A New Graduate Course on Environmental Issues In Manufacturing and Product Use

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A new graduate level engineering course, offered in the Spring of 1998 and entitled "*Environmental Issues in Manufacturing and Product Use*", explores environmental and economic aspects of alternative materials used in a product throughout the product life cycle. The objectives of this course strive to introduce industrial ecology, life cycle analysis and technical cost modeling to engineering students who have not been previously exposed to these concepts. Students work in teams to analyze case studies of specific products fabricated using metals, ceramics, polymers and paper. The system of case studies is set up so that real societal issues can be discussed and debated, with students using role-playing to present their findings. Beverage containers are the product selected for initial analyses. These case studies compare cost, energy, resources used and emissions generated through the mining, refining, manufacture, use and disposal stages of the product life cycle. Although analyses are limited due to time constraints, students are made aware of the enormous amount of information required for these investigations. Issues in legislation (manufacturer take-back, packaging, ecolabeling) and issues in disposal strategies (landfill, incineration, reuse and recycling) are debated. The difficulties associated with environmental impact assessments and the development of decision analysis tools to weigh the tradeoffs in technical, economic and environmental performance of the product are discussed. This course offers new perspectives for enhancing the breadth of engineering education, and has been welcomed as a complement to the existing curriculum.

1. Introduction

With the increasing importance of commercialization and liabilities of materials, the manufacturing cost for part fabrication and the environmental consequences of using that material are becoming significant for characterizing the success and performance of a material, and for developing engineering design and manufacturing processes. Students must be made aware of repercussions related to selection and use of materials. Using case-based course instruction involving student teamwork, an interactive course is developed to raise the environmental literacy of upper-level undergraduate and graduate engineering students, and to integrate principles of engineering economy specifically for materials processing and manufacture.

With an understanding of both environmental and economic repercussions of materials selection, undergraduate students will make more informed decisions in undertaking their Senior Design Courses, and graduate students will be compelled to include aspects of these concepts in their research objectives. The nature of multi-dimensional case problems encourages debate as a means for initiating critical thinking in the classroom, and fosters development of other skill sets (e.g., effective communication, information literacy and interpersonal skills). Exploitation of data regarding manufacturing, product use and disposal lends itself to classroom discussions of realistic engineering cases. When making engineering decisions regarding the processing of materials, their subsequent utilization in manufacturing, and their environmental consequences at the end of life, one must be familiar with an extremely broad range of parameters. Therefore, a variety of teaching strategies must be employed to raise student awareness. To this end, a case-based interdisciplinary graduate course is offered to focus on economics and environmental assessment of product life cycle, which introduces students to the complexity of decision-making in the industrial setting.

Incorporation of interdisciplinary courses that address environmental and economic issues in materials processing into the engineering curriculum brings a necessary component for fostering not only broader perspectives, but also the major tenets of the Northeastern University Academic Common Experience Program (ACE). The university-wide ACE Program is sponsored both by grants from the Department of Education through FIPSE and from the National Science Foundation for Institute-wide Reform of Undergraduate Education. One of the guiding principles for ACE lies in assisting students during their undergraduate experience to develop skill sets (e.g., effective communication, critical thinking, information literacy and interpersonal skills) that stimulate life long learning. These skill sets will be enhanced for undergraduate and graduate students who participate in courses such as this one, involving active learning in teams and case studies. In the remainder of this paper, additional driving forces for offering this course within an engineering curriculum are identified, followed by an overview for this quarter-length course, and descriptions of specific class room activities and assessment practices.

2. Drivers for Environmental and Economic Focus

Students can gain a broader understanding and strengthen their comprehension of the economic and environmental consequences of materials choices by incorporating these ideas into existing technical courses or new technical electives. Within the Department of Mechanical, Industrial and Manufacturing Engineering (MIME), there are three undergraduate course offerings that focus on materials science. Current graduate materials courses provide a good foundation for graduate students focusing on a degree in materials science. Through required and elective courses available in the industrial engineering curriculum, students have opportunities to learn about engineering economy, project management and other pertinent business and operational issues in manufacturing. There are no existing engineering courses at Northeastern University, however, that address the integration of environmental and economic aspects of multi-dimensional projects.

A report from the Committee on Science, Engineering and Public Policy (a joint committee of the National Academy of Sciences, National Academy of Engineering and Institute of Medicine), draws several conclusions and makes recommendations from a study on the nation's graduate education and training system for engineers and scientists [1]. The findings indicate that the process by which PhDs are educated and prepared for employment is becoming inappropriate because it encourages specialization in narrow disciplines, at a time when employers are now placing "high value on engineers and scientists who can communicate, collaborate and work across disciplines." The report recommends a degree program that enhances career options while broadening students' horizons. It encourages greater versatility by avoiding overspecialization and by promoting experiences that supply skills that are desired by both academic and nonacademic employers. This includes ability to communicate complex ideas and to work in teams. The report also recommends that students be given better career information and guidance so that they can make good decisions in planning their professional careers, with industry as active partners.

Participation in a classroom experience with case-based team research will produce technically competent, well-rounded individuals, and will provide them with important skill sets and insight for addressing current issues facing industry. These graduating engineers – with a broader understanding of environmental and economic issues in manufacturing – will have greater value and marketability in the workplace, and may contribute to informed decisions influencing future corporate strategy.

3. Integrating Case Studies in Engineering Education

The role of interdisciplinary and team related activities is becoming increasingly evident in research, engineering and other fields of practice and study [2]. One of the dominant instruments for examining research hypotheses utilizes case study approaches. Case methodology in research has long been lauded as an effective method for rigorously addressing research hypotheses. Applying this method to teaching attempts to stimulate the students by encouraging them to ask "how" and "why" questions of their own. By addressing these questions using a case-based method of instruction, education receives two significant benefits [3]:

1. Students must apply and hone their critical thinking skills, e.g. defining issues, using sound reasoning, and making decisions.
2. Instructors maintain important ties with industry through the development and use of cases in the classroom.

A third benefit is that interactive seminar courses offer an essential route to fostering and raising the environmental literacy of our undergraduate and graduate engineering students [4]. Courses of this type are particularly amenable to incorporation of active learning techniques into the classroom [5]. Giving students an opportunity to become aware of the multi-dimensional nature of environmental problems is an imperative means for initiating critical thinking in the classroom.

Kolar and Sabatini [6] described their evolution from a lecture-based format to a team learning case study. Their paradigm centered on project-driven assignments (or cases) places students on permanent teams and gives them a complex design question at the beginning of the term before the explanation of any substantive background material. In the remainder of the term, student inquiries on how to complete the project drives the class activities (e.g., short lectures or class discussions or group exercises). In essence, the syllabus for the course was an evolving document driven by student curiosity, thereby helping to prepare the students for life-long learning.

Environmental issues are not usually "cut and dry" problems with simple answers; rather, these issues are interconnected with many other aspects, including technological and economic constraints. An opportunity to debate these issues, exchanging knowledge and points-of-view on the repercussions of various engineering technologies and design choices, is a valuable addition to the engineering curriculum. The new course enriches the graduate program by maintaining its foundation on the technical aspects of materials processing, but exposes the student to the economic and environmental consequences of design choices and pollution prevention initiatives. This course, also offered as an upper-class technical elective, is integral for undergraduate students to incorporate environmental aspects into the Senior Capstone Design Projects.

4. Essence of the Course

Objectives of the course include helping students: (1) to think about environmental repercussions of materials used in product manufacture, and (2) to understand the tools currently used to assess these consequences. Through this course, students explore environmental and economic aspects of alternative materials used in a product throughout its life cycle. Concepts of "industrial ecology" [7], "life cycle analysis" (LCA) [8,9] and "technical cost modeling" [10] are introduced through traditional lectures. Enhancements to teaching techniques (*"T4E"*) are implemented to engage students throughout the lecture [11].

In a series of case studies, alternative materials available for manufacture of beverage containers (as cans, bottles or boxes) are compared for their effects on resources and energy consumed, and emissions generated from cradle to grave throughout the product life cycle. Teamed in interest groups ranging among state agencies, recycling advocates, bottling associations and grocery store associations, students evaluate alternative packaging options to generate and support the position of their assigned group. Each team undertakes comparative case studies for beverage containers fabricated using alternative materials, e.g., metals (aluminum or steel), ceramics (glass), polymers (PET) and paper. Depending on class size and student interest, all materials alternatives for the product need not be represented to provide a meaningful discussion. Emissions data are available from results of reported LCA investigations [12]. These emissions inventories can be analyzed using decision-modeling tools that allow valuation of the data. Students are exposed to the limitations of the methodologies and must make decisions about how to evaluate the outcomes of life cycle inventories. The course syllabus is detailed in Table 1.

The initial lectures concentrate on framing the issues in the packaging industry and identifying the major interest groups in the decision making processes for materials selection and disposal of used containers. Concepts such as industrial ecology and life cycle analysis are broadly introduced. To evaluate the container alternatives, students must gain an understanding of the manufacturing requirements for each packaging alternative. Since different mining, refining and manufacturing processes are utilized for each alternative container material, students gain an appreciation of the materials technologies and their associated benefits and detriments.

After consideration of shipping and transportation logistics, the end-of-life alternatives are addressed. Technical aspects and current limitations to recycling of certain materials are presented and discussed, as well as environmental consequences of landfill and incineration. Debate is encouraged regarding current local and international policies and legislation, such as manufacturer take-back and ecolabeling.

Table 1: Graduate Course Outline for Spring Quarter 1998

Week	Topics Covered
1	**Framing the Case Studies: Packaging Materials for Beverages** Introduction to Industrial Ecology; Life Cycle Analysis; Case Studies
2	**Manufacture of Beverage Cans** Technical, Economic & Environmental Aspects of Steelmaking and Aluminum Production
3	**Manufacture of Beverage Bottles** Technical, Economic & Environmental Aspects of Glass and PET Production
4	**Recycling – The Policy Issues & Technical Barriers** Municipal Solid Waste Disposal; Landfill, Incineration and "Recycling"
5	**Manufacturer Take-Back Policies** Ecolabeling; Bottle Bills; Product Bans
6	**Life Cycle Analysis (LCA): An Introduction to the Technique** Inventory, Impact, Valuation
7	**Valuation Methodologies** Discussion of Attributes and Limitations
8	**Ethics and the Environment** Video followed by Group Working Session
9	**Recycling: Resource Conservation or Waste Reduction?** Discussion of Global Policies and Legislation
10	**Group Project Presentations** Course Wrap-up

Techniques associated with LCA are detailed for its three phases: inventory analysis, impact analysis and valuation of results. Students encounter the complications associated with life cycle inventory (LCI) analyses in LCA, as well as difficulties associated with impact analysis. The valuation phase of the LCA provides a means for interpreting the results of life cycle inventories on materials alternatives and disposal strategies. Although decision analysis tools to weigh the tradeoffs in technical, economic and environmental performance have been under development for some time, there are many hurdles to overcome before these tools are ready to be widely used [13]. On the other hand, there is important information that can be gleaned from their implementation.

Different disposal strategies result in different environmental consequences, but students reach the conclusions that there are no obviously optimal or "right" answers. The materials choices and disposal strategies imposed by various communities depend on how consequences and tradeoffs are valued by the populous [14]. At the end of the course, each interest group team defends its position through a final report and presentation identifying appropriate packaging material and disposal strategies. Conclusions are supported by interpretation of LCI and economic data.

5. Assessment

Group presentations, class participation, quizzes and written reports provide means for student assessment, however, assessment of student learning is adapted due to the multi-disciplinary nature of the new course. New approaches [15,16] are incorporated along with more traditional means for classroom assessment to determine whether students learn and retain essential skills and knowledge. The techniques particularly directed towards case-based learning include:

1. Classroom opinion polling – to reveal preexisting opinions about material encountered in course. Students discover their own opinions regarding environmental issues, compare their opinions with those of their classmates, and test their opinions against evidence and expert opinion.
2. Goal ranking and matching – to assess the degree of fit between i) students' personal learning goals and faculty's course-specific instructional goals and ii) faculty's and students' rankings of the relative importance and difficulty of these goals. This technique helps students learn to identify and clarify their own learning goals – an important lifelong learning skill.
3. Everyday ethical dilemmas – to prompt students to identify, clarify and connect their values by responding to course-related issues and problems that they are likely to encounter. Faculty obtain honest reactions and information on what students' values are, and how they apply them to realistic case-based dilemmas.
4. Group-work evaluations – to help students and faculty see what is going well and what is not going well in learning groups, so that potentially destructive conflicts can be discovered and diffused.

Student performance in the first offering of the course will be presented orally, along with a report on the effectiveness of teaching techniques, the case study approach, team collaborations, group debate, and assessment practices.

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