INTEGRATING SUSTAINABLE DEVELOPMENT INTO THE UNDERGRADUATE ENGINEERING CURRICULUM THROUGH A MANDATORY FIRST YEAR ENGINEERING DESIGN COURSE AT THE UNIVERSITY OF TORONTO

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Abstract
This paper discusses how Engineering Science, an undergraduate division within the Faculty of Engineering at the University of Toronto in Toronto, Canada, has worked to foster engineers that can meaningfully contribute to sustainable development (SD). Specifically, Engineering Science has developed ESC102: Praxis II, a core course required for all first year undergraduate Engineering Science students, which takes both a systems engineering and an interdisciplinary approach to solving complex problems in a local context. All Engineering Science students take Praxis II, and are exposed to sustainable development concepts even if they had no prior interest in sustainable development (SD).

The 2010 Praxis II course integrated SD concepts by explicitly requiring students to consider and develop sustainability requirements, using the "DfX" concepts from the "Design for Sustainability" (DfS) and "Design for Environment"(DfE) literature, and incorporate sustainable design concepts into their final projects. Students were guided in these activities through introductory lectures, discussion groups, and tutorial activities. Sustainable design was also an explicit part of the assignment requirements.

This paper discusses the goals, process, and success of the 2010 Praxis II course curriculum integration of sustainable development concepts. It discusses the specific training in problem-solving and sustainability concepts that students received, and the challenges students faced in applying SD concepts to their solutions. We also explore how to improve student engagement in and student acceptance of SD concepts. Finally, we summarize the lessons learned for integrating SD concepts into an engineering design course.
Keywords
Engineering Education, Sustainable Design, Curriculum Integration, Systems Engineering, Undergraduate Curriculum

1. Introduction

1.1. Context

The University of Toronto, located in the multicultural City of Toronto, Ontario, Canada, is itself a multicultural institution. The University “offers an education on a global scale” with Professors and lecturers that “are leaders in discovery and teaching. They conduct more research across more disciplines than any other university in Canada and they publish more than any other public university in North America” (Uniquely UofT, 2010). The University of Toronto has been recognized as Canada's top university by several major “international rankings measuring research output and impact: The Higher Education, Evaluation and Accreditation Council of Taiwan (HEEACT), SCImago's institutions rankings and Shanghai Jiao Tong University’s academic rankings of world universities” (Smith, 2009). The University of Toronto is the largest Canadian academic institution, serving approximately 52,000 undergraduate students across three campuses (Britannica, 2010). The University offers a diverse set of undergraduate programs, with over 100 programs of study throughout several faculties both in arts and science as well as in engineering (StudyUofT, 2010).

The Faculty of Applied Science and Engineering at the University of Toronto is “Canada's largest engineering school and is widely recognized as one of the best in North America”, attracting “…the top math and science students from across Canada and internationally” (Britannica, 2010). In the QS University Rankings for Engineering and Technology, University of Toronto ranked 8th worldwide and 1st in Canada (2009). The Faculty offers eight core undergraduate Engineering programs – Chemical, Civil, Computer, Electrical, Industrial, Materials, Mechanical, and Mineral – and one elite program, Engineering Science. The core eight programs comprise approximately 3,300 students, while an additional 1,000 are enrolled in Engineering Science (Discover Engineering, 2010).

Engineering Science “…offers a unique and dynamic program designed to provide superior students with an undergraduate education in the most innovative disciplines within engineering” (Academic Program, 2010). The Engineering Science curriculum is divided into two sections, the Foundation and the Majors, each lasting two years: four academic terms. The four Foundation terms “…provide a strong foundation in science, math, technology and design” (Years 1 and 2 Curriculum, 2010), and include courses that cover classical mechanics, structures and materials, quantum physics, systems biology, fluid dynamics, robotics design, thermodynamics, linear algebra, calculus, computer programming, and...
electrical fundamentals (Years 1 and 2 Curriculum, 2010). Praxis I and II are core courses in the diverse first year foundational curriculum. An excerpt from the Engineering Calendar of the first year Engineering Science curriculum (2010) is included below in Figure 1.

<table>
<thead>
<tr>
<th>FIRST YEAR CURRICULUM- ENGINEERING SCIENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fall Session - Year 1</strong></td>
</tr>
<tr>
<td>Overture Lecture</td>
</tr>
<tr>
<td>Structures and Materials - An Introduction to Engineering Design</td>
</tr>
<tr>
<td>Praxis I</td>
</tr>
<tr>
<td>Engineering Mathematics and Computation</td>
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<tr>
<td>Calculus I</td>
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<tr>
<td>Classical Mechanics</td>
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<tr>
<td>Introduction to Computer Programming</td>
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<tr>
<td>Computer Programming, Algorithms, Data</td>
</tr>
<tr>
<td>Structures and Languages</td>
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<tr>
<td>Winter Session - Year 1</td>
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<tr>
<td>Systems Biology</td>
</tr>
<tr>
<td>Fundamentals of Electric Circuits</td>
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<tr>
<td>Praxis II</td>
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<tr>
<td>Linear Algebra</td>
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<tr>
<td>Calculus II</td>
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<tr>
<td>and one of:</td>
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<tr>
<td>Computer Algorithms, Data</td>
</tr>
<tr>
<td>Structures and Languages</td>
</tr>
<tr>
<td>Free Elective</td>
</tr>
</tbody>
</table>

Figure 1: First year Engineering Science curriculum

Engineering Science is by nature a multidisciplinary program that enables students to work within and across disciplines. In their third and fourth years, students select a discipline-specific option from a unique set of continuously-revised, multidisciplinary programs that are not typically offered at the undergraduate level: Aerospace, Biomedical, Computer, Electrical, Financial, Infrastructure, Manufacturing Systems, Nanoengineering, Physics, and Energy Systems.

Throughout their education, Engineering Science students are exposed to significantly greater depth of engineering theory than their counterparts in the core eight engineering programs offered at the University of Toronto. This approach to engineering education results in a relatively high proportion, on the order of 50 percent, of Engineering Science students pursuing Master’s and Doctoral degrees. To provide balance to the extensive theoretical education they receive during the Foundation years, Engineering Science students are simultaneously exposed to a wide variety of hands-on design projects ranging from computer science to autonomous robots to hands-on civil engineering projects like building a bridge out of cardboard.

1.2. Praxis Sequence of design courses

In conjunction with a second year mechatronics design course, the two Praxis courses focus on integrating theory with practice, design with communication, and engineering with broader society. The four key goals of the Praxis Sequence are to (Foster, 2009):

1. Have students develop a personal professional philosophy of engineering design and practice;
2. Have students apply their theoretical knowledge to the solution of new problems and to develop new knowledge to further their problem solving abilities;

3. Dispel the traditional notion that engineers must prioritize economic, safety, and functional concerns over environmental and social impact and to view impact from a sustainable development perspective; and

4. Provide training in the professional skills of leadership, cooperation, partnership, and delegation, which are necessary to solve complex problems.

Praxis II was first offered in Spring 2006, and has been running yearly ever since as a mandatory first year design course. Up until 2009, the Praxis Sequence had a third course, Praxis III, which focused on global issues and had been the target course for integrating sustainable development concepts. When Praxis III was cancelled as part of a curricular reorganisation, the focus on sustainable design was shifted to Praxis II, and to a lesser extent Praxis I. Although Praxis III was cancelled, more lecture hours and sessional lecturer marking hours as well as a greater GPA/course credit weight were assigned to Praxis I and II, allowing us to, in effect, have a greater, more positive, and more concentrated impact in these first two courses.

Praxis II was designed to help promote the Engineering Science slogan, “Engineers for the World” (E4tW). E4tW is a shorthand that describes engineers who are not only conscious of how their actions and designs will affect the environment, humanity, and the broader world, but who also actively seek opportunities to help improve the state the world. Praxis II is the vehicle for introducing the E4tW concept and for providing Engineering Science students with a first opportunity to put the concept into practice. As stated in the course syllabus (2010), Praxis II focuses on the “quality and credibility of engineering designs” through requiring that students “make and defend design decisions”. The Praxis Approach to Engineering Design Education has as core theoretical underpinnings the Perry Model of Intellectual and Ethical Development (Culver, 1990) and the Kolb Learning Cycle (Kolb, 1984).

Praxis II is unique because it requires students to engage in design for sustainability by integrating sustainable development concepts into the teaching of engineering design. At the University of Toronto, and from a brief review of curricula across other Canadian undergraduate engineering programs, at other Canadian institutions, courses that integrate sustainable development concepts are usually run much later in the undergraduate program (or not at all at this academic level) and typically, they are optional courses, designed solely for those that have a prior interest in sustainable development.

The first course in the Praxis series, Praxis I, is offered in the first semester of the first year of Engineering Science. In this course, students work in groups to complete three main
activities: improving a household appliance, bridge design, and improving the South-East University of Toronto St. George Campus. The bridge design involves students both finding and analyzing a reference design of a bridge and designing their own bridge. The bridge design must be fully documented, including reference works, engineering calculations, and engineering drawings, and must be accompanied by both analytical and descriptive explanations of the design choices. The final design project, improving the St. George Campus, involves a brief 1-2 page Request for Proposal (Design Brief) and the development of a unique design solution.

The second course in the series, Praxis II, is in the second semester of the first year. Praxis II builds on its predecessor, Praxis I, by further emphasizing and providing resources to support group work, design strategies, problem framing, and design communication. It also introduces concepts related to sustainable development. In the first stage of Praxis II, small groups of three or four students begin by developing an RFP that identifies and documents a problem relevant to their local community. The RFPs from the class are pooled and a subset chosen to proceed to the second stage of Praxis II. During this second stage the student teams develop and prototype solutions to the chosen RFPs. The solutions are presented, through a poster display and oral presentation, and a public showcase.

One of the key features of Praxis II is that it treats design for sustainability (DfS) as a routine part of any engineering design. In the core 8 University of Toronto engineering programs, SD is separated from the rest of the engineering disciplines and taught as “environmental engineering”. A quick scan of other Canadian engineering curricula reveals a similar approach. The advantage of separating SD from other engineering disciplines into “environmental engineering” is that it gives students interested in SD an opportunity to fully explore this topic. The problem with this separation, however, is that it treats SD as a separate issue that “regular” engineers may ignore, as it is viewed solely as the purview of the environmental engineer (Foster, 2009). During the EESD (Engineering Education for Sustainable Development) 2008 conference, where we presented a paper on Praxis III Heeney, 2008), the now-cancelled 3rd course in the Praxis series, a consensus of participants agreed that what the engineering profession needs is highly specialized engineers in all fields of engineering – civil, electrical, mechanical, industrial, etc. – who design sustainably in all their work. This consensus position revealed that the profession does not need a new breed of environmental engineers; rather we need to change the way we do engineering so that sustainable design is the result. This is a prime goal of the Praxis II course – to introduce students to how to engage in engineering design, which results in sustainable design.

As befits any work of engineering design, the Praxis Sequence has been under continual redevelopment, since its inception. The revisions have been prompted by both internal and
external factors, including student feedback on workload and complexity, various engineering competitions and initiatives, changes in the broader University of Toronto curriculum, and the availability and interest of guest speakers. Even with these revisions, the core values and learning objectives of the various Praxis courses have remained fundamentally unchanged. Initially, sustainable design was not explicitly stated as a core value of the course, but this is becoming more and more ingrained in the course as a requirement for good engineering design.

1.3. Evolution of Praxis II

After reviewing the lessons from EESD 2008, significant effort was put into ensuring sustainability was discussed as early as first year, with Praxis II becoming the flagship course for this, while sustainability would still be discussed in less detail in Praxis I. Before 2008, sustainability was not explicitly mentioned in either of the first year Praxis courses, Praxis I and II; sustainability was only considered in Praxis III, a second year design course.

The focus of the term-long project in Praxis II has changed since the inception of the course in 2006, though the projects have always been restricted to solving local problems in the Greater Toronto Area (GTA). In 2006-2007, the overarching project assignment in Praxis II was to “improve the state of a community in the GTA”, with no specific or explicit reference to sustainable design. Sustainable design was always an option but it was above-and-beyond what was expected in these first two years. In 2008-2009, the project was to improve an aspect of the Toronto public transit system; sustainability was not mentioned in the project description but it was implicitly discussed throughout the course.

In 2010, the overarching project for the term was revised again: “students must improve one or more of usability, accessibility, or sustainability in the City of Toronto and must incorporate sustainability into the requirements for the proposed solutions”. In 2010, the project assignment explicitly stated that sustainability either needed to be the prime focus of the solution, or at minimum, consciously incorporated into the designs proposed. While sustainable design was discussed and encouraged in past course offerings of Praxis II, the 2010 offering marked the first time that sustainability was explicitly stated as a course expectation. Although in 2008, in Praxis III, including sustainability considerations was an explicit requirement stated on the rubric for final projects, this was only a requirement for achieving an outstanding grade; strong emphasis was not put on this requirement for achieving a good grade or ensuring the feasibility of the proposed sustainable designs.
2. Sustainability philosophy: design for sustainability and design for environment

A key feature of the Praxis courses and Engineering Science (sometimes referred to as NΨ, in shorthand), as seen in Figure 2 above, is that they introduce students to sustainability concepts as part of a core first year design course. Integrating sustainable development concepts into these engineering design courses poses a major challenge: the instructors must determine how to frame these concepts in a useful and understandable manner. One of the most common ways of doing this is by framing sustainable design as an ethical requirement or part of a value system. The danger of presenting sustainable design as a value system is that it undermines the scientific basis for the necessity of sustainable design; instead, sustainability may be seen as a “cause” or something that is being “preached”. In our experience, presenting sustainability as a value system will merely preach to the converted; it is unlikely to change or affect the design practices of those that are not already strongly interested in and proponents of sustainable design.

In the Praxis Sequence, we present sustainability not as a value system but as a “DfX” or “Design for X”, among other “DfX”, where “X” can be a variety of design considerations ranging from function, to manufacturing and assembly, cost, usability, and accessibility (Meerkamm, 1994). “DfX” or “Design for X”, on which there exists a wide range of literature in the engineering community, refers to the fact “that the designer has to follow many guidelines during the whole design process, starting from the conceptual stage up to the embodiment and detailed design. These guidelines and rules (design for...) are constraints to the best solution” (Meerkamm, 1994). In the Praxis Sequence, we present sustainable design not as a value system but as one of these “DfX” – design for sustainability and design for environment - alongside other requirements such as safety, cost, usability, and accessibility.
In lecture, we explain that when engaging in engineering design, the designer must define what is in scope and what is out of scope for consideration during design. In effect, the engineer must develop a model of the real world, choosing the factors that are most important to consider. Factors that are within scope must be consciously considered, while those that are out of scope can be considered as externalities. The lecture slides that we use to present this concept of externalities and DfX are shown below in Figure 3. In the second slide of Figure 3, we show the traditional place for design for sustainability: out of scope. In lecture, we argue that when sustainability is not considered in design, it is simply viewed as an externality (as in Figure 3 below), which is out of scope.

Figure 3: Praxis II lecture slides discussing the concept of scope in the context of engineering design
(ESC102 Lecture 4 slides, J. Foster, 2010)

In the Praxis Sequence, we propose, and in fact, we make it mandatory, that students no longer consider sustainability issues as externalities; students must consciously consider sustainability issues when developing their designs. Figure 4, below, summarizes the Praxis approach to sustainability, as it was presented at the ASEE conference in 2009, by J. Foster.
However, Praxis is not prescriptive in the approach that students should take when considering sustainability. Rather than enforcing a specific set of factors for students to consider under the umbrella of “sustainability”, Praxis challenges students to develop their own set of factors subject to their being able to justify their choices. This is consistent with the first objective of the Praxis Sequence outlined in Section 1.2. Praxis II, which, requires students to be consciously aware of the scientific basis for sustainable development and thus the necessity to consider sustainable development. All design decisions that students make in the course must be justified. By extension, if students ignore sustainability in their decision-making process, they will have difficulty justifying the validity of their engineering decisions.

When presenting Design for Sustainability in lectures, we reference the key expert documents and resources in the sustainability literature. Figure 5 below presents a lecture slide from ESC102 (ESC102 Lecture 12 slides, J. Foster, 2010) where DfS was presented with reference to the Hannover Principles from 1992.
In Praxis, students must explore sustainability in design in both the means by which the design is realized and the overall outcome of the design. That is, the outcome of the design must help make the world more sustainable (e.g. by developing an energy-efficient design, or a design which has system-wide benefits for sustainability). Equally, the means by which the design is realized must be sustainable: if the production of a work of engineering design uses, for example, highly unsustainable materials, or large amounts of energy, or requires unreasonably high energy use in transportation, the design cannot be considered a fully sustainable design. The lecture slide from Lecture 8 of the 2010 Praxis II course in Figure 6 begins to illustrate this comprehensive approach to sustainability. We argue that if designs do not consider the sustainability of both the means by which the design is created and the outcome of the design, designs are not fully sustainable: they are, instead, works of “unsustainable sustainability”.

We explain this concept of “unsustainable sustainability” through additional lecture slides from Lecture 8 (Lecture 8 ESC102, J. Foster, 2010), which parse, piece by piece, our

The 14th European Roundtable on Sustainable Production and Consumption (ERSCP)
The 6th Environmental Management for Sustainable Universities (EMSU)
assignment guidelines to help students understand and explore the multiple facets of sustainable design from the beginning of the design process right through to design completion. The end result of this analysis of sustainability can be seen in Figure 7, below, where we outline the multiple considerations required regarding sustainability.

![Figure 7: ESC102 Lecture 8 slide on the many facets of sustainability in design](image)

Sustainable as attribute” refers to the means by which the design is created: the design itself must be sustainable, which could mean that the design (and/or transportation of materials) does not detrimentally contribute to, for example, carbon output, pollution, or wastes. “Sustainable as outcome” refers to how the design improves the overall sustainability of the world. For example, the design of a levee could make the world more sustainable by preventing flooding and the resulting environmental damage or degradation; it is “sustainable as outcome”. However, if the construction of the levee uses materials that create hazardous wastes in their production, materials that could damage the aquatic ecosystem, or materials that need to be transported from the other side of the world (and have a huge carbon footprint), the design would not be “sustainable as [an] attribute”.

3. Methodology for iteratively integrating sustainable development into the Praxis Sequence

Producing a work of engineering, which, at its core, is designed for sustainability, requires the ability of the designer to grapple with complex and interconnected issues. Hence, our methodology for integrating design for sustainability into the Praxis courses was to, first, establish a successful framework in the courses for handling such complex design problems and then gradually incorporate more and more sustainable design content explicitly in the course. The challenge for the engineering design educator is to determine how to ensure that the design course is structured so that students are equipped to handle sustainable
design and that the course provides enough background information and support in design for sustainability.

3.1. The problem with and tendency for students to procrastinate

Given that design for sustainability is a design problem that does not have an obviously “right” or “wrong” answer – there is fuzziness and uncertainty – students are likely to procrastinate and avoid working on the problem (McCrea, 2008) until the last minute, unless there is some external factor which pressures them to get started thinking early. This penchant for procrastination is exacerbated by the fact that students in Engineering Science already face a very demanding and challenging curriculum with more than 30 hours of scheduled class time per week (“Engineering Calendar”, 2010). Students are often overloaded, and thus tend to procrastinate on assignments until the night before the deadline. Many Engineering Science students developed these procrastination habits in high school, where the last-minute work did not significantly affect the quality of their final work or their grade. However, doing all the thinking and work at the last-minute when faced with the complex systems dynamics inherent in design for sustainability, is not conducive to good engineering design since it renders following an iterative process impossible. According to Atman et al. (1999), when students follow an iterative design process, they are better equipped to handle the complexities of the problem at hand, and thus, produce a final product of higher quality.

3.2. Step 1 for SD integration: helping students to overcome procrastination by improving course structure

Helping students overcome procrastination requires structuring the course so that it would be impossible for students to generate their final design and all supporting work at the last minute, right before the deadline. In 2006-2007, the student tendency to procrastinate was one of the most important limiting factors for ensuring student success in their design work.

In 2006-2007, the course was not structured to prevent procrastination as there were very few interim deliverables: students were only required to submit the Request for Proposal, an Interim Report, and a Final Presentation. This paucity of interim deliverables resulted in most students doing most of their work at the last-minute, right before the deadline, meaning following an iterative design process was impossible. However, in 2006-2007, the most successful teams were those that did not leave all their work to the last minute; instead, they followed an iterative design process.

In 2008-2010, to ensure that more teams followed the process model of the successful teams from 2006-2007, the course was continually restructured to include more and more interim deliverables to break the design process up into smaller chunks. This forced students...
to think about the problems earlier and thus obviated the tendency for all work to be
completed at the very last minute. These interim deliverables also forced students to follow
an iterative design process, iterating, at minimum, with each new interim deliverable.
Starting in 2009, (or 2007 for Praxis III), students were required to submit draft versions of
each of the deliverables for a pass/fail review by course staff for two reasons: students
would be forced to get their ideas down on paper (and thus iterate) and receive timely
feedback to help them improve (and thus iterate again) their designs and how they
communicate their designs. In 2010, the number of deliverables was increased further to
include: an initial problem statement, an assignment to develop engineering requirements, a
Request for Proposal, a revised Request Proposal, an interim Design Review (or practice
final presentation), and a final design presentation. These deliverables are discussed in
greater detail in section 4.2.

3.3. Step 2 for SD integration: Ensuring the course content incorporates and explores
design for sustainability more and more explicitly

Once an appropriate framework for complex systems design has been established in the
design course and appropriate scaffolding is in place to help students learn to do design for
sustainability, it is possible to increasingly explicitly incorporate design for sustainability into
the course content. This explicit integration of sustainability in course content is necessary to
ensure that students are both motivated and equipped to design for sustainability.

In 2008-2009, design for sustainability was mentioned in Praxis II as a DfX to consider, and
teams would be questioned and constructively criticized if their designs very obviously
treated sustainability as an externality. Design for Sustainability was a concept discussed in
lecture and some teams chose to explore this DfX, but it was not greatly emphasized. In
2010, Design for Sustainability was explicitly stated as an assignment requirement and
appeared in at least some assignment rubrics. It has been a gradual process, but DfS and
DfE have gained a more prominent emphasis in Praxis II over the years. This was only
possible by first establishing a good course structure which would enable students to be able
to cope with and manage the complexities inherent in DfS and DfE.

4. 2010 Praxis II course structure

In 2010, Praxis II was a 13-week course, which included two main teaching components:

- 2 hours of lecture per week in which the key course concepts were introduced; and
- a 2-hour weekly studio tutorial in which students worked on focused group activities
to apply course concepts to their design projects, under the guidance of sessional
instructors.
Students were both taught and advised by two course instructors: one with expertise in engineering design and one with expertise in engineering communication. Sessional instructors ran the tutorials – with 4 sessions running in parallel – while the course instructors moved from room to room to provide their expertise.

In the first half of the course, during which problem finding and documenting were the focus, sessional instructors with a background in engineering communication ran the tutorials. In the second half of the course, when the focus was on solution development, sessional instructors with expertise in engineering design ran the tutorials. Accordingly, tutorials in the second half of the course focused more strongly on what the students perceive as being engineering design. Each tutorial section was staffed with at least one sessional instructor who was either a graduate student or a current undergraduate with strong experience in the requisite areas, which generally meant undergraduates who were high-achieving students in the Praxis Sequence when they took these courses themselves.

4.1. Praxis II: Project description

Throughout the term, students worked in groups of three or four to identify and solve a local engineering design problem facing the city of Toronto. In 2010, the overarching assignment description for the term was: “develop a work of engineering design to improve one or more of usability, accessibility, or sustainability to improve one aspect of Toronto city life, ensuring that the consideration of sustainable design is incorporated into all solutions” (Phase One Overview, 2010). The targeted aspect had to fall under one of the following City of Toronto Divisions (2010): City Planning; Solid Waste Management; Parks, Forestry, and Recreation; or Transportation Services, including the Office of the Public Realm. As stated in the project description, the targeted aspect of city life, and associated needs for improvement must:

- Draw upon credible information (e.g. direct observation, media reports, expert testimony or commentary, etc.);
- Focus on the needs of more than one stakeholder group (e.g. multiple user groups, city employees, city management, local businesses, etc.); and
- Target a contextualized, neighbourhood-or-smaller-scale aspect of city life (e.g. where a solution will have immediate impact on a recognizable community).

4.2. Deliverables

In keeping with the strategy for reducing procrastination described in section 3.2, deliverables guided the design process throughout the course. These deliverables were designed to break up the work into smaller, more manageable, chunks or steps. Students were required to submit or present a draft of each deliverable to their sessional instructor in tutorial one week before the deadline; sessional instructors provided feedback on the draft
which students were expected to incorporate when crafting the final product. Most deliverables were a product of teamwork, but 30% of student grades was based on individual work. The deliverables required in the course are detailed in Table 1.

### Table 1: Deliverables for Praxis II

<table>
<thead>
<tr>
<th>Due Date</th>
<th>Deliverable</th>
<th>Instructions for student describing the assignment</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ongoing throughout the term</td>
<td>Online Design Journal Entries and Wiki Contributions (Individual)</td>
<td>Make regular entries, throughout the term, in your Online Design Journal, some addressing prescribed questions at key milestones in the course (solicited entries) and some entries that were entirely student-initiated (unsolicited entries). The unsolicited journal entries should demonstrate reflection on the course material as applied to the course and outside of the course, and demonstrate how students have obtained the course learning objectives.</td>
<td>25% (15% solicited entries, 10% unsolicited entries)</td>
</tr>
<tr>
<td>Studio week of 01-18</td>
<td>Topic Presentation and Précis (Team)</td>
<td>Identify, define, and provide context for a problem in the GTA, which will be elaborated on in the RFP. Identify key stakeholders and 3-4 key requirements that your group will explore as part of the Requirements HOWTO assignment.</td>
<td>5%</td>
</tr>
<tr>
<td>2010-01-31 @ 2400</td>
<td>Requirement HOWTO (Individual)</td>
<td>Develop a one-page document, which frames a high-level requirement from your team’s RFP (e.g. cost) into a suitable set of objectives (e.g. “cost effectiveness”), constraints (e.g. “must cost less than 2% of mean disposable income”), and criteria (e.g. “cheaper is preferred”) accompanied by appropriate metrics and supported by engineering literature. One member of each team must submit a HOWTO on design for sustainability.</td>
<td>5%</td>
</tr>
<tr>
<td>2010-02-14 @ 2400</td>
<td>Request for Proposal (RFP), (Team)</td>
<td>Fully frame and justify an engineering design problem that improves one or more of the accessibility, usability, or sustainability of one aspect of Toronto city life. The RFP must incorporate sustainability into the requirements for the proposed solutions.</td>
<td>20%</td>
</tr>
<tr>
<td>2010-03-01 @ 2400</td>
<td>RFP Revision (Team)</td>
<td>Revise your RFP based on instructor feedback.</td>
<td>5%</td>
</tr>
<tr>
<td>Studio week of 03-15</td>
<td>Design Critique (Team)</td>
<td>Present the first, preliminary design iteration of their solution to the RFP in a formal oral presentation using clearly labeled sketches or other visuals as well as prototype(s) to highlight key aspects of your design concept. The purpose of this assignment is largely formative in order to provide students with feedback on the viability of the design concepts developed and an opportunity to practice for the design showcase.</td>
<td>10%</td>
</tr>
<tr>
<td>2010-04-12 @ TBD</td>
<td>Design Showcase (Team)</td>
<td>Present the final design solution using the following media: prototype, poster, presentation, and brochure.</td>
<td>30%</td>
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</table>

There were two assignments that specifically addressed sustainability and sustainable design in the assignment descriptions, as shown in Table 1, above. These were the HOWTO assignment and the RFP, which formed the basis for all future assignments.

#### 4.2.1. HOWTO assignment

The HOWTO assignment was designed to allow students to do focused work on developing engineering requirements without worrying about the other additional complexities that an
RFP involves. In order to ensure that a wide array of DfX were covered and that Design for Sustainability remained an important focus, one member from each group of three was required to write a HOWTO on Design for Sustainability. The goal of this was to get at least one member of the group looking into the design literature on DfS so that the group had an expert on DfS. This would help ensure that DfS could and would be incorporated in the RFP and in the final designs. It was intended that students would use the knowledge they acquired regarding DfS requirements from this assignment when developing subsequent deliverables for the course including the RFP and final design presentations. This was to help ensure that DfS was incorporated throughout the design process.

4.2.2. Request for Proposal

The Request for Proposal (RFP), as described in the assignment guidelines (2010), was designed to engage students in identifying an engineering problem that addressed “improving an aspect of Toronto city life in the area of at least one of sustainability, accessibility, or usability, while ensuring that sustainable design was incorporated in the final design” (RFP, 2010). The RFP was framed to explicitly include sustainable design in the deliverable description to ensure that a consideration of sustainability was included in the RFP. Since responding to the RFPs would form the basis for the second half of the course, ensuring that sustainability was included in the RFPs was a prerequisite for ensuring that addressing sustainability would be an implicit part of responding to the RFPs with an engineering design solution.

5. Results and discussion

5.1. The HOWTO assignment and sustainability

The 2010 course offering of Praxis II was the first time that the HOWTO assignment was used in order to facilitate student thinking regarding requirements analysis, and in particular, sustainability requirements. As a result, some tweaking is still needed in order to ensure the success of this assignment. The structure of the assignment was problematic as it was over-constrained: students were limited to a single page to outline the objectives, constraints, and criteria of the DfX they were addressing. The result was that students tended to favour overly simplistic interpretations of SD requirements over more thoughtful and complex requirements.

The underlying problem with the structure of the HOWTO assignment was exacerbated by confusion over whether the requirements outlined in the HOWTO were intended to be specific to the group’s RFP or if the requirements were intended to be generally applicable to any engineering problem. Consequently, requirements tended to be abstract and not adequately contextualized for utility. Here is an example taken from one student’s list of sustainability requirements that typifies the problem with the student approach: “materials
used for manufacture must be derived from sustainable sources (e.g. fair trade products),
“must not create any hazardous emission”, “must be operable for more than 2 years in usual
way under minimal fixing,” and “must be a system with a capacity of producing no less than
12000 KWh/yr, which is the energy demand of average home in Toronto”. Although these
requirements begin to tackle relevant issues in sustainability, they are vague. There is no
evidence of an understanding of the complexities of achieving these requirements and the
metrics given are arbitrary.

The difficulties that students experienced with this assignment may have carried through to
additional assignments: due to time constraints students may not have had time to develop
more fully their sustainability requirements so their original, overly simplistic interpretations
from the HOWTO may have continued to be used to guide their thinking on DfS and,
ultimately, guide their design decisions.

5.2. Chosen RFP topics and sustainable development

The eight RFPs selected for solution from the pool of student submissions to be solved by
students in the latter half of the course were:

1. Pipeline Leakage Detection Program;
2. Charging Stations for Electric Vehicles in Toronto;
3. Harnessing Urban Wind Tunnels in Toronto’s Downtown Core;
4. Information Sharing Within the City of Toronto Homeless;
5. Pedestrian Safety at the Intersection of Spadina Avenue and Dundas Street West;
6. Improving the Navigation System of the PATH;
7. Promoting Toronto’s Culture of Walking through a Pedestrian Mall; and
8. Inadequacy of Infrastructure Supporting Safety of Cyclists on Bloor Street.

Topic three directly relates to environmental sustainability on a first-order basis, while topic s
one, two, and eight relate to second-order sustainable development considerations. Topic
three directly relates to renewable wind energy and developing a symbol of sustainability in
the downtown core of the City; however, when students spoke to experts regarding this
design problem, the consensus was that very little useful wind energy could be harnessed
from urban wind tunnels and that this was ultimately not a viable design problem.

Topic one relates to sustainable development of Toronto by preventing pipe failure which
could cause flooding and road damage. Topic two is a forward-thinking RFP, which
addresses sustainability indirectly - via consideration of second-order ramifications of
development- by developing infrastructure in order to support more sustainable, electric
vehicles. Similarly, topic eight also addresses sustainability in an indirect way: improving
cyclist safety on one of the major streets in the City, Bloor Street, would help create an incentive for more people to travel by bicycle instead of by car, improving the accessibility of sustainable transportation in Toronto.

5.3. Sustainability Requirements in the chosen RFPs

All RFPs (as described in the list in section 5.2) were required to include some requirements related to sustainability. The requirements that the students developed ranged from thoughtfully complex to naively simplistic. The RFPs frame the problem and students are expected to respond to the RFP. Hence, the quality of the sustainability requirements in the RFPs is crucial for shaping the quality of the final designs regarding sustainability. If students take the RFP at face value rather than questioning its underpinnings (questioning which is encouraged but not required), and the RFP has a low quality set of sustainability requirements, solutions which respond directly to these requirements will subsequently inadequately incorporate and consider sustainability.

Furthermore, since sessional instructors and course instructors were instructed to grade students based on their ability to address the requirements of the RFP (G. Frost, personal interview, August 15, 2010), if the sustainability requirements are inadequate for achieving a sustainable solution, students would not be required to achieve a truly sustainable solution; they merely needed to address the requirements given. In an interview with one of the Praxis II sessional instructors (G. Frost, interview, August 15, 2010), he commented that strong violations of sustainability were strongly penalized: hugely wasteful solutions or solutions which were extremely environmental destructive were not tolerated. However, there was not an explicit expectation that solutions should be designed to optimize and improve sustainability and reduce environmental impact. The sustainability requirements in the RFP are likely a large contributing factor to the ultimate degree of sustainability of the design solutions since students would need to go above and beyond the expectations of the RFP in order to achieve sustainability.

Table 2, below, outlines some examples of the range of sustainability requirements stated in the chosen RFPs and provides an analysis of their validity and a subjective assessment of the quality of these sustainability requirements.
Table 2: Sustainability Requirements and Subjective Assessments of the Requirements

<table>
<thead>
<tr>
<th>RFP</th>
<th>Sustainability Requirement Excerpt</th>
<th>Analysis</th>
<th>Overall Quality</th>
</tr>
</thead>
</table>
| Information Sharing Within the City of Toronto Homeless Services (Anonymous ESC102 Student Team D, 2010) | Technological sustainability will be measured by the amount of money spent on maintenance of the system. | - very narrow definition of sustainability that focuses purely on longevity with no discussion of environmental considerations  
- only considers first-order effects: does not consider how information sharing could improve other aspects of sustainability (e.g. minimizing energy use by reducing the amount of transportation between shelters in an attempt to find a shelter with space) | low |
| Pipeline Leakage Detection Program (Anonymous ESC102 Student Team A, 2010) | - Must be applicable to the problem for the next 10 years  
- Must conform to an annual maintenance budget of $75 million | - strong emphasis on longevity of the solution with little focus on the environmental impacts of the solution or the development of the solution  
- very narrow definition of sustainability which does not incorporate environmental considerations but does consider part of project life cycle from an economic (though not an environmental) perspective | medium |
| Charging Stations for Electric Vehicles in Toronto (Anonymous ESC102 Student Team B, 2010) | - The design shall be easily removable: Must not entail lasting modifications of streets and/or buildings to enable future generations to modernize infrastructure.  
- The design shall utilize more than 25% sustainable materials: materials that are all renewable, recyclable, or biodegradable.  
- The design should minimize the output of toxic/hazardous materials: Less than 0.2 kg over the entire life-cycle is preferred; should be compliant with legislation.  
- The design should minimize material and energy usage over their entire life-cycle (manufacturing, wiring, installation, repairs, recycling). | The sustainability requirements address a wide range of issues under the umbrella of sustainable design, which are appropriate to the design problem. The group also displays a good understanding of the concept of sustainable development and cites the UN definition for sustainable development. | high |

5.4. Overall integration of sustainability into Praxis II

Several of the Praxis sessional instructors were interviewed in order to ascertain, from their perspective, the degree to which sustainable design concepts had been integrated into the Praxis Sequence. A statement from a Praxis sessional instructor (P. Lam, email, July 23, 2010) provides an excellent summary of the degree of sustainable design integration in the Praxis Sequence, from the perspective of the course instructors and sessional instructors:
“The current Praxis curriculum places enough emphasis on sustainability as a design criterion that students absorb that into their own practice in Studio and assignments. This awareness that design work can have an impact on the context of the work is an important one, but is currently only explored by students in a "first-order" way. That is, beyond including features in their designs that address basic sustainability issues such as reducing waste or using recyclable or reusable materials, students aren’t exploring issues of sustainability in a more detailed way.

Students could explore sustainability in a more meaningful way within existing Studio activities. Common environmentally-related design constraints found in industry could be integrated into the theoretical design activities that students currently perform in Studio. For example, the RFPs that students follow in these design sessions could include simplified environmental regulations, or require the calculation of maintenance costs of the finished project. This would mimic design problems that engineers face in professional practice.

I’m not sure whether a first-order treatment of sustainability is suitable for a first year course, or whether a deeper understanding of sustainability should be encouraged.”

Furthermore, when determining the project statement for the course, this requires a delicate balance. The Praxis sessional instructor, quoted above, articulated this very well: “The difficulty with posing toy design problems to students is making them realistic while keeping them simple enough for students to complete them within a short period of time. Ideally, the constraints provided should allow for a solution while providing adequate difficulty to students” (P. Lam, email, July 23, 2010).

6. Lessons learned

6.1. Motivate DfS by presenting scientific content regarding sustainability

Incorporating DfS needs to be student-motivated in order to ensure that students choose to incorporate DfS into their own unique design process in future work. Hence, it is not enough to make the consideration of DfS mandatory in the course; students need to understand why they should care about DfS so that DfS becomes an integral part of their own personal definition of Engineering Design. This can be addressed by preparing at least 1-2 lectures on the scientific basis for sustainable development in engineering design, citing scientific facts about the current state of the world and the problems with unsustainable development. Ideally, these lectures could be delivered by an expert in the field at the University (e.g. a University faculty member that also is a member of the Intergovernmental Panel on Climate Change) so that the scientific content could be as technical and detailed as possible.
6.2. Provide course lectures that contain background information on what DfS is and some case studies on how it has been done

DfS is a less intuitive design consideration than other more common DfX such as cost, safety, and usability. There are many facets of DfS. Especially since students are first year students with no prior engineering design experience, students need some guidance to initiate their research and thinking about DfS. The challenge for the instructor is to address DfS explicitly in the course with examples, while finding a balance between broadening the students’ perspectives on DfS without being too prescriptive regarding how DfS should be executed.

Providing students with online resources regarding DfS is necessary but not sufficient: there is no guarantee that students will take the time to adequately explore the content of these documents. In the HOWTO assignment on DfS, many students did not access and cite appropriate resources on DfS despite being provided with some by the course instructors. If lecture time is not devoted to DfS material, students may not take DfS seriously as they may not believe it to be core to the course. Given the panoply of learning styles (from visual to auditory) that students in the course may have, addressing DfS in lecture will help ensure that students who do not learn best from reading will still become engaged in the DfS course content. The need to ensure that students understand and have access to enough background information on DfS can be addressed by:

- Dedicating two to three lectures specifically to addressing what DfS is and what some of the approaches to addressing this DfX are; and

- Providing students with some useful resources regarding DfS to get them started on their research and to begin to immerse students in the literature surrounding DfS. These resources should be provided in a manner which will ensure that at least some of these documents will get read (e.g. by providing hard copies of useful papers or textbooks in tutorial and give students time to read and discuss these materials).

6.3. Ensure that students are always evaluated on their ability to incorporate DfS into their design so that it is a core design requirement of the course

Since incorporating DfS at each step in the design process was not an explicit requirement on the assessment rubrics for each of the assignments, there was no explicit means to reward or penalise students for their follow-through (or lack thereof) of incorporating DfS considerations throughout the course. It is necessary to evaluate students on their work regarding DfS both to ensure that students feel that their effort spent on considering DfS was worthwhile and that appropriate feedback is given to aid students in improving how they address DfS considerations. Evaluating student work for DfS incorporation is also necessary.
in order to ensure that students take it seriously as an integral component of the course and are penalized accordingly if they neglect DfS considerations. This can be achieved by:

- Ensuring that all course assignments and all assignment rubrics explicitly require student to incorporate some DfS considerations; and
- Ensuring that students will be penalized significantly if they ignore DfS considerations.

6.4. Train sessional instructors to ensure that they understand DfS and their role in incorporating DfS into the course and can communicate DfS effectively

Sessional instructors need to contribute to the SD integration process in the course. In 2010, we did not train sessional instructors regarding DfS course content, which meant that the sessional instructors marking many of the assignments did not directly and explicitly evaluate student work for DfS considerations. During tutorials, when sessional instructors are asked to critique student designs, the sessional instructors were not specifically and explicitly critiquing student designs for whether or not the designs involved appropriate DfS. Since sessional instructors play an integral role in course delivery and are the primary source of feedback on student work, SD cannot be fully integrated into the course unless sessional instructors are trained in DfS. This means that the course instructors need to constantly communicate with sessional instructors to ensure that sessional instructors understand their role in contributing to SD integration and communicate SD effectively and consistently, be it through preparing for tutorials or understanding the kinds of design flaws to look for in student projects. These issues can be addressed by:

- Providing basic training to sessional instructors regarding teaching DfS at the beginning of the term to ensure that sessional instructors understand the course objectives regarding SD and their role in incorporating SD into the curriculum;
- Providing sessional instructors with useful introductory resources on DfS and SD and requiring sessional instructors to read and understand these documents;
- Encouraging and perhaps even requiring sessional instructors to do some research of their own on DfS and SD to improve their knowledge base in these subjects;
- Requiring sessional instructors to attend lectures where DfS content is delivered so that the sessional instructors learn what the students learn;
- Requiring that sessional instructors have time to prepare appropriately for tutorials so that tutorial time is used effectively; and
- Facilitating and improving communication between sessional instructors and course instructors prior to tutorials to ensure that sessional instructors understand the objectives regarding SD for each tutorial.
6.5. Ensure that students view DfS as a design decision that may require some design trade-offs

In 2010, many students considered DfS as an additional design feature that could be tacked on to an existing design without consideration of additional costs, time required for design, or design trade-offs. One of the greatest challenges in doing DfS is that design trade-offs need to be made; not all DfX can be fully considered and it would be impossible to always consciously consider all facets of design sustainability. Designers need to be innovative in how they incorporate DfS to improve the overall quality of the product to address the most common design tradeoff of increased cost. To find a way to design something better so that it is sustainable and also cost-effective is key; however, it would be naïve to assume that sustainability may always be “cost effective” since businesses may measure cost effectiveness and return on investment on different time scales which do not allow them to see the long term benefits of sustainable design. It is important that students learn that DfS often will involve difficult design tradeoffs and that students get experience in grappling with these issues during the course in order to ensure that the designs and design process are sufficiently realistic. It is not an easy task for the instructor to achieve this balance between ensuring students consciously make design trade-offs and ensuring students still prioritize sustainability.

7. Future work

7.1. Improve the methodology for assessing the quality of student DfS work and the connection between their work and the course structure

Currently, the degree to which students have integrated sustainability into their designs has been somewhat ad hoc as has been the assessment of sustainability in final student designs. As instructors, we need to develop better metrics and criteria for assessing and guiding DfS in student work. This needs to be done to ensure that all student work is graded equally and fairly regarding DfS, as well as to help us to better understand how well students have understood DfS, and how the course can better address areas of student uncertainty and confusion regarding DfS. Having now run the course once with comprehensive sustainability integration throughout, we need to revise the course assignments so that they can better help students target important and essential aspects of sustainability. The final student projects did not fully incorporate DfS to the extent that we are ultimately aiming for in the course. However, at the moment, it is unclear if this is a product of the course structure – that assignments are not adequately structured to allow appropriate exploration of sustainable design – or if it is more directly linked to an inadequate amount of technical information and guidance regarding sustainable development in the course. Once the
assignment structure is improved, it will be easier to evaluate the limiting factors for ensuring students engage in successful design for sustainability.

**7.2. Improve the structure of the HOWTO assignment**

In the 2011 Praxis II, the HOWTO assignment should be revised to a format which will allow students to explore and demonstrate greater complexity of ideas related to design for sustainability. This should be achieved by increasing the allowed length of the assignment to 2-3 pages, creating more stringent guidelines for references to ensure that students are accessing appropriate DfS and DfX literature, and by revising the assignment to address requirements specific to the group’s RFP to obviate students’ creation of overly abstract DfS requirements.

**7.3. Increase the amount of technical background information on DfS taught in the course**

Currently, SD and DfS are only introduced and explored conceptually through lectures and tutorials. Increasing the amount of technical background information available to students both inside and outside of the formal class may enhance student understanding of DfS and encourage more effective incorporation of sustainability into student designs. As a result, case studies and guest speakers with SD expertise should be added to the course in future in order to provide better technical background in DfS. Equally, the teaching staff should seek additional training in SD and continue to attend conferences on SD in order to continue to expand their knowledge base on technical concepts. Good resources about DfS and SD should also be gathered and made easily available to students and teaching staff to assist in the dissemination of technical knowledge about sustainable development and design for sustainability.

More technical information regarding DfS and SD should be integrated into course lectures, tutorials, and readings. Additionally, quantitative methods for sustainable design should be investigated to determine how these could be applied to a first year design course context to assist students in developing more realistic and quantitatively-supported sustainable solutions. Approaches that are more quantitative in nature may help to engage the engineering students more fully. Increasing the technical content in the course relating to DfS and SD will also further help to support the framing of DfS and SD as scientifically sound concepts which a good engineer should incorporate in design.

**7.4. Integrate SD and DfS into Praxis I**

With the significant SD and DfS integration in Praxis II proposed above, the next step is to integrate these concepts into the first Praxis course, Praxis I. This would introduce students to these concepts as early as possible to ensure that SD and DfS become part of the...
students’ personal and professional definitions of engineering design. Some lecture time in Praxis I should be dedicated to a very rudimentary explanation of SD and DfS and how these fit into the Praxis context. Additionally, SD and DfS should be gradually integrated into several of the Praxis I assignments. In the first assignment - improving a household appliance - a new assignment requirement could be to discuss and explore means for improving the appliance to make it more environmentally sustainable. In the bridge design project, students could be required to critique the reference bridges they find for the sustainability of the design and to investigate and explain how the bridge could be more sustainable. Finally, in the design brief in Praxis I, design for sustainability could be added as an additional requirement. Praxis II would still continue to explore DfS and SD but would do so with more depth and more quantitative or technical content.
References


The 14th European Roundtable on Sustainable Production and Consumption (ERSCP)
The 6th Environmental Management for Sustainable Universities (EMSU)


