Enhancing the Sustainability Content of a Civil Engineering Undergraduate Curriculum

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Abstract

The Department of Civil Engineering at University of Toronto has recently undertaken a transformation of its undergraduate curriculum to substantially enhance the teaching of sustainable engineering practice and design. This paper summarizes that process, including the identification of knowledge and skills required for the planning, design and management of sustainable systems, our review of the current program against these requirements, our review of other engineering programs that emphasize sustainability, and the identification of opportunities and options for enhancing sustainability in the program. Details on the curriculum changes are then presented, which include: significantly increasing core material on atmospheric physics and the science of climate change, the social impacts of technology, and sustainable energy systems; introducing elective courses on green building design, and the design of infrastructure for sustainable cities; and adding examples of sustainable engineering practice to existing courses, e.g., in transportation, environmental engineering and engineering ecology.

1 Introduction

Over the past decade, and more, many faculty in the University of Toronto Department of Civil Engineering have been actively involved in research on sustainable engineering practices. This has included work on topics such as green buildings, urban transportation, management of urban water quality, sustainable energy systems, materials and, broadly, the design of infrastructure for sustainable cities. Others in the Department have wrestled with more fundamental issues of the social impacts of technology, the moral and legal implications of sustainable engineering practice, and the economic consequence of developing sustainable infrastructure. Numerous research papers have been produced as a result of this work – and significant international conferences on sustainability have been hosted by the Department, including those

of the Association of Environmental Engineering and Science Professors (in 2002) and the International Society for Industrial Ecology (in 2007). Through this research, the Department has established a substantial body of knowledge on sustainable engineering.

Translation of this research into teaching of sustainable engineering practice was, however, relatively modest. In December 2007, a Departmental strategic planning exercise highlighted a lack of sufficient content on sustainability in the undergraduate curriculum. Despite having well-established courses in Building Science, Engineering Ecology, Environmental Engineering, and Transportation Planning (all of which are a necessary base for teaching sustainable civil engineering practice), it was felt that the Department was not doing nearly enough to educate our undergraduates in sustainable engineering. Hence, the Department's Academic Planning Committee (APC) was charged with the task of enhancing the sustainability content of the undergraduate Civil Engineering curriculum.

This paper describes the review process undertaken by the APC, and the changes to the curriculum that resulted. APC undertook a review of our existing program and a review of other engineering programs that emphasize sustainability. Opportunities for enhancing the sustainability content of the curriculum ranged from foundational courses in the first two years to applied courses typically taken in later years.

2 Review of U of T Civil Engineering Curriculum

A preliminary review of the sustainability content of our curriculum was undertaken by student members of APC in January 2008. A total of 33 courses were considered in the review. Assuming the most generous ratings given by the students, the review of the main Civil Engineering program identified only:

- 6 courses which mentioned sustainability or examples pertaining to the concept

Table 1: Technical knowledge and skills required for the planning, design and management of sustainable systems in six areas of civil engineering¹

TOPIC / SKILLS	FORMER CURRICULUM (See Note)
Sustainable Buildings	
<ul style="list-style-type: none"> Green building strategies: e.g., natural ventilation, passive solar design, double-façades, green roofs. Design of building mounted solar energy technologies: PV, solar water heaters, solar air heaters Ground source heat pumps / geothermal energy piles Integration of Building Science, Structures and Geotechnical engineering towards the design of carbon neutral buildings Low-energy building design Introduction to passive solar heating Management of construction and operations of green buildings 	<p>Not taught</p> <p>Taught in MIE 515– an elective requiring Thermodynamics as a pre-requisite</p> <p>Not taught</p> <p>Possibly could be in a CIV 425 design project</p> <p>CIV575</p> <p>CIV575</p> <p>CIV320 (2 lectures)</p>
Sustainable Transportation	
<ul style="list-style-type: none"> Urban design for active transportation and health: walking, cycling and access to transit Transit system planning, design and operation Sustainable land-use/transportation planning Sustainable inter-city transportation Sustainable freight transportation Fuel consumption and vehicle emissions: Impacts, modeling and reduction strategies 	<p>CIV 231 (one lecture), CIV 531</p> <p>CIV 231 (one week), CIV 516</p> <p>CIV 531</p> <p>Not taught</p> <p>Not taught</p> <p>CIV 231 (one lecture) CIV 531 (one lecture)</p>
Sustainable Urban Water Quality Management	
<ul style="list-style-type: none"> Water source protection Water treatment and distribution system water quality Wastewater treatment Wastewater reclamation – water, energy and materials Wastewater reuse Sustainable Water Infrastructure 	<p>Not taught</p> <p>CIV 540</p> <p>CIV 540</p> <p>Not taught</p> <p>Not taught</p> <p>Two lectures in CIV 340</p>
Sustainable Urban Energy Systems	
<ul style="list-style-type: none"> Thermodynamics District energy Systems / Cogeneration / Community scale ground source heat supply Aquifer thermal energy storage Fundamentals of electricity; micro-electricity grids; electrical transmission structures Transportation and water systems energetics 	<p>Some in CIV 575</p> <p>Not taught</p> <p>Not taught</p> <p>Not taught</p> <p>One lecture in EDV 220</p>
Sustainable Materials and Waste Management	
<ul style="list-style-type: none"> Sustainable Materials / Materials Science Systems approach to anthropogenic material flows Waste management / Treatment and separation technology Preventative design of material / waste streams Management of material streams in construction 	<p>Durability extensively covered in CIV 209 and CIV 514 (which also cover GHGs). Introductory lecture on MFA in EDV 220.</p> <p>Not taught</p> <p>Not taught</p> <p>To be introduced into CIV 220 (320)</p>

Table 1 cont.

¹ Other topics could clearly be included in this Table.

Sustainable Land Management

• Hydrology (rural and urban watersheds)	Fundamentals in EDV 250
• Biogeochemistry of watersheds	Not taught
• Impacts of urban morphology, e.g., density, on air and water contamination (at local and city scales)	Not taught
• Fate and transport of agricultural emissions	Not taught
• Surface - groundwater interaction	Not taught
• Land-use planning	CIV 531
• Impacts of land-use morphology on infrastructure sustainability	Not taught

Note: CIV 209 is Civil Engineering Materials; CIV 231 is Transport I; CIV 320 is Management of Construction; CIV 340 is Municipal Engineering; CIV 425 is Design Project; CIV 514 is Concrete Technology; CIV 516 is Public Transit Operations and Planning; CIV 531 is Transport Planning; CIV 540 is Treatment Processes; CIV 575 is Building Science; EDV 220 is Engineering Ecology; EDV 250 is Hydrology and Hydraulics; MIE 515 is Alternative Energy Systems.

- 5 courses (2 core; 3 electives) in which the concept was discussed in relation to course topics
- 3 courses (all electives) in which Sustainability was seen as fundamental to most everything in the course

While course instructors may or may not have agreed with the students' review, it was clear that our students did not recognize our curriculum as having sufficient content on sustainable engineering practice.

The APC proceeded to identify the types of technical knowledge and skills that students would require in order to plan, design and manage sustainable systems in six areas of civil engineering. These areas are summarized in Table 1. The table also identifies if and where these skills were taught in the curriculum.

3 Review of Other Curricula

Reviews of civil engineering programs at other schools by Lynch et al. (2007) and El Diraby et al. (2006) found that most are struggling to bring sustainability content into the curriculum. Moreover, most engineering programs that do incorporate sustainability do not do so in the core undergraduate program. Hence, our review of other programs had to look outside of Civil Engineering departments, and beyond the undergraduate level (Table 2).

A notable exception was UC Berkeley, which includes courses in Engineered Systems and Sustainability; Climate Change Mitigation; and Ecological Engineering for Water Quality Improvement in its undergraduate civil engineering program. UC

Berkeley also offers graduate courses in Energy, Ecosystems, and Humans; Technologies for Sustainable Societies; and Technology and Sustainability.

With respect to socio-technological aspects of sustainability, McMaster University has a specialized undergraduate Engineering and Society Programme including core courses on: The Culture of Technology; Case Studies in the History of Technology; Preventive Engineering; and Social Control of Technology, and three "inquiry" (self-directed research) courses on topics related to sustainability. The Engineering and Society Programme accommodates the additional core courses by adding an additional year to the undergraduate engineering degree. The objectives of the McMaster program are similar to those of our Faculty's Certificate Program in Preventive Engineering and Social Development.

Another notable undergraduate program is the University of Birmingham's BSc. in Sustainable Technology. The 3-year program includes courses in Technology Studies; Materials for Technology; Ethics, Technology and Policy; Risk Assessment; Sustainable Energy; and Sustainable Construction.

For more advanced technical programs on sustainability we reviewed six leading programs in Industrial Ecology and Sustainable Technologies, mainly at European Engineering Schools. The structure of these programs vary, e.g., the 2-year KTH Masters Programme in Sustainable Technology has 13 core courses and 7 electives; Leiden, Delft and Erasmus Universities have a Joint Program in

Industrial Ecology with balanced coverage of Natural Sciences, Technical Sciences and Social Sciences, while the University of Michigan offers a Graduate Certificate Program in Industrial Ecology, requiring 5 courses. Common topics found in the six programs include:

- Life Cycle Assessment (essentially all);
- Material Flow Analysis/Waste Management (NTNU, KTH, ETH Zurich, Chalmers, Leiden/Delft/Erasmus);
- Sustainable Energy Systems or similar (Michigan, KTH, NTNU, Chalmers, Leiden/Delft/Erasmus);
- Environmental Policy (Michigan, Chalmers); and
- Risk Management (Michigan, KTH).

A few other courses of note included:

- Biogeochemical Cycles (Michigan);
- Systems Analysis (Michigan);
- Ecology (KTH);
- Ecological Economics (KTH);
- Complex Systems (Leiden/Delft/Erasmus); and
- Built Environment (Leiden/Delft/Erasmus).

These are all graduate level courses, though similar material might be taught to our students in 500-level courses (which have a mix of undergraduates and graduates).

In short, our review of other programs led to the following conclusions:

- At least one regular Civil Engineering Program (UC Berkeley) includes sustainability in the core curriculum in a meaningful way.
- Other undergraduate and graduate engineering programs exist that are oriented around sustainability themes that can provide ideas and guidance.
- While there appear to be commonalities in some of the course offerings of several of these programs, each also has some unique courses and a fairly unique structure. There is no single standard approach.
- There was potential for our department to become a leader of North American universities by developing a curriculum with significant sustainability content.

Table 2. Programs with strong emphasis on sustainability that we reviewed

McMaster University Engineering and Society Programme http://www.eng.mcmaster.ca/engandsoc/
UC Berkeley Undergraduate and Graduate Courses pertaining to sustainability http://www.ce.berkeley.edu/index.php
University of Birmingham BSc. in Sustainable Technology http://www.stp.bham.ac.uk/courses/st.htm
University of Michigan Graduate Certificate Program in Industrial Ecology http://css.snre.umich.edu/
NTNU Master's Degree Programme in Industrial Ecology (2 years) http://www.ntnu.no/studies/msc-industrial-ecology
KTH Master's Programme in Sustainable Technology (2 years) http://www.ima.kth.se/ms/st/index.html
Chalmers University Masters Program in Industrial Ecology for Sustainable Development http://www.fy.chalmers.se/edu/imp/ie.xml
Leiden University, Delft University of Technology, and Erasmus University Rotterdam , Joint Program in Industrial Ecology http://www.industrialecology.nl
ETH Zurich Masters Programme in Environmental Engineering http://www.umwelting.ethz.ch/master/index_EN

4 Curriculum Changes

At the foundational level, students need to learn about the principles and dimensions of sustainability (economy, environment, and society) and the relationships between these and civil engineering systems. This foundational material is necessary background for later studies at the applied level.

At the applied level, students need to go beyond identification of “impacts” of technology and relationships between systems learned at the foundational level. They also need to learn the technical skills to plan, design and construct sustainable systems. To produce civil engineers who have the knowledge and skills to lead in the design of sustainable civil engineering systems we recognize that from a technological perspective sustainability entails “development without increases in the throughput of materials and energy beyond the biosphere’s capacity for regeneration and waste assimilation” (Goodland and Daly, 1996). We believe

that we should be teaching our students the technical skills to manage society's material and waste flows in a sustainable manner, reduce the environmental "footprint" from civil engineered systems and supply energy from renewable sources.

With these perspectives in mind, and with the findings from our reviews, the Department made the following changes to the undergraduate curriculum:

- added atmospheric physics and the science of climate change to a first year earth sciences course (APS 185) that was previously focused on geology
- added a core second year course (APS301) on the social impacts of technology (course was previously an elective course)
- introduced a new core third year course on sustainable energy systems (CIV 380)
- developed a new fourth year course on green building design (CIV 576)
- adapted a graduate course on design of infrastructure for sustainable cities to serve undergraduate students (CIV 577)
- added further examples of sustainable engineering practice to existing courses, e.g., in transportation, environmental engineering and engineering ecology.

Descriptions of the new and revised courses are given in Table 3.

Table 3. Calendar Descriptions of New or Revised Courses in U of T undergraduate curriculum

APS185 Earth Systems Science

This course introduces students to the basic earth sciences with an emphasis on understanding the impact of humans on the natural earth systems. Beginning with a study of the lithosphere, principles of physical geology will be examined including the evolution and internal structure of the earth, dynamic processes that affect the earth, formation of minerals and rocks and soil, ore bodies and fossil- energy sources. Next, the biosphere will be studied, including the basic concepts of ecology including systems ecology and biogeochemical cycles. The influence of humans and the built environment on these natural systems will also be examined with a view to identifying more sustainable engineering practices. Finally, students will study the oceans and the atmosphere and the physical, chemical and thermodynamic processes involved in climate change.

APS301 Technology in Society and the Biosphere I

This course teaches future engineers to look beyond their specialized domains of expertise in order to understand how technology functions within human life, society and the biosphere. By providing this context for design and decision-making, students will be enabled to do more than achieve the desired results by also preventing or significantly reducing undesired consequences. A more preventively-oriented mode of practicing engineering will be developed in four areas of application: materials and production, energy, work and cities. The emphasis within these topics will reflect the interests of the class.

CIV380 Sustainable Energy Systems

This course provides students with knowledge of energy demand and supply from local to national scales. Topics include energy demands throughout the economy, major energy technologies, how these technologies work, how they are evaluated quantitatively, their economics and their impacts on the environment. In addition, the ever changing context in which these technologies (and emerging technologies) are being implemented will be outlined. Systems approaches including life cycle assessment, will be refined and applied to evaluate energy systems. A particular focus will be placed on analysis of energy alternatives within a carbon constrained economy.

CIV576 Sustainable Buildings

Building systems including the thermal envelope, heating and cooling systems, as well as water and lighting systems are examined with a view to reducing the net energy consumed within the building. Life-cycle economic and assessment methods are applied to the evaluation of various design options including considerations of embodied energy and carbon sequestration. Green building strategies including natural ventilation, passive solar, photovoltaics, solar water heaters, green roofs and geothermal energy piles are introduced. Following the application of these methods, students are introduced to efficient designs including LEED designs that lessen the impact of buildings on the environment. Exemplary building designs will be presented and analyzed.

CIV577 Infrastructure for Sustainable Cities

Developing infrastructure for sustainable cities entails understanding the connection between urban morphology and physiology. This course uses a systems approach to analyzing anthropogenic material flow and other components of urban metabolism, linking them to the design of urban infrastructure. Elements of sustainable transportation, green buildings, urban climatology, urban vegetation, water systems and local energy supply are integrated in the design of sustainable urban neighbourhoods

5 Conclusion

We believe that we need to embark on a path that will ensure that our graduates are instilled with a sense of responsibility to future generations; fulfilling this responsibility means guiding students to develop solution methods that look beyond “me” and “now”, and consider the needs of future generations as well.

To better assist students along the path toward sustainability, we believe that a paradigm shift is needed in the way engineering skills and knowledge are taught and used.

Curriculum changes are only a component part of bringing about this paradigm shift. The curriculum changes outlined here may seem modest, but they should not be seen as an end. Through a process of feedback and refinement, we plan to continue to improve our curriculum. We believe that through such refinement, we can continue educating engineering students who can meet tomorrow’s challenges, today.

References

- [1] Lynch, D., et al., “Implementing Sustainability in the Engineering Curriculum: Realizing the ASCE Body of Knowledge”, American Society for Engineering Education, 2007
- [2] El Diraby et al., “Sustainability–Related Courses in Canadian Engineering Programs”, Canadian Society of Civil Engineering Annual General Conference, Calgary AB., 2006.
- [3] Goodland, R. and Daly, H. “Environmental Sustainability: Universal and Non-negotiable.” Ecological Applications, 6:1996, 1002-1017.