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Developing a Sustainability Course for Graduate Engineering Students and Professionals

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A wide variety of engineering students and professionals are interested in sustainability issues, but do not come from environmental backgrounds. As a result, courses designed for such students must strike a balance between providing useful environmental and sustainability knowledge and yet remain appropriate for those coming from a non-environmental background. This paper outlines such a course that has been taught and refined for the last three years in the Faculty of Engineering, University of Windsor, to a mixed class of civil, mechanical, environmental and industrial engineering graduate students. The paper provides examples and descriptions of what was done in the class and their effectiveness for teaching sustainability, as well as what difficulties were encountered.

Keywords: Education; engineering; environment; graduate course; professional development; sustainability

INTRODUCTION

A WIDE VARIETY of graduate engineering students and professionals are interested in sustainability, but do not come from environmental backgrounds. Furthermore, they are not necessarily interested in becoming environmental practitioners; instead, they seek to expand their personal and professional knowledge in such issues to complement their core technical interest. Indeed, environmental training is an efficient means to stimulate the interest in and develop the capability of engineers to handle multifaceted aspects of environmental issues [1] and by extension, sustainability issues. As a result, courses designed for such students must strike a balance between providing essential and useful sustainability and environmental knowledge, yet remain appropriate for those coming from a non-environmental background. Even those with backgrounds characterized as 'environmental engineering' may find such a course to be highly enlightening: conventional environmental engineering curriculums often forego specific issues that would be important for understanding sustainability.

There are various articles describing the merits and progress of graduate level programs and overall initiatives dealing with sustainability (e.g. see Semerjian *et al.* [2]). However, given that that graduate education in North America consists still largely of attending courses, many of the principles regarding sustainability can still be taught and understood within a single course. While this may not be ideal compared to program-wide initiatives, not all academic institutions have the resources to mount such a program and professionals upgrading their skills may only have the time and financial means to attend a selected course on sustainability. Furthermore, many academic professionals themselves may have little or no formal training in sustainability as an applied concept [3]. The questions are then, what should be the course structure and what should be taught?

COURSE CONTEXT AND OBJECTIVES

Sustainability has been identified for some time now as a critical aspect that must be included in engineering and design courses [4] and has been identified by various professional societies as an essential element in engineering education and practice [5]. The engineering community possesses the capability to institute widespread changes because of its involvement in multiple industries, including resource extraction, manufacturing, processing, infrastructure, municipal services and many others. A variety of papers outline how undergraduate engineering curriculums can incorporate the concepts of sustainability and impart environmental awareness to undergraduate students (e.g. see Hollar and Sukumaran [6]). A less well understood challenge is how to present a broad, interdisciplinary education to graduate engineering students [2], particularly if they come from a non-environmental background.

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Any engineering graduate course addressing sustainability would have to fulfill three main objectives at the University of Windsor:

- The course had to appeal to professionals and graduate students with little or no background in sustainability issues by addressing issues in a local or regional context.

The Faculty of Engineering at the University of Windsor—situated in Windsor, Ontario and opposite Detroit, Michigan—attracts graduate students from industrial and manufacturing backgrounds: the regional industries and businesses focus on the automotive and supply sectors. Most professionals in the region who wish to upgrade their skills and knowledge about such issues do not possess an environmental engineering, science or studies background or else have not been meaningfully exposed to environmental or sustainability issues previously. Nevertheless, increasing environmental regulations and a growing public awareness over environmental and community issues such as a newly proposed international border crossing, increased truck traffic and transboundary air pollution have increased the general concern over environmental matters.

- The course had to be positioned independently of any particular discipline to increase its general appeal and to garner support from other disciplines or departments.

Sustainability and environmental initiatives tend to reside within civil, environmental or chemical engineering programs [7]. Traditionally, environmentally related topics, including sustainability, were addressed through the Civil and Environmental Engineering Department at the University of Windsor. Such courses were thus only available to graduate students with such a background and, in reality, would only likely be attended by environmental students. Before this course, there was one course dealing with sustainability in the mid-1990s when sustainability as an applied concept within engineering was still relatively new; the course, however, had not been taught for about 6 years. It was decided by the faculty senior management to develop a new course that would at least appeal to civil, environmental and mechanical students. Actions at the departmental or program level are likely to be the most effective in meeting new graduate education challenges [8]. Civil and mechanical engineering attendees would likely lack the prerequisite environmental education typically expected of an environmental engineering graduate or practitioner, although it was recognized that some disciplines would have specialized technical knowledge related to sustainability issues (e.g. alternative fuels).

- The course would not benefit from other complementary courses or programs or have extensive resources at its disposal. It had to stand essentially as a self-contained, yet still comprehensive course.

The course had to encompass a diverse set of topics fundamental to understanding sustainability, but had to be taught with modest resources. For example, the Institute of Environmental Studies at the University of Toronto [9] offers courses that may be jointly attended by graduate students in various collaborating departments outside of engineering. Because of the program's larger size and extensive resources, the students can often choose from a much wider selection of courses to complement their interests. The University of Windsor is much smaller and the Faculty of Engineering is modestly sized, with approximately 60 full-time professors covering five major disciplines. There are also fewer courses outside of the faculty focusing on sustainability related topics. As a result, the course had to incorporate as many different topics as possible but still be taught as a standalone course in a standard 13-week term.

COURSE DEVELOPMENT AND SUBJECTS

The course was divided into three main subject areas:

- environmental assessment (EA);
- life cycle assessment (LCA) and design for environment (DfE),
- environmental decision making (DM).

There are various definitions for sustainability [10], but instead of prescribing a fixed definition for sustainability to the class, the definition and theme of sustainability was explored and allowed to develop within each successive class. However, the concept of integrating environmental, economic and social aspects is emphasized, as these aspects can be and probably are interrelated, as opposed to being exclusive of one another. Furthermore, the course considers whether the efforts undertaken to achieve sustainability might in itself be as valuable as achieving an end-product or process that is deemed sustainable.

As a result, each major subject chosen for this course would address specific topics deemed useful for understanding and then assessing sustainability in an engineering context. Environmental assessment could be interpreted as the context for setting down assessment principles, while LCA could be viewed more as an approach or tool to undertake a sustainability oriented assessment. Environmental decision making was presented as a specific decision support tool that could be used in either EA or LCA. The intent was to provide the students with a well rounded set of tools and diverse knowledge set related to sustainability and environmental issues that they could then employ within their respective fields, as opposed to expecting them to be able to, for example, conduct a contaminated site investigation or detailed deci-

sion analysis. Aspects of applied ecology or ecological engineering, are important [11] and were originally included in the first year of the course but were dropped in subsequent years because of time constraints.

Environmental assessment (EA)

Beginning the course by instructing students in the principles behind environmental assessment served three sub-objectives:

- To provide the basic language of environmental understanding and activities, particularly to students who do not come from an environmental background.
- To integrate various environmental subjects and topics that might have been taught or perceived to be distinct or discrete from one another.
- To demonstrate the degree of influence environmental regulations and policy has on business, industrial and societal matters.

Using environmental assessment provided a basis to introduce the concept of needs assessment and to illustrate how a structured manner for approaching sustainability issues can help frame important questions even if there is a lack of quantifiable characteristics or data. In particular, the specific topics covered included:

- Screening: depending on the environmental situation, a full, class or even no environmental assessment might be required. As a result, the concept of screening to eliminate the need for assessing environmental considerations or conversely, highlighting the need for a full environmental assessment, demonstrated to the students how poorly defined or understood sustainability related challenges could be initially assessed. Students began to appreciate that not all environmental issues could be aggregated under generic 'green' arguments.
- Scoping: students understood the purpose of this activity more readily because of its similarity to setting boundary conditions. The difficultly instead stemmed from their general lack of familiarity with what constituted reasonable boundaries in terms of space and time for environmental situations. For example, to what extent would aesthetic effects be felt beyond a large civil engineering project, such as a new bridge? To help the students define what might be reasonable system boundaries, the concepts of direct and indirect effects were introduced, along with methods of helping to conceptualize organize and assess the influence of such effects. These methods included network diagrams and categorical matrices.
- Consideration of alternatives: using various local examples—in the case of Windsor, the possible location and type of new crossing across the Detroit River—students were shown the importance of examining alternatives in sustainability and environmental context. While the engineering profession is often about choosing technological and economic alternatives [4], the issues related to sustainability are often less tangible in nature and do not lend themselves to conventional engineering analyses. At the same time, students begin to realize that aspects that lack numerical measures do not mean they could be treated any less rigorously.
- Furthermore, the concept of a preferred alternative, as opposed to a 'good' or intuitive alternative that often appeals to emotion, is essential to understanding the nature of tradeoffs and how such decisions affect sustainability. However, after realizing how screening and scoping exercises helped identify various alternatives, students were able to better identify the advantages and disadvantages behind each alternative. Moreover, the students realized that the zero alternative or status quo is one that should be seriously examined as a possibility, rather than always adopting a 'must fix' attitude.
- Strategic environmental assessments: environmental assessments often focus on physical constructs, such as roadways and facilities and provide an ideal starting point for discussion. However, many of the students were practicing engineers or had worked for significant periods in industry and had been exposed to a variety of environmental policies, both corporate and government. As a result, it is appropriate to introduce the concept of strategically assessing the environmental and long-term sustainability implications of policies, actions and management approaches.

A timely example that embodies such strategic issues is corporate environmental reporting (CER). Many public companies, particularly the multinationals, report their environmental and sustainability progress, often as part of the triple bottom line paradigm [12]. In essence, this can be viewed as a form of environmental self-assessment. Moreover, such reporting is often spurred by corporate driven policies and actions [3] or corporate citizenship, that result in voluntary initiatives in which a company or industry as a whole will commit to an environmental target or process that often exceed regulatory requirements: the regulatory landscape has evolved past the conventional command-and-control structure. The students therefore gained some appreciation as to how sustainability and environmental issues affect corporate practices. As an example, one student who owned a major, local manufacturing company indicated how the material in this course enabled him to speak knowledgeably with a potential, major North American client, who had a proactive, environmentally friendly procurement policy.

In terms of class performance, students with a more traditional environmental engineering background found themselves on familiar ground, while others (e.g. mechanical students) were less confident in their initial attempts to engage in class

discussions and assignments. At the end, there appeared to be little difference in actual graded performance, especially among the better students. This section did suffer from the lack of a textbook: environmental assessment textbooks tend not to cover the more integrative aspects, but instead adopt a topic specific, policy or regulatory presentation. Students were also reluctant to purchase a text that would essentially only be useful for one-third of the course. As a result, texts by authors such as Canter [13] were referenced if the student desired additional material.

In summary, the environmental assessment portion of the course provided both background material and a more familiar basis from which to engage the students in environmental and sustainability issues, as well as portraying such aspects in a more integrative as opposed to discrete context. Although most examples stemmed from more traditional civil and environmental engineering projects, they were familiar enough to most students to use as focal points for starting discussion. Students were encouraged to think about such concepts in relation to their specific professions and technical backgrounds.

Life cycle assessment (LCA) and design for environment (DfE)

The second major subject area of the course focused on life cycle assessment (LCA) and design for environment (DfE). These subjects proved to be the most challenging for the class as a whole, both from an instructional perspective as well as a student-learning perspective. Most students intuitively understood what cradle-to-gate/grave analysis implied, but not all could relate to a real-life example. Students with a mechanical or manufacturing background found this section easier to grasp: many had been exposed to quality control, production issues, the sourcing of materials, etc. Conversely, traditionally trained environmental engineering students could relate to outputs, such as emissions, but less so to resource extraction and manufacturing processes.

The specific topics and an example exercise included:

- Setting boundaries and scoping: students examined the differences between various industry sectors, such as resource extractors compared to assemblers, to understand how LCAs from one sector would differ from another and what could constitute reasonable boundaries in conducting any particular LCA study.
- Functional unit: a key aspect in any LCA is selecting the unit for comparing different alternatives. Familiar examples, such as fuel efficiency were used initially. Difficulties arose when the students examined their own selected projects. Because each project was unique, the functional unit was not always apparent and often even the instructor was hard pressed to assess confidently if one proposed unit was superior to another. Fortunately, the diversity in the class often meant students were able to assist one another in deciding on suitable indicators.
- Graphical and matrix representation of life cycle impacts: the use of graphics, tables and other pictorial indicators to represent impacts, such through target plots or spider plots proved useful and instructive for students to help organize their thoughts, assemble their data and assess the alternatives. However, because of the time and resource limitations of the course, much of the data had to be assumed and as a result, the conclusions often had to be highly qualified.

Sugar package design exercise to introduce LCA and DfE concepts

Although simple in nature, an in-class exercise that focused on redesigning a paper sugar package was adapted from a government-funded workshop [14]. Students were divided into smaller groups and each group was given a typical, rectangular package of sugar, as shown in Fig. 1. The goal was to suggest an alternative design that would be more environmentally friendly.

This exercise challenged the students to consider how the package is made, its functions, what is in

Fig. 1. Rectangular sugar packaging.

the package and how the leftover materials are discarded. For example, students had to decide early if they should consider raw material extraction to produce and then fabricate the packages from paper fibers. Student groups concluded that the purpose of the sugar package was to deliver sweetener. Some groups suggested that bulk sugar dispensers or stir sticks made of sugar would save on packaging, deliver sweetener to the user and in the latter example, also eliminate the need for a (disposable) coffee stirrer. It was soon realized, however, that the paper packaging provided hygienic protection, rationed the amount of sugar used at any one time and even provided advertising opportunities. The preferred design at the end already exists: a paper, cylindrical tube of sugar (Fig. 2), although these packages are not as common. Ostensibly, this type of design would use less paper, while still possessing many of the capabilities provided by a traditional square package.

This exercise proved to be a highly enjoyable class activity. It introduced the concepts of need and product functionality to the students and could be undertaken in a typical class or laboratory setting. However, given the constraints of the class and the amount of data readily available, it is relatively simplistic.

Longer term LCA and DfE assignments

To enable the students to more fully work with the concepts of LCA and DfE, a two-part assignment was developed. In the first part, the students selected, screened and scoped a product or process they were familiar with from either past or current experiences. They then conducted a focused LCA on their choice and using DfE principles, suggested alternative design or manufacturing approaches. Out of necessity, the assignment was restricted to a conceptual level: the students could not be reasonably expected to amass detailed data within a few weeks. However, most of the projects undertaken borrowed from existing literature and databases and as a result, were reasonably sophisticated given the constraints.

Difficulties in teaching LCA and DfE

Fortunately, the first subject areas were similar to the beginning aspects of the environmental assessment portion: students had to identify the needs and objectives of an LCA study, what could be the important categories for an LCA study and identify the 'system boundaries' of an LCA study. In addition, this section of the course benefited from a reasonably comprehensive textbook by Graedel and Allenby [15] that could used to provide examples and further information.

However, because of the diverse backgrounds of the students, it was difficult to present examples that used technical knowledge common to all students in the class. Simple examples, such as the sugar package exercise, were useful for stimulating class interaction and discussion but did not provide enough substance to sustain an ongoing discussion or meaningful assignments in a class setting. Students with dissimilar backgrounds and experiences did not easily understand complex examples such as those usually given in the assigned class textbook or journal articles. Unlike infrastructure examples used in the environmental assessment section, LCA and DfE examples often required some familiarity with specific manufacturing processes and materials that were less common to everyday experiences. There was a dearth of mid-range examples in which students could carry through several weeks' worth of work that was familiar enough to the instructor for grading purposes, remain broadly appealing to the students and also would not lead to trivial outcomes that would diminish the significance of the conclusions reached at the end of their assignments.

In summary, the LCA/DfE portion of the course proved slightly more enjoyable overall than the

Fig. 2. Cylindrical sugar packaging.

initial environmental assessment portion, mainly because examples that are more controversial could be discussed. Furthermore, students with a stronger mechanical or manufacturing background could speak more knowledgeably on the intricacies of material procurement, manufacturing and assembly. Even students with a non-mechanical background enjoyed the discussions and activities because more topical examples were discussed. However, while the LCA/DfE portion benefited by being able to leverage many of the same concepts taught in environmental assessment, there was a lack of moderately complex examples that would be feasible to analyse within a short time frame, common enough to all students and yet still provide enough substance for discussion or assignments.

Sustainability and environmental decision making (DM)

The last major section of the course focused on decision making. This section was shorter than the previous two but was considered very important: it engaged the students in using the information presented, as opposed to just possessing a general knowledge of the issues. Because very few students, even those with experience or education from an industrial engineering background, seemed to possess any prior knowledge of this material, no student was at a particular disadvantage to any other. However, as with the environmental assessment portion of the course, there was a general lack of textbooks that concisely described decision processes specific to sustainability and environmental situations.

The specific topics covered included:

- Basics of economic analysis: concepts such as supply, demand and utility were introduced to the students. Most had little or no background in basic economic theory, although such concepts were generally well understood.
- Issues specific to natural resource or environmental economics: this section included the valuation of non-quantifiable goods and services and explored concepts such as the willingness-to-pay, the value of life and discount rates. Students were then able to see why the economic perspective of benefit–cost analysis (BCA), particularly in financial terms, is so prevalent in engineering and how it could lead to problems in assessing alternatives using sustainability or environmental criteria. Topics were kept at a more cursory level, but were presented in enough detail to demonstrate the problems of accepting the lowest cost solution.
- Ranking of alternatives: students were then asked to consider how ranking could be used to help screen and eliminate alternatives, but also what are the limitations to such an approach. Most students could relate to such decision approaches based on their past or current experiences.
- Scoring of alternatives: the last major section introduced the students to the multiobjective decision process. They were shown its flexibility in assessing quantitative and qualitative data and how it was important to explicitly declare the value scheme used. However, its disadvantages were also presented: different users may disagree with the decision attributes, weightings, scoring process and so forth. At the end of the decision process, a user might not be able to determine if one score is much more significant than another.

Multi-objective decision making proved to be widely appealing for the class. Several of the LCA assessment methods presented in the LCA portion could now be better understood as variations of multiobjective decision making. Companies and industries will need to incorporate sustainability concepts into decision making should they pursue a sustainability mandate [16]. Multi-objective decision making would also prove useful to some students who work with such decision approaches in corporate or industrial applications outside of a sustainability or environmental context.

In summary, the decision making portion of the course proved highly instructive and useful to the students. The concepts introduced, particularly regarding multi-objective decision making, could be incorporated into the longer term assignments given for the LCA/DfE portion of the course. Furthermore, this portion allowed the students to integrate various sustainability topics presented throughout the course.

COURSE ASSESSMENT, FEEDBACK AND RECOMMENDATIONS

As with most post-secondary institutions, formal course evaluations are handed out near the end of each instructional term. The evaluations are not tailored to each course and some of the questions are specifically targeted towards assessing the class instructor as opposed to the course material. However, three questions out of 13 on the survey best indicate whether the students found the course interesting and useful:

- With respect to whether the course was viewed as a worthwhile course, 40 students out of a possible 47 attendees over the 3 years scored the course an average value of 4.5 on a scale of 1 (strongly disagree) to 5 (strongly disagree).
- With respect to whether the course increased the students' knowledge and competence, the same 40 students scored the course an average value of 4.7 on the same five-point scale.
- With respect to whether the course stimulated the students' interest in the subject areas presented by the course, the same 40 students scored the course an average value of 4.5 on the same five-point scale.

Such surveys can of course be misleading. Whereas most undergraduate engineering programs provide less choice for students to select optional courses, graduate students are often self-selecting: unless they have some interest in the course material in the first place, it is unlikely they would have attended. Nevertheless, given the short history of the course, such surveys suggest that the course curriculum and its implementation in its current form present at least a satisfactory approach to educating students on sustainability related matters.

Additional course feedback

To supplement the results of the formal course evaluations, which are limited in terms of the feedback they provide the instructor, a qualitative survey has been handed out at the end of each term. This exit survey attempts to solicit comments specific to the course content and its presentation, such as whether the three course topics of environmental assessment, LCA and DfE and decision making were viewed as coherent topics that related to one another. Although is not possible to numerically analyze the comments returned, the issues to highlight include:

- Several students commented that more examples, particularly industrial or commercial ones, dealing with LCA or DfE would have been helpful. This issue was noted in the course development and is reflected as a concern for the students.
- Depending on the background of the student, some students preferred less LCA/DfE coverage while others preferred more. For example, some students commented that they came from an environmental engineering background and thus while they found the LCA/DfE section interesting, such information would unlikely prove useful from a technical or practice perspective.
- Most students commented that the mix of topics—EA, LCA/DfE, DM—seemed appropriate and well integrated.

SUMMARY AND RECOMMENDATIONS

In summary, formal and informal feedback from the students indicate that they perceive the course as both worthwhile and useful and gained additional, useful knowledge about sustainability within an engineering context. The course structure, beginning with an environmental assessment focus and then shifting to life cycle assessment/DfE approaches and decision making appeared to successively build towards a more comprehensive understanding of sustainability. However, the course could benefit from improved reference materials and examples that are more topical. The instructor now is engaged in developing a mid-range example that should lend itself to more substantial but still relatively self-contained in-class discussions, activities and assignments.

Additional activities, such as visiting 'green building projects' have been actively pursued, but due to resource constraints or other limitations (for example, international students cannot easily cross international boundaries), such initiatives have not yet been successfully incorporated. Ironically, the focus on the automotive sector in Detroit and Windsor almost de-emphasize other regional interests, such as agricultural operations, that can contribute to a well-rounded curriculum about sustainability. Thus, other instructors or programs that view the description in this paper as a possible template for a course should also consider how to integrate local or regional experts from a variety of professional backgrounds to assist in planning the course or even serving as guest speakers.

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