120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #6024

Materials Engineering as a Catalyst for Sustainability Education

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Materials Engineering as a Catalyst for Sustainability Education

Abstract

Energy use, environmental impact and other sustainability-related issues are becoming increasingly important considerations in engineering designs and manufacturing processes. In response to this need, materials engineering courses related to sustainable energy technology, life-cycle analysis and mineral resources have been developed. The courses have been designed to be accessible to non-materials engineering students, and even non-engineering students, to promote interdisciplinary discussions. This paper will include discussion of the content of and experience with these courses, as well as the relationship of the courses to other sustainability-related educational efforts on campus.

Introduction

Sustainability has become an increasingly important consideration for society in general as well as for the engineering profession. Materials engineering is particularly important for addressing sustainability, since materials engineers are involved both in the production and processing of materials with low energy use and low environmental impact (supply side) as well as in the selection of materials (demand side). Thus, sustainability concepts are especially relevant in materials engineering courses and curricula.

Sustainability content can be integrated into existing materials engineering courses or presented in separate courses, both of which have value. Integration into materials courses helps students apply sustainability concepts to materials engineering design and processes, while separate sustainability-focused courses provide opportunities for engaging students from other disciplines. The latter approach is the focus of this paper.

Sustainability is an extremely broad topic and inherently interdisciplinary, which creates excellent opportunities to engage a broad range of students. Many students have a perception that engineering is about designing and building products for profit rather than for the benefit of society. Demonstrating the need for engineers to develop sustainable technologies for addressing societal needs may attract some of these students to engineering in general, or materials engineering, in particular. In addition, discussion of sustainability inevitably involves multiple disciplines, so the discussion is enhanced with multiple perspectives.

Sustainability Education for Materials Engineers

To evaluate the educational needs related to sustainability, The Metals, Minerals and Materials Society (TMS) included questions on the topic in a recent member survey[1]. One portion of this survey asked respondents to rank the desired and actual proficiencies on several sustainability-related topics. The results, which are summarized in Table 1, show that the most important topic is energy use and efficiency, followed by recycling/reuse, life cycle analysis and corporate social responsibility. In all cases, the desired proficiency is lower than the actual proficiency as illustrated in Figure 1. The courses discussed in this paper address these high-priority and high-need areas.

Table 1. Results from TMS member survey on desired and actual proficiency in sustainability-related topics on a scale from 0 (none) to 3 (very proficient)[1].				
Topic	Desired		Actual	
	Average	Rank	Average	Rank
Energy use and efficiency	2.18	1	1.34	1
Recycling and reuse	1.82	2	1.20	2
Life cycle analysis	1.79	3	1.04	4
Corporate social responsibility	1.78	4	0.99	6
Carbon management and climate change	1.56	5	1.02	5
Environmental law and responsibility	1.53	6	0.88	9
Water and land use and reclamation	1.50	7	0.93	7
Social and community issues	1.49	8	1.08	3
Industrial ecology	1.49	9	0.89	8

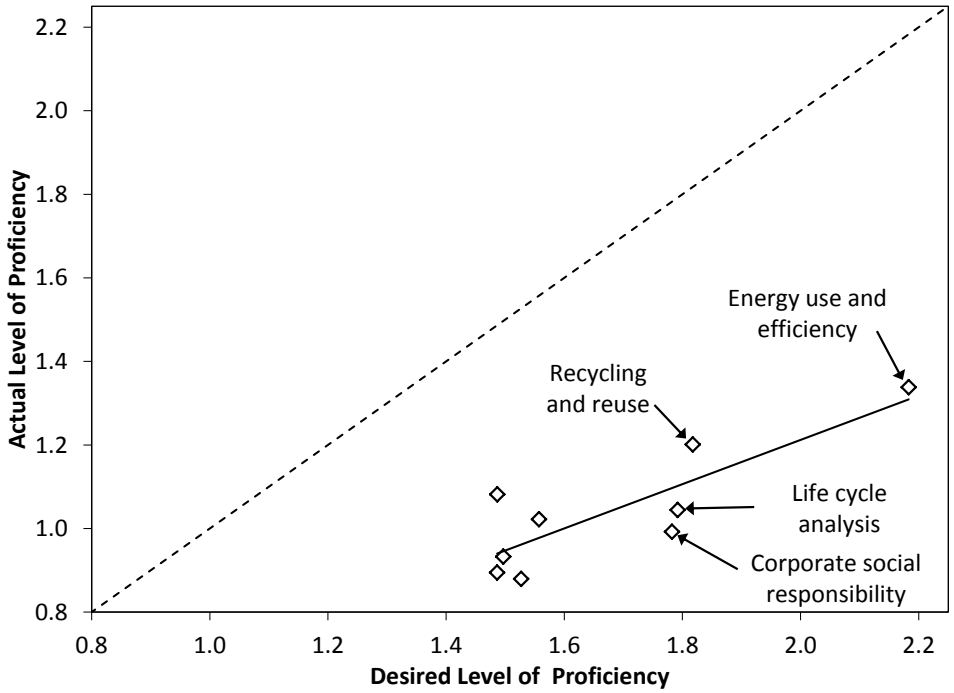

Figure 1. Desired and actual proficiencies in sustainability-related topics according to survey of TMS members[1].

Sustainability Courses

To address the need for education in sustainability-related topics, the following three courses have been developed.

- MATL 2210: Materials for Sustainable Energy Production and Storage
- MATL 2220: Materials and the Environment
- MATL 2230: Mineral Resources: Processing and Availability

The courses do not count for any degree requirements, so to increase the likelihood that students the courses, they are one-credit-hour courses. The courses are listed as materials engineering courses (MATL), but they are designed to be accessible to students in other majors (engineering and non-engineering). Freshman chemistry is listed as a prerequisite, but the necessary chemistry is minimal so students with high school chemistry or other sciences are allowed to take the course – as long as they are not distressed by seeing chemical equations.

These courses have also been approved as electives in a university-wide Sustainability Minor. The Sustainability Minor has six hours of required courses (an introduction to sustainability and a capstone course) and nine hours of elective courses from a wide variety of topics in the general areas of Society and Market, Environment, Social Justice[2]. The three one-credit-hour MATL courses can be used for a three-hour elective in the sustainability minor.

The first course, Materials for Sustainable Energy Production and Storage, introduces the various energy conversion and storage technologies. The course objectives and topics are summarized in Table 2 and the textbook for the course is *Sustainable Energy - Without the Hot Air* by David MacKay[3]. For each of the technologies introduced in the course, some materials issues are identified to illustrate the importance of materials science and engineering in enabling technology to address these important societal needs.

The other two courses are related to life cycle analysis, which as illustrated in Figure 2, includes the natural resources, the processing of those resources into usable engineering materials, the manufacturing of products from those materials as well as the use and disposal of the resulting products. Mineral Resources: Processing and Availability (MATL 2230) (course objectives and topics in Table 3) focuses on issues related to producing usable engineering materials from raw materials, while Materials and the Environment (MATL 2220) (course objectives and topics in Table 4) focuses on the cycle starting with the manufacture of products from the engineering materials through use and disposal of the product and its components. Materials and the Environment (MATL 2220) uses the text of the same name[4] by Michael Ashby and Mineral Resources: Processing and Availability (MATL 2230) uses *Minerals, Metals and Sustainability: Meeting Future Material Needs* by John Rankin[5] as the text.

Based on lessons learned in the first offering of MATL 2210, the courses have since followed a common format. The approach in the first offering of MATL 2210 was to survey the various topics and then have the students choose a topic to present in multiple formats (oral / poster / paper). This resulted in too much emphasis on the final project which came at the same time as assignments and examination in other courses. In subsequent offerings of this course, and in the other two courses, students were asked to prepare brief (usually one slide) presentations throughout the semester. The assignments could typically be completed based on information

obtained by searching on the internet. One example is to identify a device, product or activity and estimate the amount of energy it uses in a year. Another is to present the source and availability of a particular element. In some cases students could choose any example and in other cases they chose from a list. This approach served to both distribute the workload throughout the semester and to promote class participation and discussion. There is still a final project, which is larger than these one-slide presentations, but less involved (and a smaller portion of the grade) than the final project in the first offering of MATL 2210.

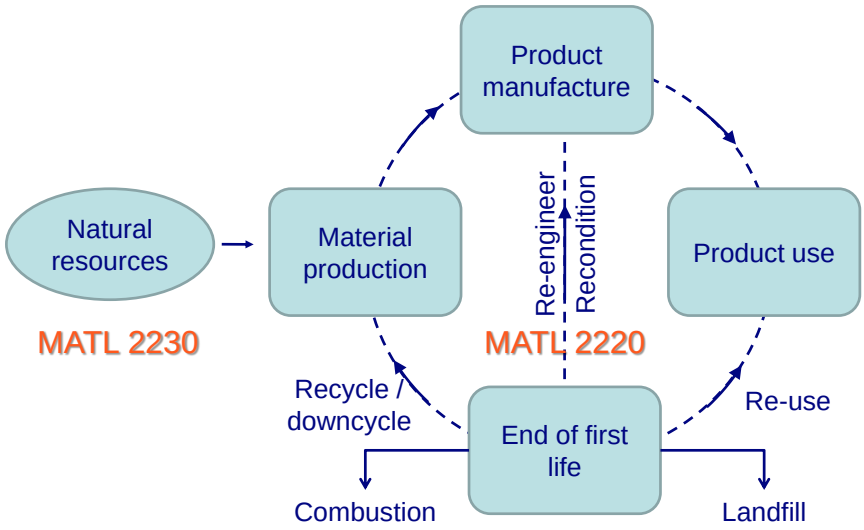

Figure 2. Materials engineering courses related to life-cycle analysis.

The courses have been each been offered 2-4 times with an average enrollment of 10 students per class as shown in Figure 3. The distribution of the majors of the students taking the courses is shown in Figure 4. Although, the courses are intended to be accessible to non-engineering students, most (87%) of the students are from engineering. The large number of engineering students is due not only to the courses being listed as an engineering topic, but also because the instructor has good connections with the network of engineering advisors. The course announcements are shared with advisors in non-engineering disciplines, but they may not be as diligent in promoting the courses as the engineering advisors.

Within engineering, the largest number of students is from civil engineering. This is in part due to students interested in the environmental aspects of civil engineering, such as water quality, but also due to changes in the civil engineering curriculum which led to students needing a one-hour elective course to meet graduate requirements. A similar change was made in the aerospace engineering program which made the one-hour elective attractive.

Student survey results indicate that the students were satisfied with the course and learned useful information and concepts on sustainability related research. Approximately one quarter of the students enrolled in the courses took more than one of the three courses. About half of those students who took multiple courses, took them in different semesters, which indicates that they found the first course valuable.

Table 2. Materials for Sustainable Energy Production and Storage (MATL 2210)

Course Objectives

Provide the student with a basic knowledge of technologies for sustainable energy production/ storage and some of the materials challenges associated with these technologies. With this knowledge the students should be able to:

- Compare the advantages and disadvantages of current and potential energy conversion and storage processes
- Identify critical materials challenges associated with current and potential energy conversion and storage processes

Course Topics

Overview of energy use and production

Energy conversion

- Thermal
  - Heat → (mechanical) → electrical
  - Combustion (fossil fuels, biomass-derived) (high temperature creep / corrosion)
  - Nuclear (radiation damage in materials)
  - Direct heat-to-electricity conversion (thermoelectric materials)
- Electrochemical
  - Chemical → electrical
  - Fuel cells (electrolyte / electrode / interconnect materials)
- Solar
  - Radiation → electrical
  - Solar-heat / photovoltaic (semiconductor devices)
- Mechanical
  - Mechanical → electrical
  - Wind / water flow (high-strength low-density materials)
  - Vibration (piezoelectric energy harvesting)

Energy storage

- Electrochemical (materials for batteries)
- Hydrogen storage (solid-state hydrogen storage)
- Mechanical (flywheels)

The courses benefited from having students with different academic backgrounds and interests. At times, students were uncomfortable with topics outside their major (e.g. technical details for the non-engineering students), but there were no major problems, and any detrimental impact from this was more than offset by the beneficial impacts of having students with diverse backgrounds in the class together. Some students chose projects that allowed them to share details from their major disciplines. For example, electrical engineering students included details on power conversion and civil engineering students on water management issues. Other students chose projects based on their personal interests, such as musical instruments, sports and hunting.

Table 3. Materials and the Environment (MATL 2220)
Course Objectives
Provide information on the environmental impact of materials throughout their life cycle. By the end of the course, the students should be able to: • Compare the environmental impact of products
Course Topics
Overview of materials science and engineering The materials life cycle • Primary production • Manufacturing • Use • Disposal Constraints • Economics • Availability • Legislation Materials selection • Materials properties • Environmental impacts • Recycling

Table 4. Mineral Resources: Processing and Availability (MATL 2230)
Course Objectives
Provide information on mineral resources and processes required to produce usable engineering materials. With this knowledge the students should be able to: • Identify the raw materials from which common engineering materials are derived • Describe the processes required to produce common engineering materials
Course Topics
• Overview of materials science and engineering • Where do the materials used to make products come from? • How are they processed? • Where are the resources located? • Why are supplies of some materials limited?

University-Wide Sustainability Activities

The courses have attracted students from a wide distribution of engineering majors, but the level of participation of students from non-engineering disciplines is lower than desired. This is likely due to reluctance among non-engineering students to take engineering courses because of the perceived difficulty. Also, there are more opportunities for publicizing the courses to engineering students, such as in a regular presentation in the engineering orientation class taken by all freshman engineering students and through the strong engineering advising network.

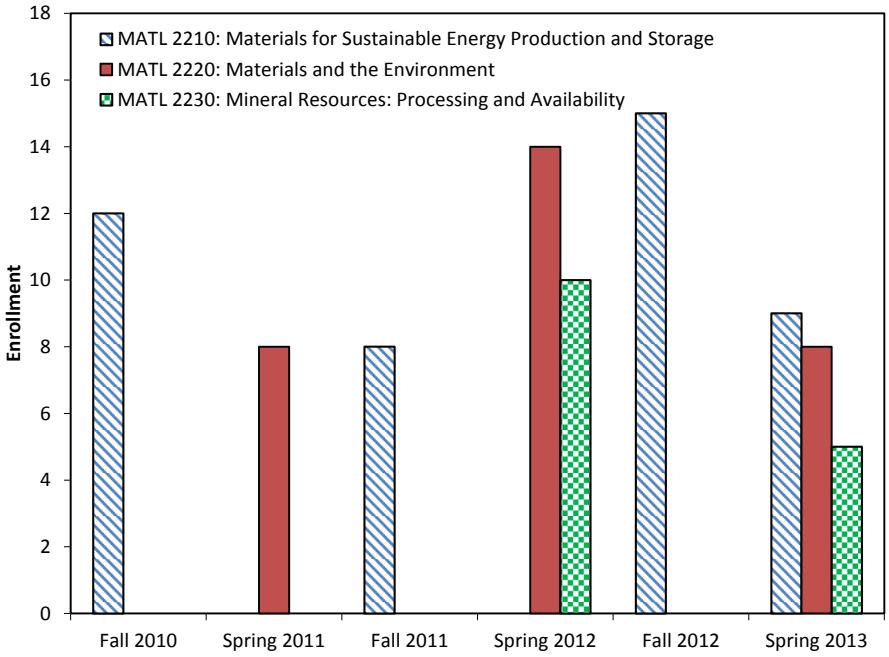

Figure 3. Enrollment in sustainability courses.

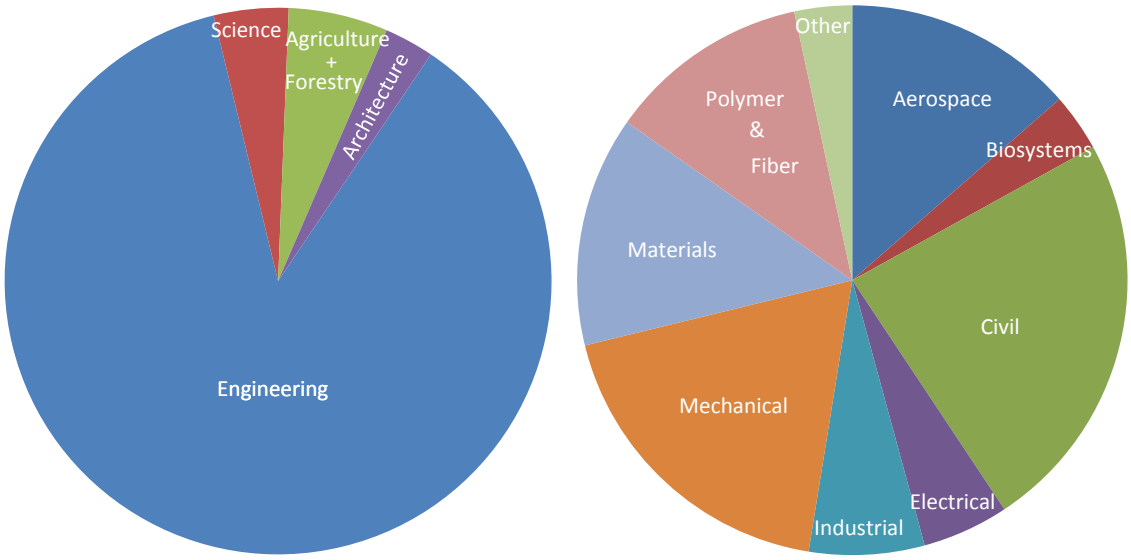

Figure 4. College/major of students enrolled in sustainability courses.

As noted above, the three courses can be used as elective courses for the sustainability minor, but this was just recently approved in 2012, so the impact on enrollment in the courses has only just begun. With increasing awareness among students in the sustainability minor and an increase in the number of students in the sustainability minor, the enrollment of non-engineering students should increase. The instructor also gives a guest lecture in an honors seminar course on sustainability, which provides an opportunity to introduce the courses to students outside of engineering.

One of the objectives of the courses is to demonstrate the importance of materials science and technology to sustainable technology. Although evidence of the effect of these courses on recruiting is not available, these courses have had a positive effect on the decisions of at least two students in choosing materials engineering as their major. This is only anecdotal and the relative impact of the courses is not known, but it does indicate that there is an opportunity for recruiting students interested in sustainability to materials science and engineering.

Conclusions

Three one-hour courses have been developed to introduce a wide range of students to sustainability issues and the relevance of materials science and engineering to sustainability. The courses have been taken by a wide distribution of engineering students and a small number of non-engineering students. The breadth of the concept of sustainability is both a challenge in defining manageable, accessible, yet sufficiently-focused courses, but is also an opportunity to engage students in interdisciplinary discussion on topics important to society.

References

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