The Development of a Sustainability Emphasis in McMaster University's Engineering Programs

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Abstract

In 2009, McMaster University's Faculty of Engineering approved a 5-year strategic plan entitled "Engineering a Sustainable Society". Developing a sustainability thrust in the undergraduate engineering programs was a key goal in the implementation of that plan. A task force on sustainability in engineering education, comprising faculty, students and staff, was given the responsibility of implementing that thrust.

A key feature of the implementation strategy was to add a sustainability attribute to the 12 graduate attributes which are now prescribed for accreditation of Canadian engineering programs. The task force developed a set of five competencies which need to be achieved in order for engineering graduates to have the sustainability attribute. Bloom's taxonomy is used as the basis for determining the learning outcomes required for each of the five competencies. Short and long term goals were then set with regard to achieving sustainability learning in the curricular of each of McMaster's engineering programs. The primary goal is for a significant level of sustainability learning to be achieved in at least one course in each year of each program. Engineering-wide and programme-specific strategies were put in place to enable accreditation-related targets to be achieved by the time of the next accreditation.

In addition to developing the curricular strategy, the task force has been active in providing practical assistance to instructors. Expanded descriptions of competencies and example learning outcomes were developed to help instructors incorporate sustainability learning into their courses. More direct assistance is being provided in the form of various workshops dealing with specific aspects. One particular type of "mini-workshop" provides advice and assistance directed at a specific course. Another workshop was focused on capstone design courses, which are particularly important for developing higher levels of sustainability learning.

The paper describes the above features in detail and also describes other sustainability –focused initiatives of the Faculty of Engineering, including the establishment of an Engineering Centre for Experiential learning, which is being designed as living laboratory for sustainable building technologies. The paper also discusses and reflects on progress being made to achieve a sustainability thrust within McMaster's Faculty of Engineering.

1 Introduction

The strategic plan of the Faculty of Engineering of McMaster University, Engineering a Sustainable Society (Faculty of Engineering, 2009), identifies sustainability as a major thrust in its educational and research activities. This plan specifically describes sustainability very broadly to mean "the application of engineering in a socially responsible manner" rather than restricting it to environmental sustainability. The vision for undergraduate engineering education is that engineering graduates have an educational experience in which competence in technical material is balanced with "a deep understanding of the role of an engineer in addressing sustainability and related key issues affecting our world." The specific goal is to establish McMaster as the leading institution in Canada for the education of socially responsible engineering practices, including a focus on social, environmental and economic sustainability.

In order to implement this sustainability thrust in the undergraduate engineering programs, the Dean of Engineering struck a Task Force on Sustainability in Engineering Education (which will be referred to as the task force). This task force comprises a number of engineering faculty and students and was given the mandate of shaping the approach of the Faculty of Engineering to incorporating sustainability into the undergraduate engineering programs. The context of the task force was the recognition that sustainability needs to be front and centre in the work of the Faculty of Engineering. While the "buy-in" from individual faculty and students must be voluntary, it is critical that a culture of sustainability be established.

With reference to embedding sustainability into the curricula of McMaster's Engineering degree programs, the task force decided that the most effective strategy would be to include sustainability within our accreditation commitments. The accreditation approach and the inclusion of sustainability are described in the next section.

2 Competencies

In Canada, the accreditation of engineering degree programs is the responsibility of the Canadian Engineering Accreditation Board (CEAB); programs are required to be accredited in order for graduates to be eligible to license as professional engineers. The accreditation approach which is now being adopted requires that engineering schools demonstrate that their graduates have achieved 12 graduate attributes.

Most attributes are technical in nature (e.g., knowledge, analysis, investigation, tools and design) but some are complementary (e.g., communication, professionalism, impact and ethics). A few of the competencies associated with some of the complementary attributes include implicit or explicit sustainability considerations, but these do not necessarily ensure that engineering graduates will have a developed strengths in sustainability. Consequently, in light of the sustainability thrust in its strategic plan, McMaster's Faculty of Engineering decided to add an additional specific graduate attribute of Sustainability. For each graduate attribute, there are a number of indicators or competencies which need be achieved. The sustainability task force developed and defined five competencies which are required for the sustainability attribute, as given below:

Triple Bottom Line (TBL) - Design and evaluate complex open-ended engineering systems using a triple-bottom line of sustainability dimensions: social, economic and environmental;

Metrics and Tools - Demonstrate an understanding of and an ability to use and interpret sustainability metrics and tools;

Stakeholders – Interact and collaborate with stakeholders having a broad range of cultural and social backgrounds to consider the needs of present and future generations in developing creative solution(s) to an engineering problem;

Sustainability Ethics and Responsibilities (for simplicity, referred to as **Ethics** in this paper) **-** Recognize and value the importance of dealing ethically with uncertainties, diversity, intra and inter-generational equity and other non-technical challenges which affect engineering decision-making;

Complexity – Work within complex systems (environmental, social, economic or technological) using sustainability considerations and understand the limitations due to uncertainty.

While the task force did not prioritize among these five competencies, it is clear that the Triple Bottom Line (TBL) competency is very much a "core" competency and that the other four are complementary. While they are complementary, they are also essential in order for "completeness", i.e., engineering graduates having a full breadth of sustainability skills. TBL being core means that sustainability cannot really be understood without having that competency

3 Sustainability Learning and Instruction

It is important to recognize that the five competencies described in the previous section are very broad statements of what engineering graduates need to be able to do to practice sustainable engineering. While these competencies are applicable to any and all branches of engineering, theycannot be measured directly in any one course. Rather, learning outcomes need be specified for each competency, preferably in a framework which is related to the level of learning which is expected.

Bloom's taxonomy of cognitive learning (Bloom, 1956) is a useful way of delineating different levels of learning; in the original taxonomy, the levels of learning are defined as: Knowledge, Comprehension, Application, Analysis, Synthesis and Evaluation. For this purpose, the revised Bloom's taxonomy (Anderson and Krathwohl, 2001) was deemed to be more appropriate for the purpose of describing learning in an engineering or technical context. There are two reasons for this: a) the levels are defined by action verbs rather than by nouns, which facilitates development of learning outcomes, and b) the upper two levels are repositioned to reflect a clearer hierarchy of learning, i.e. Evaluation followed by Creation. The levels in the revised taxonomy are: Remember, Understand, Apply, Analyze, Evaluate and Create.

While it is not feasible to provide details of the application of Bloom's taxonomy for all five competencies, examples of learning outcomes for the Ethics competency are given in Table 1. These learning outcomes are "generic"; they would need to be modified and more specific when developing learning outcomes for a particular course. For example, the target learning outcome associated with the Analyze level for a senior mechanical engineering course in sustainable energy systems is stated as: "examine and characterize the social and ethical challenges involved in a variety of energy systems and designs"

Table 1: Generic Learning Outcomes for Ethics Competency.

Bloom Level	Generic Learning Outcome
Remember	Identify several specific ethical challenges which are important for sustainability
Understand	Explain the ethical challenges associated with intra and inter-generational equity
Apply	Illustrate how ethical challenges have been dealt with in a particular engineering project development
Analyze	Distinguish between facts and values, selecting between them appropriately when making decisions in an engineering design project
Evaluate	Critique how uncertainties and/or ethical dilemmas are being dealt with in an engineering project design process
Create	Develop a strategy for weighing and taking into account ethical issues in the development of a particular design project.

Both for purposes of accreditation and achieving the goal of the Faculty's strategic plan, it is important that there be target learning levels for each of the five sustainability competencies. Two target levels were defined: a) **Threshold** - which all engineering graduates are to achieve and b) **Desirable** - to be achieved by a significant proportion of graduates(e.g. 50%).

Since accreditation requires that all graduates achieve the sustainability attribute, then the **Threshold** level is the target to be achieved for accreditation purposes. It was set initially (in 2011) at the Bloom **Understand** level for all 5 sustainability competencies, anticipating that this would be increased to **Apply** by the time of the next accreditation (2015).

The **Desirable** target was set at Evaluate for all 5 sustainability competencies. This is a long term internal target which will require concerted deliberate actions in terms of curricular changes.

While targets are determined in terms of learning, the Faculty of Engineering was just starting the process of establishing learning outcomes and developing mechanisms of measuring achievements in relation to the target outcomes. In the short term, it was decided that it would be useful to measure the extent to which sustainability was being included in the syllabi of engineering courses.

Instructors were asked to map this "intensity" of coverage of sustainability in their courses for each of the five sustainability competencies on a 1-2-3 scale in which 1= mentioned, 2=taught, and 3=used. When this mapping was done (2011), the primary observation was that each competency is taught or used in at least one course in all of the Engineering programs. In most cases, where the competency is taught or used in only 1 course, that course tends to be one of three general Engineering courses (i.e. taken by all engineering students), namely a first year engineering design course, a course in engineering economics or a course in ethics and social responsibility. It was also observed that senior or capstone design courses develop some of the sustainability competencies.

While coverage in courses does not ensure that specific levels of learning are taking place, it does give some indication of the potential for achieving the Threshold learning level by 2015. In particular, it should not be difficult to achieve the Bloom Apply level in a course in which a particular sustainability competency is already being used, i.e. mapped at a scale of 3. To help move towards the learning targets, the task force established two short term (within 2 years) goals for coverage in courses:

a) that all Engineering programs should have at least 1 course in each year which is mapped at the "3" (use) level in at least the Triple Bottom Line competency, and
b) that it would be desirable for most, if not all, Engineering courses to be mapped at least at the "1" level in one of the sustainability competencies.

The achievement of the Desirable target (Bloom Apply level in all 5 competencies) by the time of the next accreditation will rely on Engineering-wide and discipline-specific strategies. The Engineering-wide strategy is intended primarily to ensure that students in all engineering programs are taught and make use of important sustainability concepts at an early stage in their programs. This is important because, at McMaster, the first year of engineering is common to all disciplines and the opportunities for discipline-specific sustainability learning is primarily in the upper years. The key features of the Engineering-wide strategy are:

a) enhancing the scope of the first year engineering profession and practice course to achieve TBL learning at the Understand level; this is expected to have a significant impact on the development of sustainability competencies in the later years of the students' programs,
b) revamping the engineering economics course (normally taken by students in their second year) to give it a sustainability focus, including higher levels of learning in TBL as well as the other sustainability competencies.
c) developing several senior courses which can be taken by students desiring to develop a higher level of sustainability learning; at present these include a course in sustainable development & social responsibility and a multi-disciplinary capstone design course with a distinct sustainability orientation.

While the discipline-specific strategies will vary from program to program, they do include some common elements. First, some technical areas lend themselves to the development of sustainability- focused technical courses, e.g. energy, manufacturing, and environment. Departments with those opportunities are finding that such courses are a good way to reach the target learning level in one or more of the sustainability competencies. Another common element is what is referred to as senior level capstone design courses, which are taken by all students in each program. While the methodologies for these capstone courses differ from program to program, they all involve group or team projects. Such projects provide an excellent opportunity to reach higher learning levels in most, if not all, of the sustainability competencies. Of particular interest and importance for such projects are developing the stakeholder and ethics competencies.

Each engineering department has developed its plans to meet the targets discussed above, beyond the courses common to all disciplines that provide basic aspects of sustainability. Some departments had a culture of sustainability in place before 2009, and had courses incorporating sustainability; thus, minor changes to meet the goals are being instituted. Other departments initially thought that sustainability was an imposition on an already heavily loaded curriculum, so some assistance to instructors was required (see next section). Each department is approaching it in a different way; for example, assignments and problems are good ways to illustrate the way sustainability goals influence engineering design, without introducing increased load on students.

Parallel to the thrust in sustainability, there has been another on experiential learning for engineering students. Many of the issues in sustainability are very open-ended and lend themselves to experiential learning very well. Several departments are developing courses in the second and third years that have experiential components, such as hands-on experimentation, design, and inquiry on sustainable technologies.

4 Assistance to Instructors

While sustainability needs to be incorporated into the curriculum, achieving the actual learning outcomes requires that the course instructors incorporate various aspects of sustainability into their course syllabi. During the past several years, the task force has taken a variety of initiatives to provide support and assistance to instructors. The most significant of these are outlined below.

Expanded descriptions and example learning outcomes for the five sustainability competencies were developed so that instructors, particularly those having limited familiarity with sustainability concepts, could understand the competencies and help them incorporate learning outcomes into their courses. As an example, the description of the stakeholder competency was expanded to discuss the definition of stakeholders and to list a variety of types of stakeholders. For the same competency, the following learning outcomes were then listed as examples:

1. Demonstrate an ability to effectively communicate with stakeholders with a broad range of cultural and social backgrounds, and political perspectives.
2. Assess and research the needs of stakeholders and future generations.
3. Demonstrate sensitivity to the needs of stakeholders and future generations.
4. Devise creative solutions to overcome opposing needs.
5. Show an ability to collaborate with designers and experts of all disciplines.

Another form of assistance was to organize and conduct several kinds of workshops. One particular type, which was termed "mini-workshop", has been particularly effective. Each mini-workshop is focused on one specific target course in which the instructor has expressed a desire to incorporate significant sustainability content but needs some advice and assistance in actually making that happen. Mini-workshops involve 8 to 10 participants who include the target course instructor, the workshop facilitator, a primary resource person (an instructor with experience in teaching sustainability), several other instructors and several students. Target course instructors have these sessions (typically 3 hours in duration) to be valuable both for the specific advice received and for establishing a longer term network of support contacts.

As stated earlier, the senior capstone design courses are particularly important for developing higher levels of sustainability learning. The task force recently organized a workshop on capstone courses, which included but was not restricted to sustainability aspects. The content of the workshop included rubrics for evaluating students, which are particularly important for the more qualitative learning dimensions for the stakeholder and ethics competencies. It also included discussion of project selection, including projects proposed by external organizations, i.e. businesses, governments and not-for-profits. Departmental representatives also shared best practices with regard to the format and organization of their capstone courses. There was also a discussion of the proposal for an Engineering-wide multi-disciplinary capstone course to have a distinct sustainability focus.

5 Other Aspects and Future Plans

In addition to the curricular and learning aspects organized by the task force, as described in the previous sections, the Faculty of Engineering has also been taking other initiatives to promote its sustainability thrust, including developing experiential learning opportunities for its students.

The most prominent and important initiative is the establishment of the Engineering Centre for Experiential Learning (ExCEL). The physical manifestation of ExCEL is a building project which will provide a venue for Engineering students to experience "hands-on" learning and for showcasing sustainable building technologies. The provision of this space recognizes that many of the most powerful student experiences take place outside of classrooms and laboratories. Student cocurricular involvement also provides opportunities in leadership, entrepreneurship and social responsibility, all of which are important aspects in developing the sustainability competencies described earlier in this paper. The building itself is being designed with a focus on incorporating the integrated application of a number of sustainable building technologies to achieve a high level of energy efficiency. In addition to being a demonstration of those technologies, it will serve as living laboratory for research on those technologies, with the resulting data being used both for the advancement of the technologies and for student learning.

As part of the Faculty's interest in promoting a sustainability culture both within Engineering and throughout the university, it has initiated the development and implementation of a university-wide course called "The Sustainable Future Project". In this course, which was first run in early 2013, students engaged in real-world local community sustainability projects while learning about global sustainability concepts and their impact on local communities. One significant benefit of this course is the interaction of students from different disciplines, enabling them to appreciate and learn from perspectives of others with very different interests and career objectives.

The Faculty of Engineering has long been involved with the local industry in a variety of ways, including research partnerships, continuing education for their workforce, internships and full-time employment for current students and projects for capstone courses. With the success of "The Sustainable Future Project" it is now envisioned that even wider community engagement can be developed. In the fall of 2012 a workshop was held with Sustainable Hamilton (a local not-for-profit organization that coordinates sustainability activities) in which projects were identified for an eco-entrepreneurship program at the graduate level, as well as projects for final year students. As mentioned in the previous section, an engineering-wide multidisciplinary capstone course with a sustainability focus has been proposed. Sustainable Hamilton provides a very good way to network with the local community for projects for the proposed course. It is envisioned that this arrangement could provide a wide range of interaction from research, to eco-entrepreneurship, to capstone projects and projects for experiential learning at the lower levels.

6 Discussion

Most of the initiatives described in this paper do not lend themselves easily to quantitative analysis for purposes of evaluation. While the intensity of sustainability "exposure" in the various degree programs is some indication that some progress is being made in achieving a sustainability thrust, the more important aspect is the extent to which our students, when they graduate, have developed both a personal attitude and professional skills which will enable them to incorporate sustainability into their work as professional engineers. The development of sustainability competencies and learning objectives to achieve those competencies is a systematic approach which should, in the long term, enable the measurement of progress. That will certainly be necessary for accreditation but will also be important for the Faculty of Engineering to be able to measure progress towards its vision of being a leader in providing an engineering education which supports the development of engineering practices for a sustainable world.

References

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