FILLING THE GAP IN ENGINEERING EDUCATION FOR SUSTAINABILITY: DEVELOPING A COHORT-BASED MASTERS DEGREE OF ENGINEERING LEADERSHIP FOR SUSTAINABILITY

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Abstract: The current approach to undergraduate engineering education provides graduates with the knowledge and skills required to address many technical challenges posed by sustainability. This education can be furthered through a number of degree offerings at the graduate level such as a Masters degree in Sustainable Water Management or Clean Energy Engineering. However, there is a growing need for engineers educated with a global perspective regarding the role of the engineer to facilitate change and with leadership skills. This aspect of engineering education for sustainability is consistent with the American Society of Civil Engineering's Book of Knowledge, the Canadian Engineering Accreditation Board Program criteria, and the University of British Columbia's (UBC) learning goals. To address the need for engineers able to facilitate change, a Cohort-based Master of Engineering in Engineering Leadership for Sustainability program, modelled after the MPhil in Engineering for Sustainable Development offered at the University of Cambridge, is being designed and developed at The University of British Columbia (UBC), Canada. The students will live at a college on the UBC campus to foster community building and facilitate social change. The constructively aligned curriculum will consist of active learning opportunities embedded within coursework, a seminar series, a summer project course and added value sessions; including field trips, opportunities to work with UBC staff to enhance sustainable operations on campus, international and/or local service learning, retreats/workshops and academic exchange. The program will utilize on-line collaborations and optional travel exchanges with the University of Cambridge to enhance the students' course-based learning experiences. This paper discusses the program development and provides details of the program structure designed to enable the development of leadership for engineers. The constructively aligned curriculum focuses on active learning and community projects. Novel characteristics of the program are described with regards to meeting the program learning outcomes and developing the five key competencies required for sustainability problem solving.

1 INTRODUCTION

The recent history of industrialization, urbanization, and globalization is resulting in a number of large scale, urgent, and potentially damaging challenges including climate change, desertification, poverty, and war (Wiek et al.,, 2011). Sustainability is an approach based on systems theory that is aimed at thwarting these complex and daunting problems, all of which affect humanity over a range of scales, have associated underlying technical and social aspects, and are without an immediate or obvious resolution. With their strong technical background and potential to understand complex social system, engineers can and must contribute to addressing these global challenges. However, while current undergraduate engineering education focuses on student development of strong technical skills, it lacks learning

opportunities for the foundational development of leadership skills necessary to tackle complex, systemic, social challenges. A number of new graduate programs focusing on Sustainability Education have been developed that address the need for sustainability thinking (Onuki & Mino, 2009; Wiek et al., 2011). The authors of this paper are developing a proposal for a new Master of Engineering in Engineering Leadership for Sustainability (MEELS) at The University of British Columbia that aims to provide the complementary skills needed to prepare engineers to facilitate societal change. We have viewed education as the enterprise of a social system—a learning community—where-in students construct their knowledge by participating in activities that are hierarchically connected such that the broad learning outcomes of the educational program are achieved.

1.1 Curriculum Development

During best-practice course and program design, three key aspects are considered: learning objectives or learning outcomes, teaching and learning activities, and assessment exercises (Blumberg, 2009). A constructively aligned course or program is one in which these aspects are intentionally aligned to maximize student learning by beginning with the end (or objectives) in mind, and designing the teaching/learning activities and the student assessment methods to guide the student to fulfilling these objectives. In a constructively aligned curriculum, each course is designed to facilitate the overall program goals such that students progress toward program completion (Biggs, 1996). When viewed as part of an adaptive social system (i.e., a self-organizing holarchic open system as described by Kay and Boyle, 2008), the constructively aligned curriculum is seen as being situated within a management strategy that enables the entire socio-curricular system to learn and improve (Nesbit et al., 2013).

1.2 Sustainability Competencies

Wiek et al. (2011) have identified five key sustainability competencies from an extensive review of the literature (Barth et al., 2007; de Haan, 2006; and Sipos et al., 2008, among others) that are required to perform sustainability research or problem solving. These competencies provide a general list of attributes that practitioners should strive for, with the intent of leading change in sustainability. The five key competencies are:

1. Systems-thinking competence—the ability to analyse complex systems and incorporate the understanding of components' interrelation into decision making criteria.

2. Anticipatory competence—the ability to analyse and evaluate future issues within the sustainability context and plan for the required problem-solving.

3. Normative competence—the ability to assess the goals and targets of projects.

4. Strategic competence—the ability to implement projects and facilitate change.

5. Interpersonal competence—the ability to achieve collaboration and motivation for sustainability projects to account for all stakeholders' viewpoints.

1.3 Engineering Education for Sustainable Development

With its focus on small-scale problem-solving, engineering undergraduate education develops aspects of sustainability-related systems-thinking and anticipatory competences (Segalas et al., 2010). The normative and strategic competencies are less-well refined through typical undergraduate engineering education as these competencies require melding sustainability's technical challenges with justice, ethics, equity, contemporary societal issues and relationships, and political concepts—which prevent single, quantitatively accurate solutions and introduce uncertainty from the different stakeholders' perceptions (Mulder et al., 2012; Wiek et al., 2011). The interpersonal competency, requiring leadership skills to "motivate, enable, and facilitate" (Onuki & Mino, 2009; Wiek et al., 2011), is the least well-developed competency within engineering education. This competency involves the development of self-awareness, self-regulation, motivation, empathy, integrity, and social skills (including listening,

negotiating, and collaborating) (Goleman, 1996), none of which are the core focus of engineering education.

This paper describes a proposed Master of Engineering program at The University of British Columbia, highlighting its unique features that address the normative, strategic, and interpersonal aspects of education for sustainability. The paper discusses the program development process (focussing on the socio-curricular management that enables continual learning and improvement) and on the development of the constructively aligned curriculum. It presents the mechanisms used to develop students' sustainability competencies. The paper concludes by discussing the program proposal's future direction.

2 PROGRAM SUMMARY

2.1 Overarching Goal and Program Learning Outcomes

The proposed Master of Engineering in Engineering Leadership for Sustainability is designed to prepare engineers to become "agents of change" by developing their key competencies for sustainability. The goal of the proposed program is to provide the learning opportunities to:

- comprehend the dynamics of complex systems, and the interdependencies among ecological, social, economic, technological and other elements of society,
- comprehend and apply sustainability-engineering know-how, and
- provoke personal growth and change,

there-by enabling effective engineering co-creators of societal change toward sustainability.

Three broad program learning outcomes (PLOs) aim to achieve the overarching goal. Students will develop:

- a deeper understanding of problem context,
- the ability to facilitate personal, organizational, and societal change, and
- an understanding of, and ability to employ, tools specific to engineering sustainability challenges.

The PLOs, with the related topics of course-specific learning outcomes, is provided in Table 1.

2.2 Program Structure

The MEELS curriculum's structure has been designed around achieving the overarching goal and PLOs described above. The structure is summarized in Figure 1. The 1-year Master of Engineering is a course-based program consisting of two 4-month terms that focus on sustainability related coursework and one 4-month project course. The courses include two core courses in each term (developed specifically for the program and taken by the MEELS cohort) and two electives (chosen from the pool of graduate-level sustainability courses offered at UBC, including up to 4 newly developed courses that the MEELS faculty would add to the pool). The core courses incorporate both field trips designed to enhance learning of sustainability tools and workshops focusing on facilitating change. A seminar series presents talks from engineering practice for sustainability, and talks from non-engineering scholars on non-technical, contemporary, issues related to sustainability. The final project course requires the application of sustainability tools and problem contextualization to facilitate change. Ideally, these final projects focus on organizational or societal change. Throughout the program, a partnership with the University of Cambridge will be incorporated. This includes teaching exchanges, online course exchange, and student exchanges between the two universities.

Table 1: Program learning outcomes

Program Learning Outcome	Topic of the Course Learning Outcomes
Contextualizing the Engineering Problem	Sustainability theory
	Systems/complexity
	International development
Facilitating Change	Human behaviour
	Consensus building
	Leadership skills
	Personal development
	Organizational change
	Critical thinking
Applying Sustainability Tools	Industrial ecology / supply chain
	Built environment
	Global engineering

2.3 Program Cohort

The program is designed to accommodate a cohort of approximately 24 students each year. It may be that the typical student will be a recent engineering graduate. Students are expected to live as a cohort in a common residence on the university campus, thereby facilitating opportunities to experience and contribute to the on-campus community. Approximately one-third of the cohort is anticipated to be from North America with the remaining made up of international students.

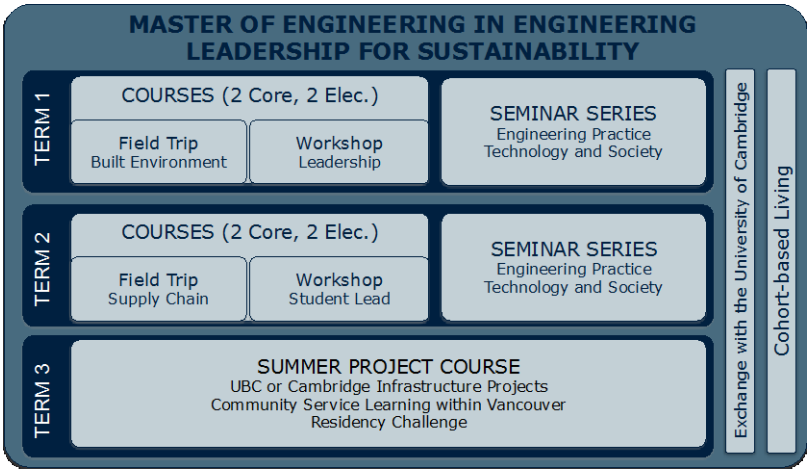

Figure 1: MEELS program structure

3 DISCUSSION

The program components have been developed to meet the overarching program goal and to prepare the students with the key competencies of sustainability. The program management framework and three of the program's components will be highlighted to illustrate the integration and alignment with the overarching goals and key competencies. The components discussed include coursework, community building, and the project course, focussing on how these program aspects improve the leadership and other soft skills of the students.

3.1 Curriculum Management

If viewed as a socio-curricular system, the MEELS program can be conceptualized as clusters of components that aim to educate those engineers who desire engineering sustainability knowledge. The system's components are physical, non-physical, and human, and include students, administrators, the profession, educators and other communities-of-interest, as well as classroom space, communication and computational tools, and resources. The system continually grapples with changing sets of framing issues and, from the system, arises the details of the planned (constructively aligned) curriculum offered to students. Figure 2 describes this socio-curricular conceptualization.

Again conceptually, management of the curriculum needs to ensure that the education enterprise functions well and that the system is continually learning. Therefore, its tasks are three-fold:

1. Manage the annual teaching and learning activities (e.g., allocate teaching, ensure teaching space is available, etc., etc.)

2. Monitor the system functions (e.g., the teaching and learning activities), and report monitoring results to the governing body

3. Govern the system activities by learning from the assessment reports (i.e., make important decisions that influence the system, such as how and when to review the constructively aligned curriculum and the teaching and learning tasks, also

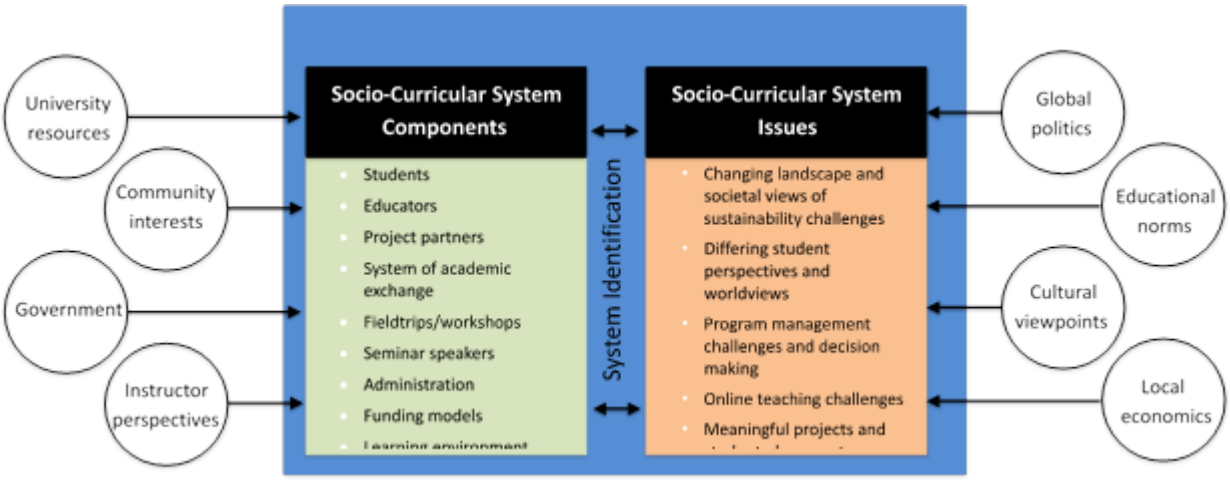

Figure 2: The MEELS program depicted as a socio-curricular complex system.

3.2 Course work

The MEELS is composed of 8 courses (4 core, and 4 elective) taken over two academic terms, followed by a significant term-three project. In addition to standard classroom discussions and readings, the core courses incorporate one field trip and one workshop each term.

Enabling students to conceptualize the problem is primarily achieved via the program structure, i.e., through core courses that aim to equip the cohort with a strong background in sustainability theory, an understanding of systems and complexity, and international development. The newly developed core courses include:

1. Concepts in Engineering for Sustainability

2. Leadership in Engineering for Sustainability

3. Systems Theory and Applied Systems for Sustainability

4. Life Cycle Assessment Fundamentals

The proposed program structure allows freedom of choice for students to develop sustainability tools by selecting 4 elective courses from a list of sustainability courses offered across the university that includes three courses offered by MEELS faculty, namely:

1. Applied Industrial Ecology

2. Sustainable Engineering for International Development

3. Sustainability in the Built Environment

A comparison of the course titles with the list of course learning outcome topics in Table 1 shows a strong alignment between course learning outcomes and the specific PLOs that they are designed to address. This hierarchical alignment along with suitable course learning activities (eg., lectures, field trips, workshops, and small projects) and assessment methods (eg, reflective journals, individual and group projects, writing, presenting, community building, etc) is deliberately used to reinforce the reason for each aspect of the program to students. It is envisioned that the cohort will be given a learning map that explicitly links all components of the program. This level of understanding of why one is learning something and how it fits within the larger context of the program has been shown to enhance student learning (Biggs, 1999).

The courses also allow for enhancements to the students' sustainability competencies. The systems thinking competence is enhanced directly through learning and application of systems theory within the core and elective courses to further strengthen this attribute amongst engineers. The course "Leadership in Engineering for Sustainability" is designed to specifically address the initial shortcomings in interpersonal competence. This is a course used to promote the growth of "soft" skills required to address sustainability issues such as communication, collaboration, leadership, and empathy through in-class discussions and exercises designed to identify personal shortcomings and promote personal growth.

3.3 Community Building

One of the most underdeveloped competencies within the typical engineering education is the interpersonal competence. This is incorporated into several of the MEELS program's element through community building. The living and interacting in a close-knit community will lead to improved interpersonal competence. The PLO that is most affected by community building activities is facilitating change through the topics of human behaviour, concensus building, leadership skills, personal development, and organizational change.

The students form a community from the program outset through cohort-based living. All of the students within the program will be housed within a single residence on campus. This will foster a sense of community amongst the students and facilitate communication and an understanding of viewpoints from different groups and cultures, which are critical aspects to success in overcoming any sustainability challenge. Learning from peers within the program cohort will also improve the students' normative competence through learning to understand and negotiate different value systems while improving the ability to facilitate change that is acceptable to all.

Community building is also incorporated within the course structure of the program. The four core courses will be offered only to students of the program to allow for personal growth within a familiar community. The students will also undertake fieldtrips and workshops as a component of the core courses, which will provide educational context and development of the cohort based community outside the classroom and university. One of the goals of fostering this community amongst the students is to promote continued communication amongst sustainability practitioners after the completion of their degree.

A key component of MEELS is to integrated exchange within the general curriculum. A main focus of this exchange is with the MPhil in Engineering for Sustainable Development at the University of Cambridge. The exchange will enhance student learning through electronic exchange as a staple component of coursework as well as through the opportunity for a physical exchange between universities as an optional program component. One of the purposes of the use of exchange within the program is to foster an understanding of the importance of communication on a local scale (through the cohort) as well as a global scale of community to further emphasize the scale of sustainability challenges and to prepare the students to think of change on a global scale.

3.4 Project Course

The final deliverable for the MEELS program is the completion of a final project course. The project course's purpose is to allow the application of the sustainability concepts developed throughout the program to facilitate change through a project or community based learning activity. Examples of possible projects include infrastructure projects at a university to reduce energy or carbon footprint, a behavioural change project such as modifications to recycling patterns and practice, or projects focused on improving personal and social wellbeing.

The projects are all short-term and sustainability related requiring students to showcase the successful achievement of the program PLOs and the use of all five sustainability competencies. The main PLO achieved through the completion of the project course is facilitating change as these are the skills that revolve around action to meet sustainability goals. The projects will focus on one or more aspect of change (behavioural, personal, organizational, technical, etc.) as required by the project definition. The use of sustainability tools will also be required to progress through project completion, depending on the project goals.

As with all sustainability projects, the final project course will require students to have (and use) the five key competencies of sustainability to achieve success. The typical projects available for engineering students will focus on systems relevant to the operation of the university campus or city infrastructure. This will require an understanding of systems thinking and complexity to analyze potential impacts of the project implementation. The students will utilize anticipatory competency when analyzing potential impacts of multiple project solution scenarios before selecting and implementing the optimal solution. Normative competence will be required throughout the project when determining the effects of project solutions on stakeholders (both active and silent). The projects will be chosen to require implementation of the solution and not simply a theoretical analysis or design. This will emphasize the importance of strategic competence when working with real world challenges instead of the typical theoretical focus of undergraduate work. Finally, the projects will all be student-lead but have a representative from the main stakeholder or project provider (university, company, city, etc.) among others with whom the students will be required to interact. A large focus of the projects will be on the use of the interpersonal competence developed through the program as outlined above.

4 CONCLUSIONS

There are a number of large-scale challenges that must be overcome in the near future which require a specific skill set represented by the five key competencies of sustainability. These competencies are not taught through typical undergraduate or graduate education programs but engineers possess a number of the skills required. The new Master of Engineering in Engineering Leadership for Sustainability described in this paper will provide a complement to the standard undergraduate engineering education in order to address these needs.

The new program is designed to be constructively aligned throughout the entire curriculum. Examples have been provided of how aspects of the program have been used to meet the program learning outcomes and how these will also specifically enhance the existing skills of the students to meet the key competencies of sustainability. A constructively aligned program will ensure that the students are successful at meeting the learning outcomes and gaining the abilities required for solving sustainability problems in their future careers.

The new program is still in the development stage and work will continue with revisions to further strengthen and ensure future success. The first cohort is being targeted for start in September 2016.

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