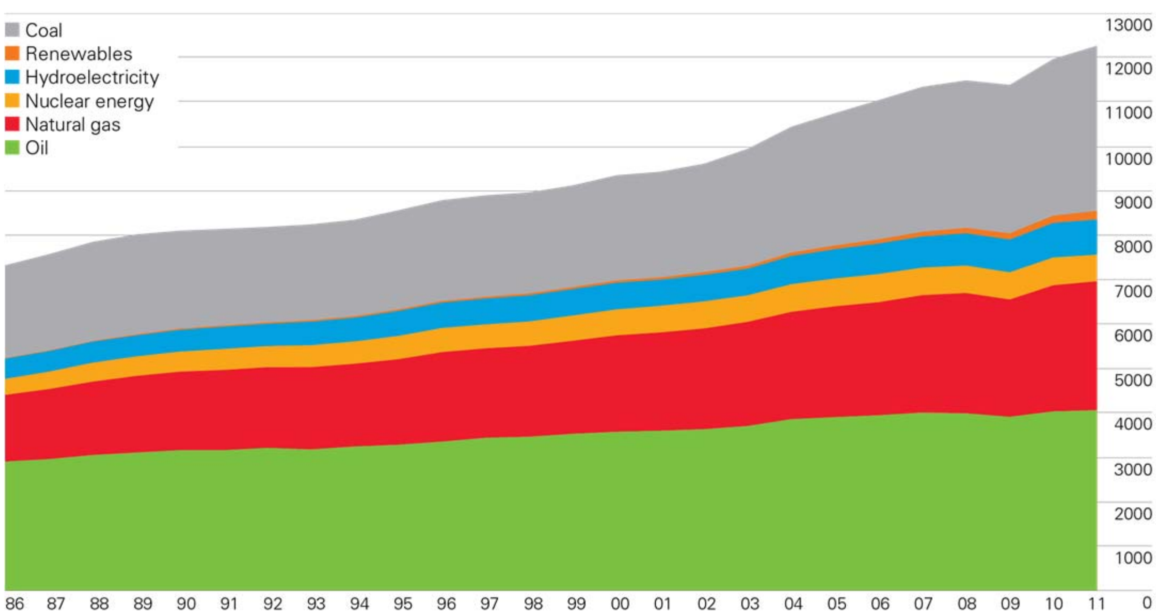

Figure 1: Recent world energy consumption (BP, 2012).

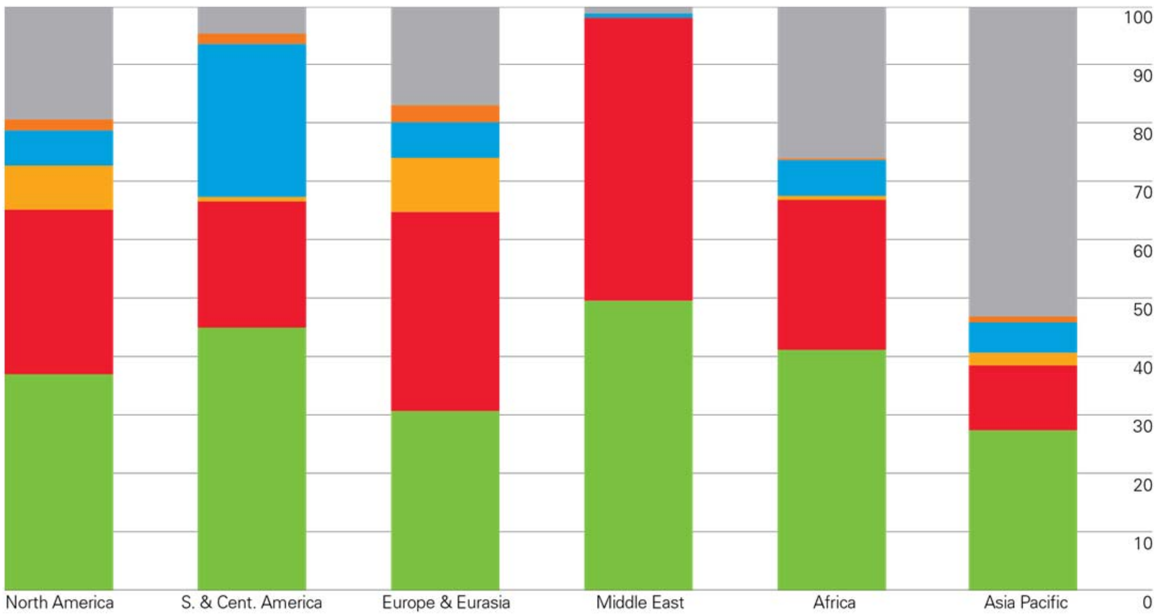

Figure 2: World energy consumption by region and type (BP, 2012).

In addition, the global environmental impacts of the continuing use of fossil fuel are a concern to both the general public and the industrial manufacturing sector. The trends illustrated here again reinforce the need for introducing energy concepts to engineering students. Since sustainability includes not only environmental concerns, but also economic and societal impacts, the costs of primary fuels are also a concern. Data from the BP *Statistical Review of World Energy 2012* shows the historical trend of crude oil prices, as illustrated in Figure 3 (BP, 2012). Other primary fuels sources like coal and natural gas show similar historical trends of increasing prices.

Although biofuels continue to be a small fraction of the total world energy portfolio, their utilization is increasing worldwide, particularly in North America. This trend is illustrated in Figure 4. As a result, biofuels must also be a part of any course on sustainable power and energy. Based on this data, it is clear that world energy usage is rising in all regions and becoming more expensive. Designing and operating manufacturing systems within this climate will require future engineering graduates of all disciplines to understand the key concepts of sustainability and be able to apply the tools and methods of power and energy assessment.

Concepts, Assessment Tools and Methods in Sustainable Power and Energy

This new course focusing on sustainable power and energy is included as part of the Power and Energy Certificate program at the University of Kentucky. The Power and Energy Certificate is an add-on to graduate or undergraduate degrees in engineering. Developing a multidisciplinary course of this type also presents some challenges due to the fact that each engineering discipline approach the topic from a slightly different perspective, and the academic backgrounds are different in each discipline as well.

This course is intended for upper division undergraduates and graduate students and, as previously noted, is multidisciplinary, so the material is intentionally generic, without going in depth with discipline specific material. The purpose of this course is therefore to introduce undergraduate and graduate engineering students to the principles and tools involved in utilizing renewable energy and analyzing processes for sustainability and environmental impacts. The course does not require any previous background in sustainability – in fact, it is organized under the assumption that this course is the student's first introduction to sustainability.

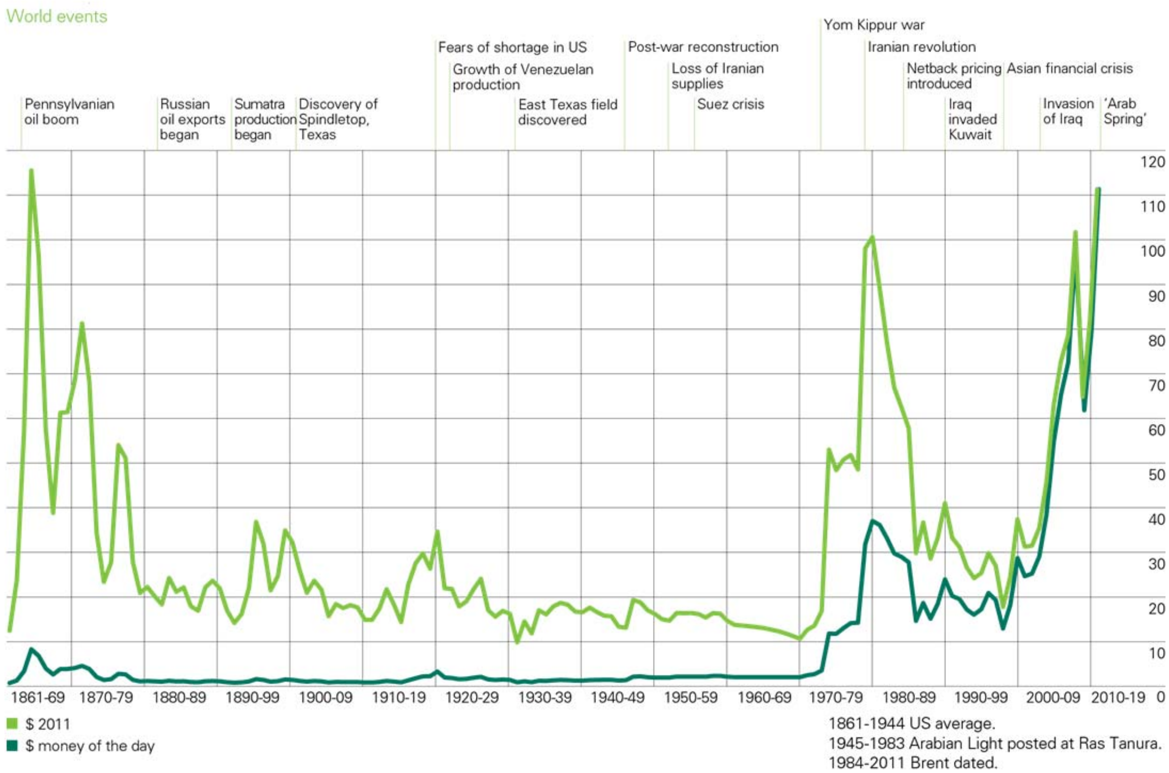

Figure 3: Average history of crude oil prices from 1861 to the present (BP, 2012).

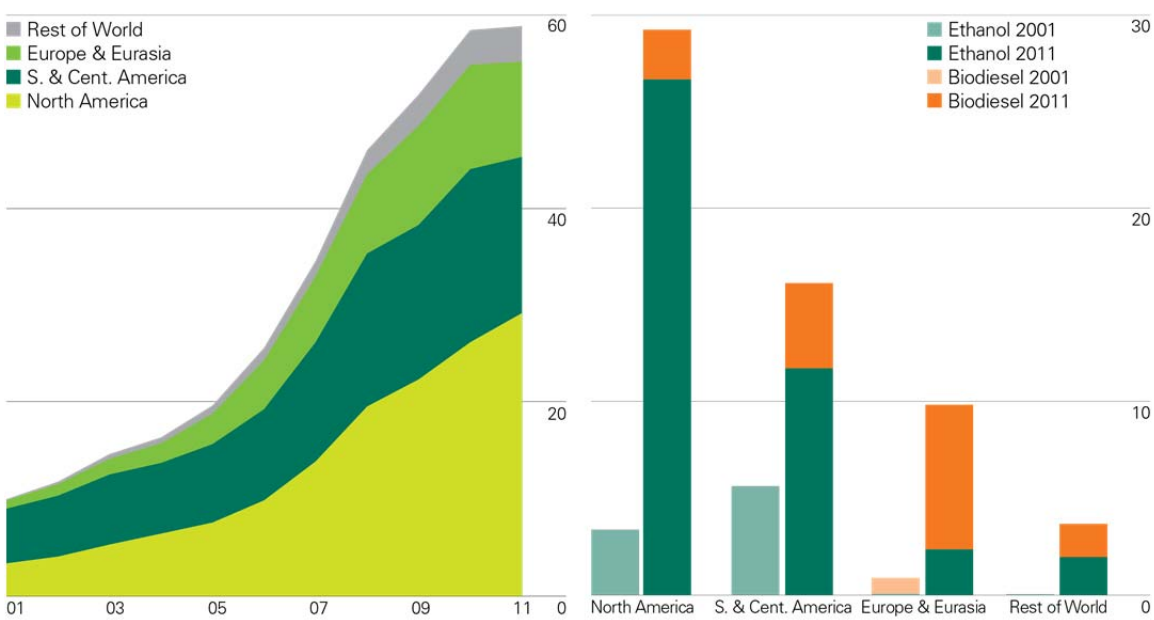

Figure 4: World biofuel production by region (BP, 2012).

Thermodynamics is the common language of most engineering disciplines. In this multidisciplinary course in sustainability, maintaining a focus on thermodynamics ensures a common basis for all students. Since thermodynamics is the only engineering prerequisite for the course, topics like power and energy integration (thermal pinch assessment), exergy analysis, site-wide energy assessment and the solar basis for both fossil and renewable fuels are prominently featured. Furthermore, all manufacturing processes utilize power and energy in some way. This focus makes the course relevant to each engineering discipline. Sustainability includes the triple bottom line of environment, economy and society, so this course seeks to bring a global perspective to the fundamental issues in sustainable power and energy generation.

Multidisciplinary and Multicampus
The University of Kentucky College of Engineering maintains a campus in Paducah in Western Kentucky. The Paducah Campus is linked to the main campus in Lexington through an interactive television link. Course instructors can address students on both campuses in real time using this link. For the Sustainable Power and Energy Course, "in-person" lectures alternated between Lexington and Paducah. In addition, Mechanical Engineering students at Western Kentucky University in Bowling Green, Kentucky are also able to enroll in this course as undergraduates or graduates through the interactive television link.

Course Organization
Due to the multicampus organization of the course, a unique format was utilized. The course included both traditional lecture and self-directed learning modules. The self-directed learning modules consisted of an introduction from the course instructor, a set of reading assignments, a written response assignment and traditional homework assignments. Each self-directed learning module is intended to replace one week of lecture content. Self-directed learning modules were included so that part of the course can eventually be converted to an on-line only professional development seminar. Additionally, the lectures were organized in seminar format, where the students attended four half-day seminars spread throughout the semester. The course content is summarized as follows:

- 4 Half Day Seminars
- 2 Exam Review Sessions
- 8 Self-directed learning modules
- Midterm Exam
- Final Exam
- Term Paper

The self-directed learning modules were designed as stand-alone units. Each module focused on a single topic and, as previously mentioned, included reading assignments, written response assignments and traditional calculation based homework problems. The self-directed learning modules are implemented using Blackboard. The topics for the self-directed learning modules are as follows:

- History of Energy Usage and Sustainability
- Engineering Economics
- Principles of Sustainability
- Energy Systems Sustainability Metrics
- Alternative Power and Energy Generation

- Thermodynamic Assessment of Energy Systems
- Exergy Analysis
- Heat and Power Integration

The self-directed study modules are organized as self-contained units, focusing on a single topic. The modules begin with a 1 – 2 page written overview by the course instructor. This overview outlines the key topics, the expected learning outcomes and provides a brief introduction to the subject matter. Next, each module contains 1 or 2 reading assignments – usually peer reviewed journal articles, published technical reports or book chapters covering the subject matter of the module. To ensure that the students read and comprehend the assignment, they are required to submit a 1 – 2 page memo summarizing each reading assignment. Next, the modules contain an open ended assignment, which usually involved exploring a web-based resource on the topic. For example, for the module on Energy Systems Sustainability Metrics the students are asked to explore the Dow Jones Sustainability Index, then write a short memo on the sustainability report from a company of their choosing. Finally, the modules contain a set of traditional calculational based homework problems that reinforce the engineering concepts presented in the module.

The four half-day seminars each focused on a specific theme. The seminars were organized in traditional lecture format using PowerPoint slides and worked example problems. The topics for the seminars are as follows:

- Sustainable Energy and Systems Engineering
- Estimation and Evaluation of Energy Resources
- Environmental Impacts and Energy Assessment
- Life Cycle Assessment

The expected course outcomes are based on the students achieving a basic understanding of the fundamental concepts of sustainability. At the conclusion of this course, students should be able to:

- Understand the fundamental concepts of traditional energy processes.
- Understand the fundamental concepts of renewable energy processes.
- Determine the Potential Environmental Impact of an energy generating process.
- Understand the pertinent issues of sustainability as pertain to energy production and utilization.
- Determine the Life Cycle Impacts of an energy generating process.
- Understand the key principles of energy audits and site-wide energy assessment.
- Be able to apply the principles Heat and Power Integration to the design of Energy Recovery Networks.

Assessment

A Pre- and Post- Course assessment of the student's attitudes and perceived knowledge with regard to sustainability, as well as their personal assessment of the novel course structure and delivery format was conducted. The assessment test was given to all students on the first day and last day of the course and was designed to gauge the student's background attitudes with regard to sustainable power and energy. The first page of the survey was identical for both the pre- and post-course assessment test, however, the post-course assessment test asked for the student’s experiences, rather than expectations. Participation was voluntary and anonymous, although demographic data was requested.

The questions were grouped into 3 categories. The first group of questions were designed to determine the student’s self-assessed belief in the importance of sustainability to themselves, the country and industry. The second group of questions was designed to determine the student’s self-assessed knowledge of engineering job functions as well as their how sustainability might fit into their future career plans. Finally, the third group of questions was designed to determine the student’s self-assessed knowledge of key concepts in sustainability. The assessment questions are illustrated in Figure 5 and the results are given in Figures 6 – 8. The demographics of the assessment included 22 chemical, 4 mechanical and 1 biosystems and agricultural engineering major. These students included 4 doctoral students, 1 masters student, 21 undergraduate seniors and 1 undergraduate junior.

These results of the assessment showed that even though the students came into the course believing that sustainability was important to the country and the manufacturing industry, their knowledge of sustainability concepts increased from the beginning to the end of the course. This was a positive outcome and indicates that the course outcomes were achieved.

CME/ME 599 – Pre Course Assessment Survey

Spring 2012

University of Kentucky College of Engineering

Assessment of Student Perceptions on Sustainability and Engineering

	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
I believe that sustainability is important to the economic future of our country.	1	2	3	4	5
I believe finding renewable sources of energy is an important concern to industry today.	1	2	3	4	5
I believe that energy efficiency is an important challenge faced by industry today.	1	2	3	4	5
Sustainability and the environmental impacts of the products I use are important to me personally.	1	2	3	4	5
I believe that sustainability considerations are an important part of an engineer’s job.	1	2	3	4	5
I can describe well the tools used by engineers in my field to design sustainable systems, processes and products.	1	2	3	4	5
I have experience in sustainable engineering through an internship, co-op, or previous employment.	1	2	3	4	5
I can describe well the process of conducting a Life Cycle Assessment.	1	2	3	4	5
I can describe well the process of conducting a Site-Wide Energy Assessment.	1	2	3	4	5
I can describe well the process of heat and power integration.	1	2	3	4	5
I can describe well the process of determining the potential environmental impacts of a manufacturing process.	1	2	3	4	5
I am interested in pursuing a career involving sustainability.	1	2	3	4	5
The novel course delivery format was an influencing factor in my decision to take this course.	1	2	3	4	5
The ability to use this course as a PEIK Certification elective was an influencing factor in my decision to take this course.	1	2	3	4	5

ADDITIONAL QUESTIONS ON REVERSE

Please answer the following questions:

1) My current classification is:
   a. Junior
   b. Senior
   c. Masters
   d. Doctoral

2) Please list your academic major:

3) Are you pursuing a PEIK certification (graduate or undergraduate)?
   a. Yes
   b. No

4) Please briefly comment on your expectations for this elective course in terms of sustainability and energy assessment content?

5) Please briefly comment on your expectations for this elective course in terms of the mix of lecture and web based self-directed content.

6) Please list previous courses (name and number) you have taken at the University of Kentucky that included sustainability focused content. List core courses as well as electives.

Note: No personal identifying information is requested or is being collected. Participation is voluntary. Results may be used in a future journal publication.

Figure 5: Pre-course assessment survey given to all enrolled students.

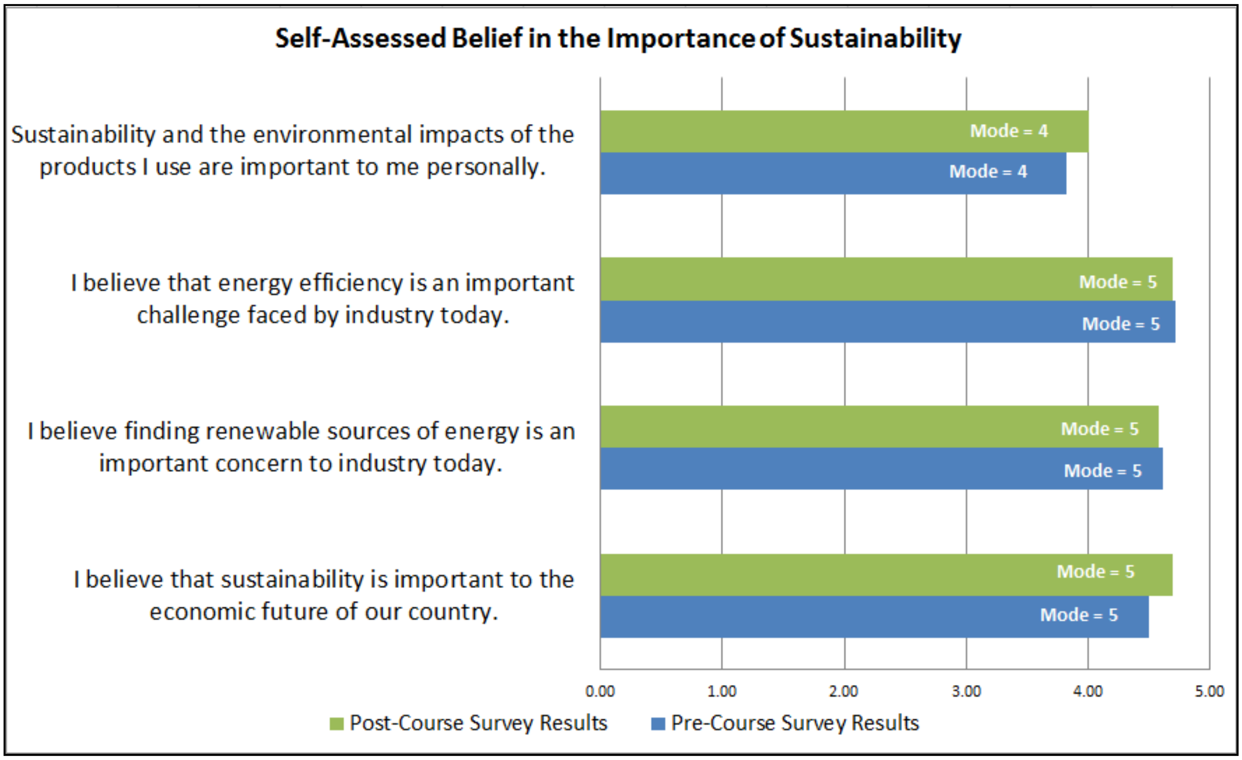

Figure 6: Assessment Results: Self assessed belief in the importance of sustainability.

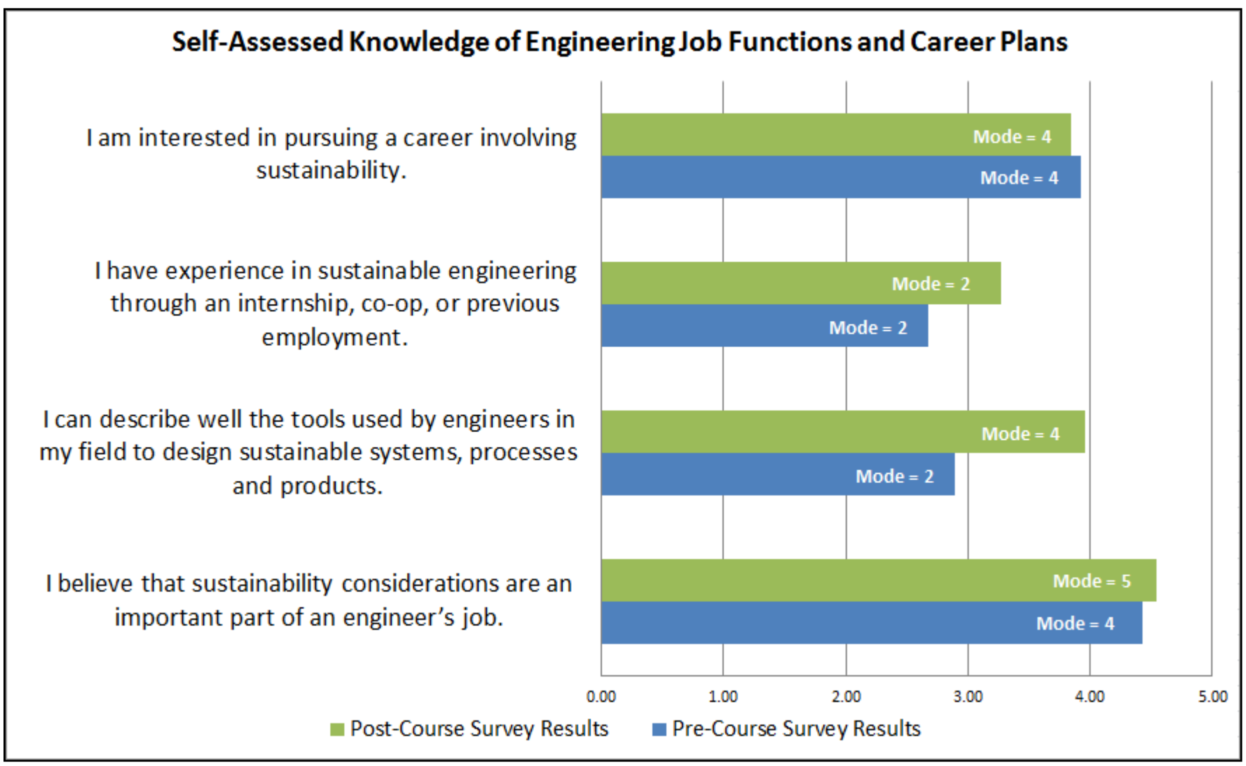

Figure 7: Assessment Results: Self assessed knowledge of engineering job functions and career plans.

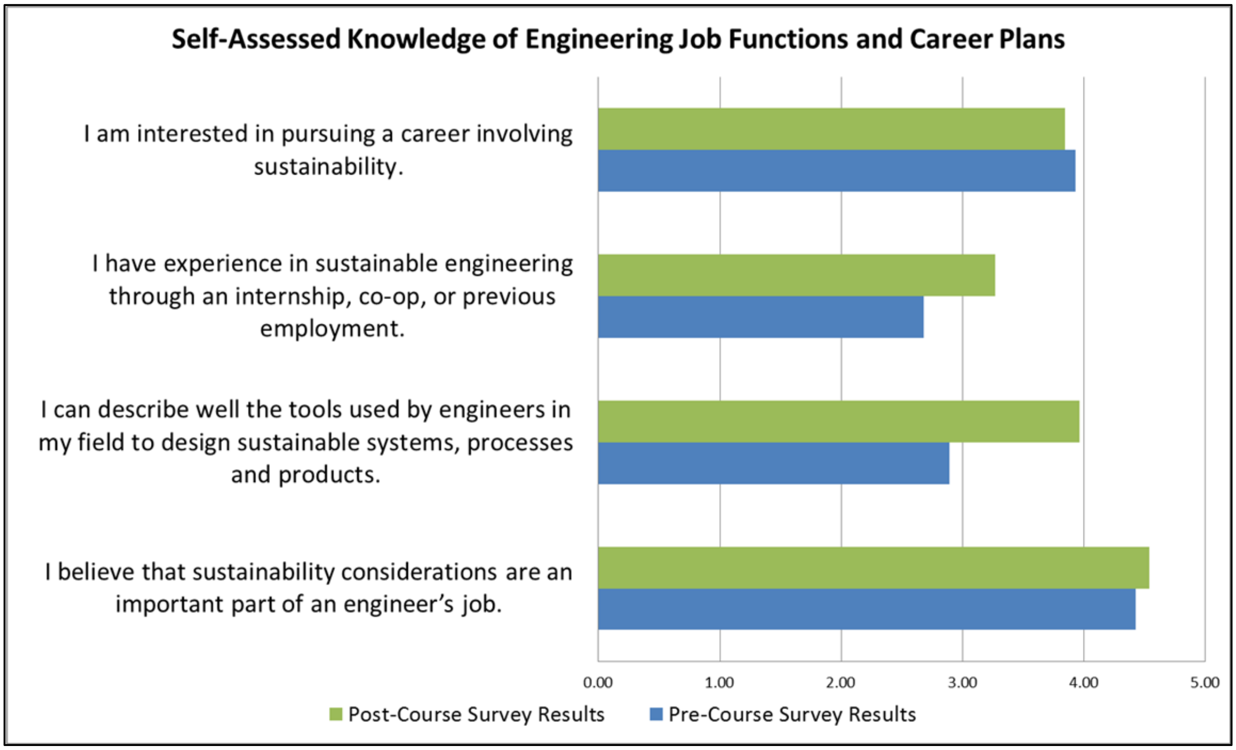

Figure 8: Assessment Results: Self assessed knowledge in sustainable engineering topics.

Student Comments

Students were also encouraged to provide their written comments on the course. Comments were collected anonymously from any student who wished to provide them. Some of the positive comments were:

> *"I really increased my understanding of sustainability"*
> *"I realized the importance of sustainability to engineering."*
> *"I thought sustainability was only about the environment – now I know it involves much more"*

Some of the negative comments provided by the students were:

> *"Seminars were too long – would prefer to meet more often for less time"*
> *"Too much reading"*

Most students chosen to provide comments, however, most comments fell into the same categories. The key findings from the course surveys are summarized below.

- Students seemed to prefer more "face-to-face" contact.
- Overall, the self-directed learning modules were well received.
- Students liked the "work at your own pace" structure of the self-directed study modules

Conclusions and Path Forward

In general the course can be considered a success, but as evidenced by the student survey results, there is room for improvement. The primary issue was the length of the seminar sessions. The 4-hour format was simply too long, especially for a traditional lecture based format. Future offerings will include a modified lecture schedule – most likely 2-hour seminars every other week instead of monthly 4-hour seminars. In addition, the Interactive Television link used to connect the students at different campus was sometimes problematic, but providing at least some lectures at both campuses alleviated some of the impersonal nature of remote lectures. In conclusion, power and energy continue to be important topics and ensuring that they are available in ways that are sustainable is a key challenge for future engineering graduates of all disciplines.

Acknowledgments
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