2006-954: GREENING OF EDUCATION: ECOLOGICAL EDUCATION IN ENGINEERING

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Greening of Education: Ecological Education in Engineering

Carnegie Mellon University has embarked on a "Greening of Education" project, sponsored by the Henry Luce Foundation. This project aims to instill an appreciation of the environment in students at the beginning of their college careers in hopes of carrying this appreciation out into future careers. Over the three-year duration of this project 24 new courses have been introduced into the university curriculum. Specifically within the Carnegie Institute of Technology (the engineering college), two courses became part of this program to be taught to students with majors outside the engineering program as a technical elective for arts and humanities degree requirements.

These two engineering courses lend themselves to what has been termed a new "metadiscipline" of sustainability science and engineering[1] which merges engineering, environmental, and social concepts into an integrated course. Incorporating environmental and social concepts into engineering courses has been a growing interest for several years,[2,3] although recent efforts for sustainability have been at the graduate level or upper undergraduate level[4,5] after basic principles have been acquired. Integrating technological literacy into humanities curriculum has been proposed[6, 7] although many engineering programs typically do not offer courses aimed at non-majors.

Our experience demonstrates that technical course content can be made more approachable. By framing the engineering skills and topics in everyday life experiences and choices, we successfully teach the environmental aspects of technology to non-engineering audiences. Students recognize how even basic knowledge of technical topics can assist them in making better choices to reduce environmental impact. The success of the courses leads to further development of the engineering material to a program for high school students interested in learning more about engineering careers.

The Greening of Education Project

The Greening of Education project at Carnegie Mellon University targets students at the beginning of their college careers and introduces them to environmental topics. The aim is to provide a context of ecological education that they can carry through their four (or five) years regardless of their chosen discipline. The interpretation of ecological education is broad – inviting students towards knowledge of the self, of the environment, of the underlying principles, and of the processes of learning, doing and understanding[8]. The project also supports the University's focus on three core strategic areas in educational and research, one of which is Environmental Issues.

Three general objectives are pursued by all courses taught within the project:

1. Systems thinking of connections and influences between ideas, people, and communities
2. Life cycles and respect for the role of time in nature, human activities, and our lives
3. Self as agent and knowledge and uncertainty as a basis for decision-making

Each objective strives both to enhance the knowledge and skills students acquire within a course, as well as to change student attitudes toward environmental issues that will hopefully remain with them in other courses and after graduating. Courses across the curriculum have been taught under the auspices of the project, including sections of the required English writing course for first-year students, Architecture, Art, Design, Economics, History, Philosophy, Public Policy, and Engineering. Despite the variety of domains and the wide range of content of each course, the three general objectives are applicable, demonstrating the potential to impart environmental education throughout the university curriculum and student experiences.

Within the engineering college, two courses are a part of the university project: in Civil and Environmental Engineering, *Technology and the Environment*, and in Materials Science and Engineering, *Materials, Energy and the Environment*. Both courses are open only to first and second-year students outside the engineering college to fulfill requirements for Science and Technology general education credits. The courses use typical consumer goods and choices as a foundation for introducing technology, engineering design, and the associated environmental impacts. Despite current students' inclination towards technological products (cell phone and iPod use are ubiquitous with undergraduates), many have no knowledge of more basic factors such as how these instruments function or how these products come to be, and thus are unaware of the environmental impacts of them. The courses aim to combat the disconnect between user knowledge and functional knowledge of new products.

Technology and the Environment

Technology and the Environment provides an overview of major environmental issues and concerns associated with modern technology. This course examines technological innovations and their impacts bringing together concepts from science, math, natural systems, government and policy, ethics, and individual behavior. The topics covered build from small scale (material level) to large scale (systems level) as the semester progresses. This path allows students to recognize that the various stages involved with bringing technology to market (and phasing it out) each have impacts to be considered. The course builds on existing knowledge and choices of everyday life, while plugging gaps and correcting factual misconceptions where necessary to broaden perspectives of our influence on the world.

Life cycles, in various ways, fill the course. Life cycle assessment of an individual product presents a basis for understanding the far-reaching impact one item may have. Students often enter without a notion of where or how materials and products came to be (via mining, materials production, product manufacturing, transportation to a store). Simple exercises using basic products, such as soda in an aluminum can, ask them to determine what contributes to them having a soda to drink. The exercise demonstrates the actual complexity of the product, the many industries and materials and energy resources involved, and the connectedness between seemingly diverse facets of the real world. A subsequent reflection of their own use and disposal of products enlightens them further to the intricacies of technology and the environment.

Life cycles of technology development, launch, and replacement highlight the rapid growth and dissemination of technology products. While strides in technology have scaled down the size of products, it has also shortened time to obsolescence. For example, desktop computers have benefited from the developments in circuitry miniaturization that have significantly reduced the materials requirements for significant increases in memory and speed. However, computers are effectively a disposable item and are typically replaced every 3 years. Students reflect on the environmental impacts and tradeoffs that occur with the trend in increased obsolescence being offset by advances in dematerialization.

Typical themes in the course have been chlorofluorocarbons and the unintended and unanticipated depletion of stratospheric ozone as a lesson for the concerns with nanotechnology applications or genetically modified organisms and their potential yet unknown environmental harms. Introducing the precautionary principle into these discussions brings legal and ethical perspectives. Electronics from computers to iPods are case studies for changes in product distribution, materials use, and electricity consumption. Energy for products is paralleled to energy for transportation. Students consider their own habits as a basis for problem solving and comparison: which saves more energy and reduces carbon dioxide emissions more – turning of the lights when you leave the house for the day or choosing a fuel-efficient vehicle for a shopping trip?

Recognizing how human activities related to science and technology have changed the world we live in is a starting point for making future decisions to minimize future problems. While environmental problems are often scientific in nature, it is essential that students consider the issues accessible to their general comprehension. This allows students to analyze issues and think critically about these complex problems. Despite what knowledge is gained in the class, students realize that decision-making is difficult and often does not have one right answer. The role that uncertainty plays in all facets – technology development and dispersion, extent of environmental impacts – is stressed throughout the course. Pursuing degrees outside of engineering, the students are presented with potential roles they may have in their careers in addressing these and potential future problems as historians, economists, attorneys, and policy makers.

Materials, Energy and the Environment

A course titled *Materials, Energy and the Environment*, taught by Materials Science Engineering, attempts to make students aware of the connection between consumer demands for goods and materials, and looks subsequently at the impact of consumer choices. Students learn how material selection and design is a balance of performance, economic and environmental issues. This relatively new field of Eco-materials makes students aware that their choices as informed citizens can influence material selection and influence industrial interaction with our natural resources, thus affecting sustainability, energy usage, and environmental outcomes.

To begin to introduce awareness of, and responsibility for, individuals' impact on material usage, students focus on a well-known theme, the progression of civilization. The need for survival and the subsequent quest for comfort are surely one of the main goals for any civilization. Survival can easily be related to man learning to conquer his local environment, not only climate but also including enemies and predators. Successful accomplishment of this task involved skillful development of material solutions for the needs of tools and weapons.

In a more modern world, it may be difficult to determine if needs arose to create a demand or if the supply of local environmental materials was pushing the demand. It is the supply and demand economics that developed the world economy as we know it today. Recognizing that supply and demand economics plays a large role in the development of civilization should not be a surprise, however the relationship to materials may. To illustrate the role of materials in the development of civilization, historical trade in materials is an example of technology transfer and the progression of civilization. Looking at the history, the economics and the development of societies, the students can gain awareness for the importance of material production, circulation and control as civilization progressed through the Stone, Bronze, and Iron Ages and now into the Silicon Age.

Having established how materials have played an influential role in the development of economics and civilization, students now connect production processes for materials with a requirement for available energy. Today's vast selection of materials is a result of the Industrial Revolution, beginning in 18th century. The discovery of inexpensive fuel, coupled with the technological advances at the time, was the single most defining event in for civilization to date. The result of this revolution has been the ability for civilizations to produce goods at a rate and at a cost that could supply mass markets. The course draws attention to the need for cheap, abundant energy and the exploitation of natural resources to fuel the industrial economies that we have developed.

Material flows use mass and energy and also monetary units. It becomes apparent that the development of energy was an underpinning of the industrial revolution and remains so today. Students explore the material extraction, processing and product stages of manufacturing for the materials in a cradle to product framework. End-use questions introduce environmental awareness. The course illustrates these in more detail with examples of everyday items popular to the students (computers, pens, cars, etc.) and presses them to consider the implication the technological development of the materials has played, and the cost of the technological development to the environment.

The use of materials is driven by product design, therefore a more detailed section of course extends the manufacturing and end-use discussion to involve the driving force for material selection. The aesthetic nature and the performance requirements for products consider the material viewpoint. Students play roles as consumers with demands for aesthetic and performance requirements that form constraints that must be met by the material selection. As consumers, they become aware that they have a large role in determining the aesthetic quality and that this and product expectation have a major influence on the material selection process.

Green Design Apprenticeship Program

The content of the two courses has been developed into the Green Design Apprenticeship Program, an opportunity for high school students to learn about research and opportunities in engineering within an environmental context. The program is part of a broader Apprenticeship Program coordinated across schools and school districts in the local county to provide learning experiences with professionals in all walks of life. The program encourages hands-on experiences to give students insight into possible career choices. Students from 9th to 11th grade are invited to apply to a particular Apprenticeship and are selected based on merit and interest. Most students who participate in the Green Design Apprenticeship Program excel at science and math, and desire to learn more about engineering careers, especially in Environmental Engineering. The program meets with a cohort of 15 students for during 5 school days over 5 months and is now ending its second year.

The students spend two of the days examining the life cycle of a simple product and investigate the materials and energy resources as well as the process for producing it using various life cycle assessment tools. A third day is spent on electricity and energy generation, consumption, sources, and environmental impacts. A fourth day considers water quality, quantity, and consumption. A final day examines advances in green building infrastructure using the grounds and buildings of the Carnegie Mellon University campus as examples.

Activities incorporate hands-on exercises and demonstrations as much as possible. Student evaluations have indicated a desire for additional days, so as to more deeply investigate a given topic. Overall participants have been highly satisfied with the opportunity to learn how their decisions lead to environmental impacts and have continued interest in pursuing engineering (in various fields) with environmental interests. The program has provided a testing ground for exercises for the courses, and vice versa. Content for one day of the Apprenticeship Program transfers to one or two class sessions plus a homework assignment for a course.

Tailoring Engineering Content for Broader Audiences

The material for *Technology and the Environment* and *Materials, Energy and the Environment* has been on-going research in the fields of the instructors. A major challenge has been to translate sophisticated research methods and conclusions to an audience with much less aptitude and background in engineering.

A first step in translating the research results and conclusions for broader audiences has been to shift the context from learning engineering principles to learning impacts of everyday decisions. This shift generates interest in the students by identifying with their current actions and experiences. The material is now familiar to them and resonates with decisions they see themselves experiencing. In addition, the topics are placed in broader perspectives – historical, economic, political, cultural, ethical, and social – to resonate with students' broader interests. Students recognize that a need exists for them to become knowledgeable in technical areas as future decisions require much more than technological feasibility, but also understanding and experience in writing, researching, litigating, negotiating, and analyzing multidimensional problems.

A second step is identifying and then correcting misinformation, especially in environmental issues. Although the technology and materials may be familiar to them, a complete and accurate understanding of environmental issues often is not. Students enter with diverse background of environmental knowledge, perhaps from a prior course in a single topic. Assessing this knowledge has been critical in providing additional background material in the environmental phenomena under consideration. Current global issues, such as climate change, which involve complex interactions between anthropogenic activities and natural systems, and which require international compromise and resolution along with technological solutions, are often misunderstood. Students have collected knowledge from sources outside scholarly literature, especially Internet sites based on opinion. Concepts maps, where students are asked to list words or phrases related to an issue and indicate the links between them, are a critical component of the courses.

A third step in bringing this technical content to these audiences is eliminating jargon and sophisticated methods and derivations, and replacing them with common language and simplified text descriptions and diagrams. The engineering and science content remains high, but the material is delivered in a style more accessible for the students. Rather than having students manipulate an equation to generate data and graph the outcomes, students observe a sequence of graphs and describe in their own words what is occurring and why. This pattern eliminates the frustration and apprehension the students have with math problems without eliminating the broader comprehension of the overall picture. Texts have largely come from popular newspapers and magazines as a starting point for learning how technology interfaces with commerce, society, policy, and the environment. The university campus becomes the laboratory as specific examples of technology development and environmental impacts the students experience first-hand exist around us. Instructional activities and assessment tools rely more on having students reflect on data and results, then discuss outcomes from various contexts. They demonstrate learning critical thinking, problem solving, and analytical skills not by performing complex mathematical algorithms but by interpreting results and writing concise, accurate responses. This approach complements students' strengths and comforts while balancing the requirement for technical content.

A final step in developing this content has been trial and error. Instructors learn how the content is misunderstood in one course, and then make adjustments to the material for another course; students probe for further information, so the instructor broadens scope and detail for another course. We note that a graduate-level engineering course on life cycle assessment has incorporated some of the in-class exercises as a means of introducing the topic, although with added technical content. The timing of the courses allows a synergy to develop, as material is presented, updated, and presented again to a different group of students. Each iteration provides an opportunity to keep both technical and environmental topics current, reevaluate use of technical information, and introduce new instructional activities and assessment tools. Each time has resulted in content becoming more accessible to students' understanding.

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