2006-378: INFUSING THE MATERIALS ENGINEERING CURRICULUM WITH SUSTAINABILITY PRINCIPLES

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Infusing the Materials Engineering Curriculum with Sustainability Principles

ABSTRACT

In order to better prepare our students for the complex, global world outside the confines of the university, we have been making concerted efforts to incorporate sustainability principles (i.e., balance of economics, society, and environment) within the materials engineering curriculum at California Polytechnic (Cal Poly) State University. Many future engineering tasks will require the understanding of complicated interplays of technology with the environment and society. In addition, energy demands and dwindling natural resources have emerged as significant challenges for scientists and engineers. The materials engineer has great opportunity to help devise sustainable solutions through appropriate materials selection and processing, and our faculty has been trying to convey such ideas and skills to our students.

Many different sustainability activities and assignments have been woven into several of our materials engineering courses. Some activities are to promote awareness and to give motivation for our students to use their engineering skills for the betterment of society and the planet. Pertinent articles from popular media sources have been used as the basis for reflection exercises and to stimulate student discussions. A freshmen design course has been developed to highlight sustainability through service learning. In addition, we have used software tools (CES Eco-selector) to quantitatively assess the environmental impact due to particular materials selection and processing techniques. Several different pedagogical techniques have been employed for these different activities.

BACKGROUND: revising our curriculum

The engineer for the year 2020[1] has been proposed to be somewhat different from the current engineering student. ABET also requires programs to train students to solve problems and to design within realistic design constraints that include sustainability[2]. The Brundtland Commission has defined *sustainability* as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[3] Accordingly, our materials engineering curriculum at Cal Poly is currently being revised to nurture more global, effective materials engineers for the future. Our department website[4] highlights our commitment to sustainability (Figure 1).

Figure 1. Cal Poly Materials Engineering department website[4] displays the sustainability theme in the curriculum.

Our strategy is to infuse sustainability principles within the curriculum, rather than to offer a stand alone course. The reasoning is to show how sustainability needs to be part of the whole engineering problem solving process, and not an afterthought or even an optional thought. Various activities have been attempted, from freshmen to graduate level courses, and can be modified to be made appropriate for different classes. Assessment plans of our efforts are currently underway, and will not be discussed in this paper.

AWARENESS: presenting the challenges, responsibilities

In order to lay the foundation for presenting sustainability principles, students must first be made aware of current global challenges. Videos, news articles, seminars, and class discussions are used to highlight issues such as climate change, rising gas prices, poverty, etc. The role of an engineer is also discussed, and the National Society of Professional Engineer ethics creed[5] is introduced: "…I dedicate my professional knowledge and skill to the advancement and betterment of human welfare." Like many other professional society ethics statements, engineers identify service to humankind as their greater purpose. If engineering students are trained to be "problem solvers," why not present the world's problems as challenges for our engineers to tackle?

One of the most effective ways used to raise the awareness of global issues for students is to assign reading articles from mainstream publications, such as *Time* magazine and *Technology Review*. Some special issues of *Time* address the environment ("How to Save the Earth")[6] and poverty ("How to End Poverty").[7] Students welcome the departure from the usual technical textbook, and the articles are well written and quite interesting. Different perspectives are given with the multiple journalists or authors, and several pictures are presented. Students feel the sense of urgency of the topics and realize these problems or challenges in the world are *real*, not abstract concepts found only in the classroom. The fact that the articles come from magazines found in most bookstores reinforces the *life-long learning* process.

With global awareness raised, the students must also see the connections to how they, as scientists and engineers, can be part of the solutions. In terms of the environment and renewable energy sources, we have also used journal articles to explore the current research and development. *Technology Review* has had several articles dealing with hybrid cars[8], fuel cells[9], and organic solar cells[10], as well as presenting complex issues concerning nuclear energy and wastes (e.g., Yucca Mountain).[11] Popular magazines such as *Discover* and *Scientific American* have featured issues such as the hydrogen economy[12,13] and renewable energy technology.[14] Students often become much more interested in learning about the science behind technological solutions (such as fuel cells[15]) once the application and impact are realized.

Group discussions and/or reflection exercises are an integral part of the learning process with the assigned reading articles. The class is typically broken down into smaller groups to ensure that all students have the opportunity to participate in the discussions. A list of probing questions based on the readings is usually distributed to each group to initiate discussions. Many students have commented that they enjoy this aspect of interacting with and learning from their classmates.

These same principles with the reading articles can be applied to shared book experiences. In freshman and senior level courses, we have used reading and discussion groups to promote a change in students' perspectives toward global concerns. One book that we have used is *Biomimicry*: *Innovation Inspired by Nature* by J. Benyus.[16] Another book is *Cradle to Cradle: Remaking the Way We Make Things* by W. McDonough and M. Braungart.[17] There are many others that can be used to precipitate global perspectives in the design process.

Seminars by guest speakers have also been employed to create awareness of sustainability principles. Dr. Savitz of the National Academies of Engineering discussed "The Hydrogen Economy,"[18] and Dr. Zimmerman of the U.S. Environmental Protection Agency gave an enlightening seminar on "The What and How of Sustainability" at Cal Poly. A Cal Poly materials engineering alum and former CTO of Hypercar, Inc. (with the Rocky Mountain Institute[19]), David Taggart, presented "Engineering Sustainability into Design" on light weight, energy efficient vehicles. The seminars not only educated the audience but also served to show students that individuals out in the "real world" are actually doing something exciting and are making a difference. The talks offered exposure to additional career paths and inspired many students. Sometimes the seminars were part of a class, but all the talks were open to the public and were well attended.

ANALYSIS: employing "systems thinking"

Some students (and faculty) might feel uncomfortable at first about veering into what we traditionally consider the "social sciences" in an engineering class, but students rightly demand for relevance in what they learn. So far, the response has been very positive. Students generally have an interest in making a difference in the world, and they are motivated by the thought that their knowledge and skills could be helpful to others (which is especially appealing to female and underrepresented students). The key is to connect science and technology to the same issues that affect their daily life, community, country, and planet. The interconnectedness is an important aspect to stress. The individual engineer no longer works in a vacuum, and one's actions can have far-reaching impacts. Thus pedagogically, one must think more holistically and invoke "systems thinking."

Flow diagrams with boxed inputs and outputs, casual loop diagrams (Figure 2[20]), or concepts maps can be utilized to help map out how things are interconnected. The basis of *life cycle assessment* and *cradle to cradle* design also deal with the flow of resources and the different, yet connected stages of a product's life. With materials processing, it is important to consider other stages, such as transportation of the goods or use of the product, and not just the manufacturing done in the plant. The other stages may end up having a larger impact on the environment.

The ability to think beyond an immediate problem is essential for an effective engineer. We had inadvertently been doing a disservice to our students when stripping away problems to a single question to be computed, and stopping there. Rather than compartmentalizing knowledge, we should try to promote more *systems thinking*. For an example, students could do very well in

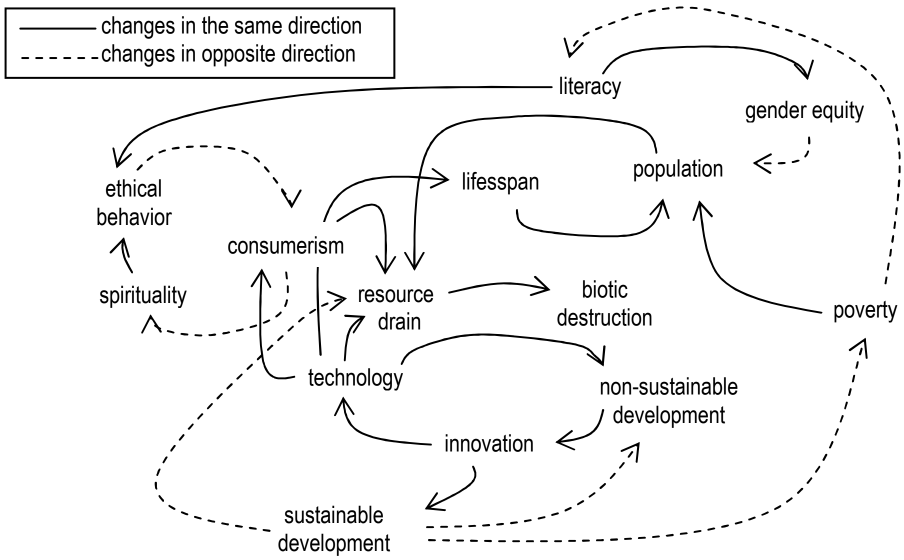

Figure 2. Causal loop diagram showing the interrelatedness of the drain on resources and societal issues such as consumerism and poverty.[20]

selecting the material with the greatest strength. But often in real situations, the maximum strength is not the only criteria. Other properties, such as electrical or thermal, may need to be considered at the same time. Costs and manufacturing availability could turn out to be even more important for a company. In addition, use of natural resources and impacts on the environment (e.g., toxicity, greenhouse gases) are other important factors to take into account. Thus, the initial problem becomes larger and larger as one considers the multiple layers involved. It may become more complicated, but also more realistic and appropriate. Thus, the recent changes in ABET has reflected such as push for "realistic design constraints"[2]. Sustainability naturally forces us to consider the larger picture and the interconnections, and thereby invokes *systems thinking*.

Sometimes simple changes to existing assignments can be made. For instance, a common term project for the Introduction to Materials Engineering course (for almost all engineering students) is to highlight a particular material or application of a material. In the last few years, our faculty has been adding the criteria of societal and environmental considerations with the projects. Even with very little lecturing on sustainability principles, students are easily able to incorporate the ABET design criteria into their project. While the treatment may be only on the surface, the fact that future engineers have enough awareness to give consideration to environmental and societal factors is tremendous. Deeper levels of analysis are required for the higher level materials engineering courses. For instance, senior projects require the analysis of environmental impacts due to their project design or topic.

ACTION: doing engineering through a freshmen service learning project

An excellent technique to create motivation for the betterment of society and environment is through *service learning*. This is an applied project in which the students are engaged in experiential learning that addresses human and community needs. A number of researchers in engineering education have documented the benefits of service learning toward fostering qualities within students that help them understand their societal role. For example, engineering students involved in service learning demonstrate a stronger ethic of social and civic responsibility[21], develop empathy for others[22], demonstrate greater personal growth (maturity) and develop a broader appreciation of non-technical concerns and the impact of technology on society.[23]

In our curriculum, we had the freshmen work in teams of four to five students to interface with a local family who uses well water. Their design challenge was to design and build a system that would bring the family's water up to drinking water quality standards and not require anything but renewable energy from their site (Figure 3). They were also given a number of other design constraints.

Figure 3. Service learning was accomplished by teams of freshmen that designed and built water purification systems powered by renewable energy for local families.

ABILITY: gaining skills and using software tools

As a means to equip students with the capability and tools to provide sustainable engineering solutions, we have utilized the CES Materials Selector Software[24] by Granta Design. As materials engineers, they can play a role in selecting the best material to minimize environmental impact. The software contains a large database of material properties, including "eco-properties," in order to make intelligent decisions on which candidate materials to use for particular applications. The eco-properties include production or manufacturing energy, CO_2 emissions during production, recycleability, toxicity, and resource availability. Since the eco-properties are considered along with other material properties (such as yield stress, thermal conductivity or density), consideration of environmental impact is at the forefront of the engineering design, rather than an afterthought.

In order to use the materials selector properly, one must first consider the whole life cycle of the product, as shown in Figure 4, from Granta Design's software. The appropriate eco-property to use is dependent upon which stage in the life cycle would have the biggest impact on the environment: material production (from the Earth's resources), product manufacture, product use, or product disposal. With these assignments, systems thinking and the interconnectedness of the life cycle stages of a material or product get reinforced.

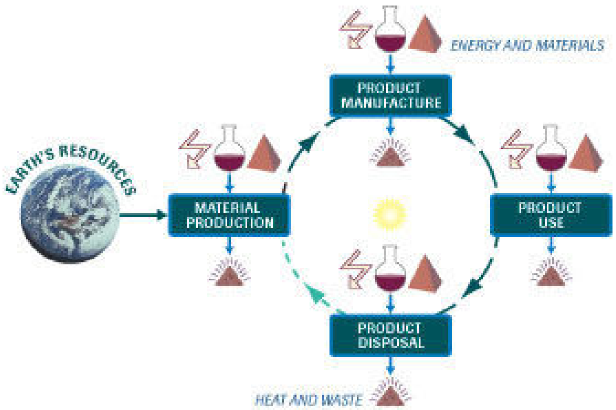

Figure 4. A flowchart used in the Cambridge Engineering Selector software that demonstrates the life cycle of a product.[24]

Use of the eco-selector was incorporated into a Ceramics course term project. Students researched a particular ceramic product for a class presentation and also had to assess the environmental impact due to the processing. Students could later utilize the software for their senior projects where they are required to consider environmental impacts of their projects.

A brand new sophomore level course is currently being developed to give students an even earlier exposure to eco-friendly materials selection and is entitled "Materials Selection for the Life Cycle." Several other software programs, such as Eco-It[25] and SimaPro[26], are being considered. In this new course, the role of materials in product design is highlighted, and the 12 principles of green engineering[27] is introduced. Case studies of sustainable design[28] are covered, as companies that have adopted sustainable engineering approaches are investigated.

CONCLUSIONS

In our efforts to train effective engineers for a complex, global world, we are currently infusing the materials engineering curriculum at Cal Poly with sustainability principles. We have found that presenting contemporary problems requires a *systems* approach to thinking and involves several of the realistic design constraints required by ABET. Much of our efforts so far have been to create awareness of issues and the introduction of sustainability principles through readings, class discussions, and seminars. Service learning projects and software tools have also been employed to give students experiences of practicing engineering with consideration to society and the environment. Student response has been very positive thus far, and we plan to further develop our efforts of sustainability in our curriculum.

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