3. Approaches to Teaching Engineering for Sustainability in the Department of Bioresource Engineering at McGill University, Canada.

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This paper provides an overview of various approaches that have been taken by the first author over the course of the last four years in one new undergraduate course and one new graduate course in the Department of Bioresource Engineering at McGill University in Canada, aimed at introducing the concepts of engineering for sustainability to undergraduate and graduate students. At the undergraduate level, a new course was developed entitled "Engineering for Sustainability", which provides an overview of the main principles, frameworks, methods and practices of engineering for sustainability. Some key elements of this course include group model building exercises via qualitative system dynamics models, as well as multiple case studies given by engineers from various organizations, and an emphasis on the concept of acting as a change agent within engineering organizations. At the graduate level, a new course entitled "Watershed Systems Management" was developed; it is a central part of a new Master of Science degree, as well as a new Online Certification, that were developed with a focus on integrated, collaborative and adaptive water resources management. Both the undergraduate and graduate courses involve a final project where students analyze an engineering problem, engage with local stakeholders, and provide recommendations on how to ensure that the engineering project, product or process is more sustainable. This paper provides an overview of some of the unique elements of the undergraduate and graduate courses, as well as the graduate MSc and Online Certification programs, and provides some reflections on teaching sustainable development to engineers in the Department of Bioresource Engineering at McGill.

Keywords: Engineering; Sustainability; Education; Systems thinking; Adaptive management; Stakeholder engagement; Change agents.

1. Introduction

There is an urgent need to address the issue of sustainability in engineering processes, projects and products, and one of the important ways of doing this is by incorporating the topic of sustainability into higher education. The past decade has witnessed widespread interest around the world in incorporating the skills, attitudes and concepts of sustainability into university courses across a range of disciplines (Carew and Mitchell, 2007). The World Summit on Sustainable Development in Johannesburg highlighted the importance of education as one of the key elements required for sustainable development and proposed a decade of education for sustainable development ending in 2014 (United Nations, 2002). Only one year is left until this decade ends; however, progress has been slow - the engineering profession has failed in many ways to embrace the positive role engineers can play in securing a sustainable future (Brunetti *et al.*, 2003). The Institution of Civil Engineers (ICE) in the UK has urged the inclusion of sustainability as one of the expected competencies of a civil engineer. This emphasis on sustainability in education seems especially relevant in light of the recent change of definition of professional engineering in various organizations. For example, the Professional Engineers Act in Ontario now requires engineering activities to be concerned with the safeguarding of life, health, property, economic interests, the public welfare and the environment (PEO, 2010)

In Western Canada, the University of British Columbia has been pursuing the theme of sustainability in some of their engineering programs. Since 1996, initiatives have been implemented in the Department of Chemical and Biological Engineering to introduce pollution prevention, green engineering and sustainability into the curriculum (Bi, 2005). However, it has also been found that there is a lack of institutional commitment to change and many ideas, which are greeted with enthusiasm in theory, encounter difficulties during implementation (Moore *et al*., 2005). Filion (2010) explored the pedagogical development of a new undergraduate course teaching applied sustainability and public health in civil engineering design in the Department of Civil Engineering at Queen's University in Kingston, Ontario, Canada. This course introduces undergraduate civil engineering students to concepts and methods for the evaluation of global environmental impacts and local public health impacts. Undergraduate students are expected to apply these concepts and methods in a final design project. However, many courses such as this lack detailed discussion of the social side of sustainability, change management, and change leadership, among other topics.

In a study focused on institutions of higher learning in Atlantic Canada, Beringer *et al.* (2006) found that most of these institutions realize the importance of including the principles of sustainability in curriculums, but that few institutions are taking action with respect to integrating sustainability into the curriculum. The social pillar of sustainability in the form of courses addressing human-nature relationships, social justice and social change, citizenship, or sustainable living was found to be underrepresented. This is cause for concern since an understanding of and motivation for social change is what will help drive students to become change agents, who implement the principles of sustainability. While most universities have gone to great lengths to "green" their campus operations, it can be argued that curriculum development has not progressed as much. While McGill University in Montreal, Canada, has already introduced a few programs and courses in sustainability in the Departments of Geography and Management, the programs and courses presented in this study are the first to focus exclusively on sustainability in the engineering curriculum at McGill University.

This paper provides an overview of various approaches that have been taken by the first author over the course of the last four years in one new undergraduate course, one new graduate course, and two new graduate programs in the Department of Bioresource Engineering at McGill University in Canada, aimed at introducing the concepts of engineering for sustainability to undergraduate and graduate students. These courses and programs combine innovative approaches to overcome the difficulties of integrating the social, technical and economic pillars of sustainability in engineering solutions. The courses are aimed at creating change leaders, who will be able to advance the shift towards sustainability in the engineering profession on a project-by project basis. There are five main concepts that unite the two courses, the MSc program and the Online Certification program. First, they emphasize an integrated approach to sustainability, including social components. Second, both courses provide knowledge on how to instigate and manage change. The ability to effectively initiate a change process is a vital skill that needs to be formally developed in those engineers wishing to seek sustainable solutions from within the organizations for which they will work (Fenner *et al.*, 2005). Third, both courses explore, in detail, how to move forward in the face of uncertainty through approaches such as adaptive management. Fourth, the two courses courses use active and case-based learning to provide a real-life outlook, which integrates diverse subjects and makes them easy to understand for people from various backgrounds. Finally, both courses focus on improving the communication and teamwork skills of engineers through group projects and presentations, as well as facilitation exercises.

2. Overview of the two programs and courses

At the graduate level, a new one year non-thesis Master of Science (MSc) degree, as well as a new two month Online Certification, were developed with a focus on integrated, collaborative and adaptive water resources management. Both programs are composed of participants with very diverse disciplinary backgrounds (e.g., geography, engineering, social sciences, environmental studies, law, business, etc.). The MSc program is designed to accommodate students that have a Bachelor’s degree, usually with some work experience in the water resources field. This program provides a thorough overview of various biophysical, environmental, engineering, legal, institutional, and socio-economic aspects of water resources management in an integrated context. The program features site visits to organizations in the water management field (e.g. the International Joint Commission, various consulting firms, NGOs, Environment Canada, Ouranos, etc.), and a three month internship. The Online Certification is designed specifically for professionals who want to upgrade their skills in water resources management concepts and practices. This program uses a web-based system coupled with a comprehensive text book developed specifically for this program. Participants are required to participate on a daily basis in the online discussion forum.

As part of the MSc program, a new graduate course entitled “Watershed Systems Management” was created. Relying on a combination of systems thinking, participatory engagement and modeling, the course provides a systems approach to managing water resources. This course brings together the social, economic and environmental aspects of managing a watershed. At the undergraduate level, a new course was developed entitled "Engineering for Sustainability", which provides a broad but thorough overview of the main principles, frameworks, methods and practices of engineering for sustainability in diverse engineering fields such energy, water, construction, transportation, agriculture, and others.

Both courses are similar in structure and focus. They concentrate on the need to incorporate social, economic, political, management and governance issues in engineering project design and implementation. The courses emphasize that the successful implementation and operation of an engineered system usually depends as much on non-engineering analyses (e.g. economic and social analyses) as on sound engineering design. The first part of each course focuses on integration and participation as key elements in designing and implementing effective engineering solutions. Various systems interactions are explored to demonstrate the need for integration. The second part of both courses introduces various frameworks as a means of transitioning from 'theory' to 'practice'. In the graduate course, the practical integration of various disciplines is introduced through the detailed development of integrated water management plans, which include quantitative watershed systems analysis tools and organizational steps. An important part of this is the development of change leaders.

In the undergraduate course, practical frameworks are introduced such as the FIDIC Project Sustainability Management System, Life Cycle Assessment, and alternative region/topic specific frameworks, such as the USEPA framework for Ecological Risk Assessment, and the BC Guide for green infrastructure. Various tools such as the GoldSET software, developed by Golder Associates to incorporate the principles of sustainability into engineering projects, are introduced as decision support tools. The implementation of these frameworks is demonstrated via numerous case studies. The graduate course focuses on case studies emphasizing various aspects of water management, while the undergraduate course covers a wider range of engineering disciplines, including thirteen different engineering fields such as transportation, waste management, sanitation, and construction engineering. In both courses, frameworks to identify and then engage key stakeholders in engineering design and implementation are presented (e.g., participatory systems dynamic modeling). In both the undergraduate and graduate courses, the third part focuses on adaptive management as a tool for water management in the face of increasing uncertainties due to, for example, climate change. This part of the course introduces both the active and the passive forms of adaptive management. In addition, the third part of both courses focuses on change management within engineering organizations, and how to act as a change agent/champion within an organization to help transition the organization towards sustainability.

3. Unique themes taught in the two courses and programs

Although declarative knowledge has been found to be one of the least effective way to promote pro-environmental behaviors, it has been a central focus of most educational programs to date (Simmons and Volk, 2002; Pooley and O'Connor, 2000). This type of knowledge typically addresses how environmental systems operate in technical, mechanical or biophysical terms (Kaiser and Fuhrer, 2003; Frisk and Larson, 2011). While this type of knowledge is important as a foundation, it is not sufficient, and difficult to present due to the transdiciplinary and integrative nature of sustainability. Moreover, sustainability itself is a contested concept, which has many definitions, and is often referred to as a process rather than an outcome (Wals, 2002; Carew and Mitchell, 2008). Procedural knowledge, which refers to the basic "how-to" information, has been found to be more effective in promoting behavioral change. It is especially crucial for developing an understanding of the strategies that can be taken under a set of circumstances, and it tends to be most effective when coupled with effectiveness knowledge and social knowledge (Frisk and Larson, 2011). To evaluate the effectiveness of proposed sustainable engineering solutions, the two courses described earlier provide students with procedural knowledge, leaving them with the understanding of how to integrate and analyze complex transdiciplinary issues with inherent uncertainty. Effectiveness knowledge addresses the outcomes of different behaviors, answering the question "is the behavioral sacrifice worthwhile?" (Kaiser and Fuhrer, 2003; Monroe, 2003). There are two key factors which determine effectiveness knowledge: the perceived consequences of behaviors (taught by frameworks and simulation demonstrations) and the beliefs as to who is responsible for environmental outcomes. This relates to the confidence and a belief that one can make a difference, and his or her efforts can stimulate action by peers and the broader community. Social knowledge encompasses information regarding the motives and intentions of other people, otherwise known as social norms (Kollmuss and Agyeman, 2002). Social knowledge explains two types of norms: conventional norms refer to customs, traditions, and expectations associated with the need for social approval, while moral norms refer to the value or importance a person places on behavioral outcomes.

3.1. A "toolbox" of various frameworks and methods

In the two courses described above that were developed at McGill University, a "toolbox" of various frameworks are provided to the students as a way to transform qualitative goals and values into a set of quantifiable indicators. Goals for sustainable development tend to focus on broad problems and issues facing all of society, such as global warming, biodiversity, access to fresh water, and materials and energy use. While this whole-society focus is absolutely essential, it makes it difficult for project owners to clearly define and specify the requirements for sustainable development.

Through the use of the various approaches in this "toolbox" of frameworks and methods, students are able to understand the environmental and social impacts of a project and choose between alternatives. For example, the FIDIC Project Sustainability Management (PSM) process, explored in detail in the undergraduate course "Engineering for Sustainability", allows the project owner, consulting engineer, and various key stakeholders to balance the owner's project vision against cost and available alternatives by working together to select appropriate project goals and indicators for sustainable development which are linked back to higher level goals (FIDIC, 2004). The FIDIC indicator system is designed to provide a balanced approach by preventing the project from focusing on one area of sustainability while neglecting other areas. A significant benefit of FIDIC PSM as a tool for change towards sustainability is that it is compatible with, and can be integrated directly into, current project management processes and ensures, where possible, that each of the indicators has a measurable success criteria associated with it (FIDIC, 2004). Being able to understand the link between design choices and their environmental and social impacts is crucial for engineers if they are to engage in environmentally sustainable design in the future. The Life Cycle Assessment framework, which is also presented in the undergraduate course, acts as a link between the regional and the global scope, making it possible to link the selection of project materials and components to their global environmental impacts and supply chain implications.

The graduate “Watershed Systems Management” course features frameworks for the development and implementation of integrated water management plans and water resources assessment. Watershed assessment based on cross-sectoral tools such as institutional and legal analysis, hydro-geological assessment (i.e., land use and water), demand assessment, environmental impact assessment, social assessment, and others, are discussed in detail. Methods for quantitative watershed systems analysis are discussed, along with simulation modeling and forecasting. For example, students are exposed to new methods in data driven modeling that are based on machine learning methods (e.g. wavelet bootstrap support vector regression, and wavelet cross-wavelet forecasting methods). Guest lecturers are invited to discuss their experiences in working with stakeholders and institutions to build political will through change leaders. The Participatory Model Building Framework (see Figure 1) is also explored in detail as an effective way to identify key stakeholders, and then engage these stakeholders at various levels ranging from exploratory participation to institutional engagement. Both courses present participatory system dynamics modeling (explained in more detail below) as an effective tool for stakeholder engagement in the design and implementation of sustainable engineering solutions.

3.2. Participatory systems dynamics modeling

An important feature in both courses is the teaching of participatory systems dynamic modeling as an effective tool for stakeholder engagement and collaborative engineering design and implementation. The social elements of sustainability are often overlooked in engineering curriculums, and systems thinking in general, and the participatory systems dynamic modeling approach in particular, are not widespread in engineering programs despite the recognition of the important of a systems or ‘holistic’ approach to designing and implementing engineering solutions, as well as managing natural resources. Participatory systems dynamic modeling provides a way of integrating social aspects into engineering design and implementation, and supports collaborative decision making. This method separates the underlying system structure from the behavior of the system and allows participants to simulate the effects of policies and discuss the trade-offs of various scenarios and ‘what if’ situations. Both the undergraduate and graduate courses provide a detailed overview of methods and software available for such engagement (e.g., Vensim), and both courses include a 3 hour hands on group model building exercise based on participatory system dynamics modeling.

3.3. Acting as a change agent

Both the undergraduate and graduate courses place significant emphasis on the concept of acting as a change agent within engineering organizations. Embedding sustainability into practice constitutes a burden of responsibility, yet an opportunity to provide leadership (PEO, 2010) and educational institutions should embrace this opportunity. Several lectures are devoted to the discussion of engineers as change agents/leaders/champions. It is emphasized that the main reason most changes fail is human resistance rather than the lack of resources or ability. The understanding of team dynamics and an overview of strategies for addressing this resistance provide insight into organizational behavior, while case studies and a change management methodology provide a structure for the process. Conflict management as a part of change management is also explored. This is important as sustainability solutions are, among other things, related to an understanding of the role of the engineering community in pushing forward sustainability, a sense of social responsibility and an awareness of tools and techniques for identifying more sustainable solutions (Perdan, 2000).

Overall, the above described unique themes of the two courses – graduate and undergraduate - allow learners to understand sustainability as a concept that stretches beyond technical issues into everyday life and integrate sustainability with other fields of study. These courses emphasize the value of the ecosystem and human welfare and provide tools and frameworks (the know-how) to combine the social, economic and technical aspects of sustainability. Just as importantly, these courses present techniques to instigate and push through change towards sustainability in the form of acting as a change agent within an engineering organization.

4. Unique pedagogical tools

To date, engineering programs in universities have not really been at the forefront of instigating change towards sustainability in industry, in part because knowledge is organized into "traditional", specialized disciplines, where sustainability does not fit (Rogers, 2013). New and unique pedagogical tools for transformative learning are necessary to further the paradigm shift towards sustainable practices within the engineering profession. These tools must support learning objectives which target not only cognitive abilities, but also psychomotor and affective domains. Psychomotor tools support experiential learning. Truly experiential learning requires the learner to initiate the learning process, the experience to be genuine, and reflection to lead to new ideas that can be tried in a new situation (Battisti *et al.*, 2008). The affective domain is also critical for learning, but is often not specifically addressed. This is the domain that deals with attitudes, motivation, willingness to participate, valuing what is being learned, and ultimately incorporating the values of a discipline into a way of life (Battisti *et al.*, 2008). The integration of the three types of learning (cognitive, psychomotor and affective) creates a change in the behavioral domain, which is responsible for values and actions. The transformative approach to sustainability allows learners to move beyond the knowledge of facts and empowers them to change their frames of reference or worldviews (Moore, 2005). The programs and courses described in this paper have unique features that help foster transformative education, including: an internship, hands-on simulation exercises, group case studies and projects, guest speakers, and active interaction with stakeholders.

4.1. Internship and online discussions

A key element of the Master of Science in IWRM program is a 13 week internship, and a key element of the Online Program is extensive online discussion. The MSc internship entails three months of work in a water-related field with a final project write-up. During the internship the students have both a faculty supervisor and an on-site supervisor who provide them with guidance. These elements are crucial to achieving transformative learning because they allow students to initiate the learning process in areas specific to their interest, feel social support for their work and reflect on their experience through writing. The support accompanying real-life experiences helps learners view sustainability as a social norm and gain confidence in their abilities. The analysis of their work through writing allows students to assess the effectiveness of their work, providing confidence in the methods they use and giving rise to new solutions. This social knowledge, created by online discussions and mentorship, along with effectiveness knowledge, is important. The reflection of the students on the results of their actions creates a solid social and experiential base for students to rely on when they convert their knowledge to action. Furthermore, the internship provides an entrance into the profession, encouraging students to seek employment within their field of study.

A key element of the two month Online Certification program is an online discussion forum where students are actively encouraged to participate on a daily basis. As part of this forum, students discuss various topics they are exploring in their readings, ask questions, etc. On average, there are around 40-50 posts per day on a very wide variety of issues related to the course. Student feedback indicates that this online discussion forum is a key component of learning in the online certification.

4.2. Simulation games and exercises

Simulation games provide an effective way to facilitate sustainability learning by providing students with an experience in acting within complex systems and dealing with uncertainties that characterize the world in which we live. Simulation games create a safe-to-fail environment, where students can practice decision-making and action-taking. Through the iterative process of the simulation game, students find social mechanisms to overcome complexity and learn to consider both immediate problems and long-term consequences that decision making processes could generate. Educating for sustainability demands learning approaches and environments that require the development of systems thinking and problem-solving, rather than solely the acquisition of factual knowledge.

To experience the complexity and unpredictability of the real world, students in the graduate "Watershed Systems Management" course engage in a 3 hour session of the UVA Bay Game (Learmonth *et al.*, 2011). The UVA Bay Game is a large-scale participatory simulation game based on the Chesapeake Bay watershed. It combines a video game format with current demographic, economic, and scientific data to create a powerful tool with real-world applications and impact (University of Virginia, 2013). This game allows students to simulate various scenarios of managing a watershed, where they take on roles as different stakeholders. Each student makes decisions concerning the regulation of a business or an industry within a watershed, based on both economic and environmental indicators on their screens. The game has multiple decision-making cycles, where students encounter the consequences of their decisions and unexpected natural disasters. The gaming exercise is followed by discussion and reflection by the students. While no one game experience will accurately "predict" an outcome, it enables players to appreciate the complexity of the modeled environment. It demonstrates that a complex system does not always respond to policy initiatives as planned and implemented and that, despite due care and consideration, unusual – *emergent* – outcomes may yet arise (Learmonth *et al.*, 2011). Furthermore, the students quickly find themselves discussing and integrating concerns across sectors. It has been found that the UVA Bay Game provides players with a new sense of individual and collective agency (University of Virginia, 2013). As it stands now, these types of conversations and integration are rarely carried out in practice. The gaming experience provides students with a visible demonstration of the necessity of such communication, and motivates them to use these techniques in their future work. Furthermore, game play records suggest new directions for research in behavior change and policy development (University of Virginia, 2013).

While the UVA bay game does not provide a framework for social interaction and debate, the group model building exercise that the students engage in (both in the undergraduate and graduate courses) demonstrates the usefulness of systems dynamic modeling as a tool for the integration of social and technical aspects in the design and implementation of engineering solutions. The systems dynamic group modeling exercise allows students to experience and overcome the difficulty of multiple perspectives by separating the underlying system structure from actions or outcomes. In this exercise a critical issue is chosen (e.g. water scarcity in Cyprus, agricultural water pollution in Quebec, traffic congestion in Montreal, etc.), students are separated into groups of 6-8 students, and each student in a group takes on the role of a stakeholder (e.g., farmer, government official, NGO, etc.). One of the students in the group assumes the role of a facilitator (and receives training on the method prior to the exercise). Using a four step process developed by Vennix (1996) (see Figure 2), students begin by discussing the problem, and then model the causes of the problem, the consequences of the problem, and then explore various feedback loops (reinforcing or balancing). Students then explore various policies that could be used to address the problem variable. The group built system dynamics models (or causal loop diagrams) encompass social, economic, environmental and technical components. Figure 3 provides an example of results of such an exercise. This practical exercise allows students to experience the complexity of designing sustainable engineering solutions, and demonstrates the value of varying opinions as sources of knowledge and collaboration, rather than sources of debate and conflict.

4.3. Final group projects and case studies

To effectively research opportunities for change, engineers need the ability to integrate complex information across organizational hierarchies and various disciplines. In addition to the teaching of frameworks, the courses presented in this article use many case studies to incorporate a variety of topics and effectively expose students to study problems in fields, which are adjacent, but not directly related, to their field of study. The use of case studies is well-suited for teaching sustainability due to the complexity of the subject: the more complex and contextualized the subject, the more valuable the case study approach (Scholz *et al.*, 2006). Both the graduate course and the undergraduate course involve a final project where students analyze an engineering problem, engage with local stakeholders, and provide recommendations on how to transition to a more sustainable solution, while incorporating the principles, frameworks, and tools learned during the course. This is useful, because the projects allow students with different backgrounds to explore topics closer to their desired field of study. It also helps establish practical knowledge of the process of analysis, allowing students to ask questions and to get to know sources of information before they try applying the same methodologies in the real world. For example, in the graduate course the project consists of a holistic analysis of a watershed. Students with various backgrounds work together to select the major issues in a watershed, and then analyze these issues and provide recommendations for action. During this assignment they are encouraged to contact stakeholders and watershed organizations to integrate the viewpoints of local stakeholders. In the undergraduate course, the final project consists in identifying an engineering design issue, and after careful analysis, providing a detailed set of recommendations on how to improve the sustainability of the selected engineering project, process or product. Emphasis is placed on ensuring that the consideration of sustainability is incorporated into all components of the proposed solution, and that there is a balance in the integration of technical, social, economic and environmental aspects using the principles, frameworks and methods explored throughout the course. Having been exposed to these experiences, students have stated that they feel more comfortable when tackling broad issues, which lie at the intersection of multiple disciplines.

Individual and social change can result through transformative group learning (Cranton, 1994). The case studies, guest presentations and collaborative projects, along with the explicit study of change leadership provide important elements that are necessary to implement change towards sustainability on a project-by-project basis. Social norms as predictors of behavior are especially critical in a field such as sustainability, where societal values are central in guiding what one must sustain and how (Frisk and Larson, 2011). Transformative learning alone is not enough to effectively produce social change. It produces change within an individual, and there is an assumption that if enough individuals are "transformed" social change will occur on its own. An advantage to motivating sustainability via social concern is that all behavior is grounded in social context. This type of motivation is based on peoples' desire to be responsible citizens, to be accepted and respected by others, and generally to behave in ways consistent with group or societal norms to receive social praise. While this context can be used to effect change (for example, through education and a supportive social environment in academia), it can also cause a reverse change away from sustainability if social context of unsustainable behavior prevails (Becker and Jhan, 2000). Unfortunately, sustainability is not yet deeply embedded into the engineering culture and social norms often play a negative role by suppressing sustainability initiatives. Pretty (2003) found that "without changes in social norms, people often revert to old ways when incentives end or regulations are no longer enforced." Supportive social networks are an inherent characteristic of successful change leaders (Taylor, 2008). Schultz *et al*. (2007) distinguish between different types of social norms: descriptive norms refer to perceptions of what is commonly done (case studies and guest speakers address this in the two courses), whereas injunctive norms refer to what is approved or disapproved by others, established by one's social networks - this is the reason it is important to have supportive networks.

4.4. Creating support networks and practical know-how: guest speakers and team assignments

Instilling strong personal values through transformative learning alone is not sufficient to create change leaders. Strong support networks and mentorship beyond the university environment are essential to helping engineering students become successful as change leaders in engineering organizations. Both courses presented in this paper foster the creation of such networks by promoting collaborative work among students and providing them with many opportunities to network with engineering professionals engaged in the transition towards sustainability in the engineering field.

The final projects in both the graduate and undergraduate courses are group assignments. Group work is also introduced in the assignments to analyze case studies. By engaging in these activities students develop interpersonal and team working skills. Furthermore, these activities encourage students to bond as a group and build connections that they can rely on in their future work. The collaboration in the simulation game and model-building exercise strengthen this bond. This bond helps create an operational support network of peers; this is important since it is known that to create effective change leaders it is necessary for a change agent to have strong operational networks and structural networks of professionals and mentors.

The regular discussions and interactions with practicing engineering professionals via guest presentations (around ten guest speakers per course) helps students enhance their communication skills and broaden their structural networks, which are usually the hardest to build. Guest speakers (in the undergraduate course) who regularly provide detailed presentations on their experiences in trying to implement the principles of sustainable development in various engineering sectors are presented in Table 1. Some examples are provided here. A presentation on green infrastructure (housing/building development) by engineers from Exp emphasizes the need for meaningful stakeholder engagement and capacity building programs in large engineering projects. Organizational change leadership strategies are discussed in detail by an expert in change management from Bombardier. Experiences in engaging First Nations stakeholders in Canada are discussed by an expert from Speiran Consulting. A manager from the World Resources Institute explains the risks and opportunities water presents for businesses, and discusses various strategies for managing these risks. A Manager of a Watershed Organization in Quebec explains the activities of a watershed organization in Quebec, along with details on each stage of the IWRM and AM planning cycle in the watershed. A former senior leader from the Canadian Section of the International Joint Commission gives a lecture on transboundary issues associated with water, and engineers from organizations such as Golder Associates, AECOM, and SNC Lavalin give talks about their experiences in implementing the principles of sustainability in their engineering projects.

5. Results and conclusions

To date the above mentioned two courses are the only engineering courses at McGill that are focused on engineering for sustainability. While research indicates a need to integrate sustainability into all subjects, it has been found to be difficult to achieve in engineering courses since this requires reorganizing and installing new teaching approaches that disregard the traditional division of subjects and disciplines in engineering (Hegarthy *et al.,* 2011). As part of initial efforts in a complete makeover of the engineering education system, stand-alone courses and programs are easier to implement and constitute a critical step towards accelerated change in both the engineering profession and in institutions of higher education. Stand-alone courses in engineering for sustainability foster crucial, transferable skill sets and seek to locate new knowledge within disciplinary spheres (Hegarthy *et al.,* 2011). They foster the development of crucial interdisciplinary and intergenerational networks of sustainable engineers, which make individuals in such networks robust to pressure from social norms.

The two programs and two courses described in this paper have achieved some useful results to date. Both the “Watershed Systems Management” and “Engineering for Sustainability” courses have had significantly increasing enrolment each year since they were first developed. In addition, approximately 25% of the students in these two courses continue their education in a Master of Science or a PhD program in topic related to engineering and sustainability. More than half of the remaining students end up working in the sustainability field. Educated and supported as change leaders, graduates of these two McGill courses are expected to help lead change towards sustainable practices in their workplace.

Although the literature points to a lack of success in relying only on information-based approaches to behavioral change (Finger, 2010; Leiserowitz *et al*., 2005; Barr, 2002; Trumbo and O'Keefe, 2001; McKenzie-Mohr, 2000; Stern, 2000), educators still cling to the idea that more knowledge will spur transformative action (Simmons and Volk, 2002; Sterling, 2001; Senge, 2000). The failure to incorporate behavioral sciences into educational philosophies and practice in the engineering field has resulted in an inability to promote transformative action (Frisk and Larson, 2011). The two courses discussed in this paper use transformative learning, following the teaching approach that addresses the three components as suggested by Sipos *et al*., (2007): the head, the heart and the hands. While this is an effective approach to teaching subjects where values need to be addressed, it alone is not enough to create a shift towards sustainability in engineering culture. To accelerate the integration of sustainability into the engineering profession, it is essential to create change leaders. Thus, change leadership must be directly addressed in teaching approaches to engineering for sustainability. Furthermore, it is critical to create support networks and tools which will last beyond the university years of engineering graduates.

Acknowledgements

This research was supported by a SSHRC Standard Research Grant held by Jan Adamowski.

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Figure 1. The Participatory Model Building Framework

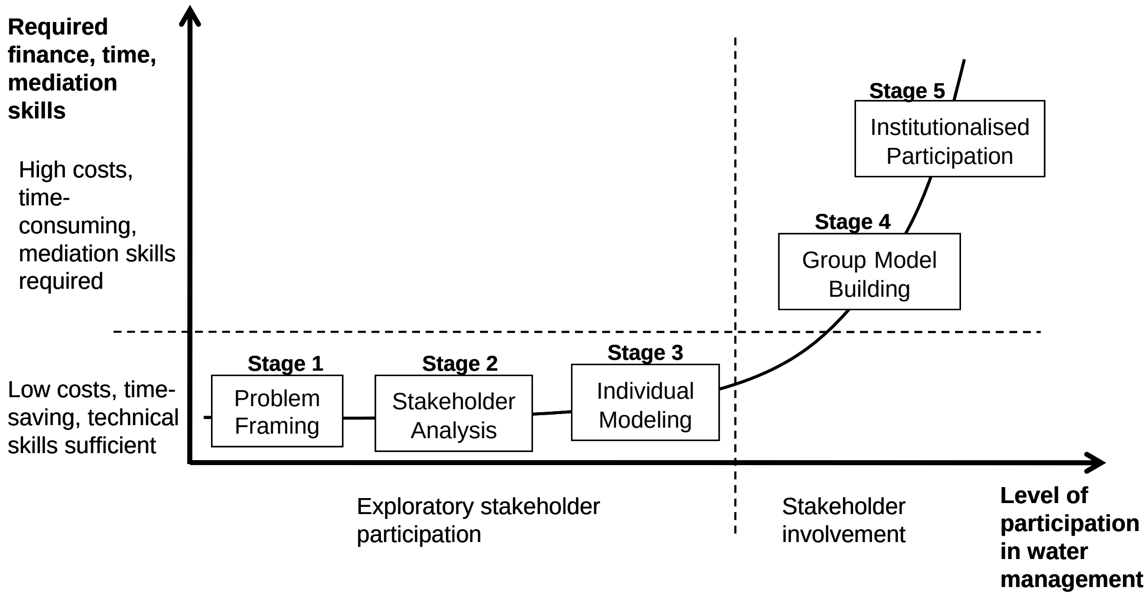

Figure 2. Steps in participatory systems dynamic model construction (Vennix, 1996).

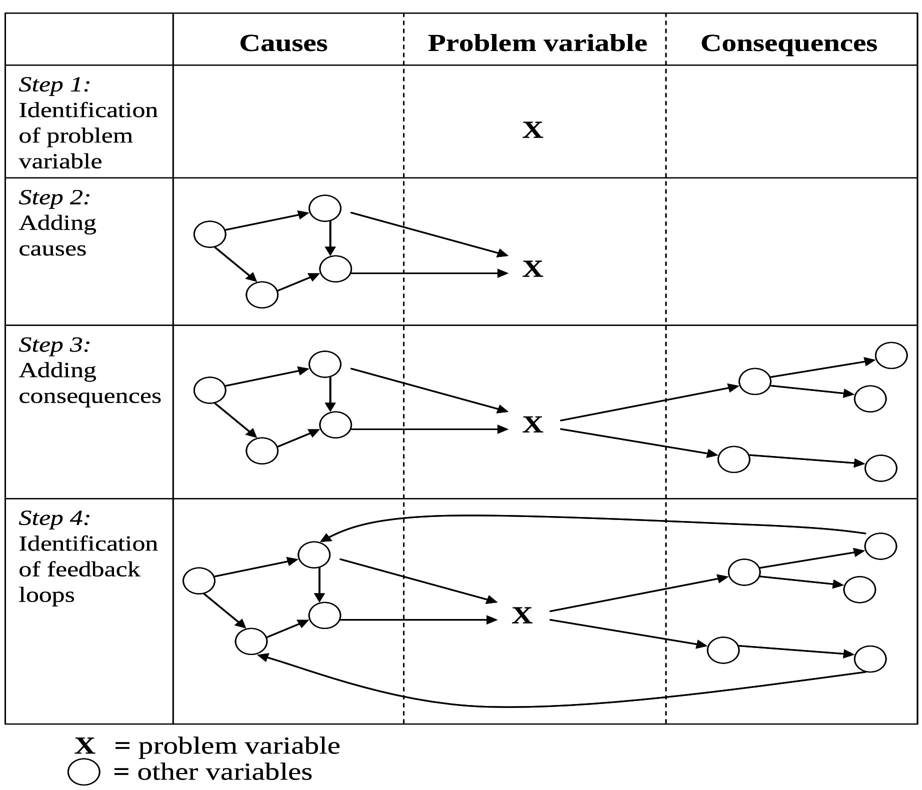

Figure 3. Example of a Causal Loop Diagram from the class participatory model-building exercise.

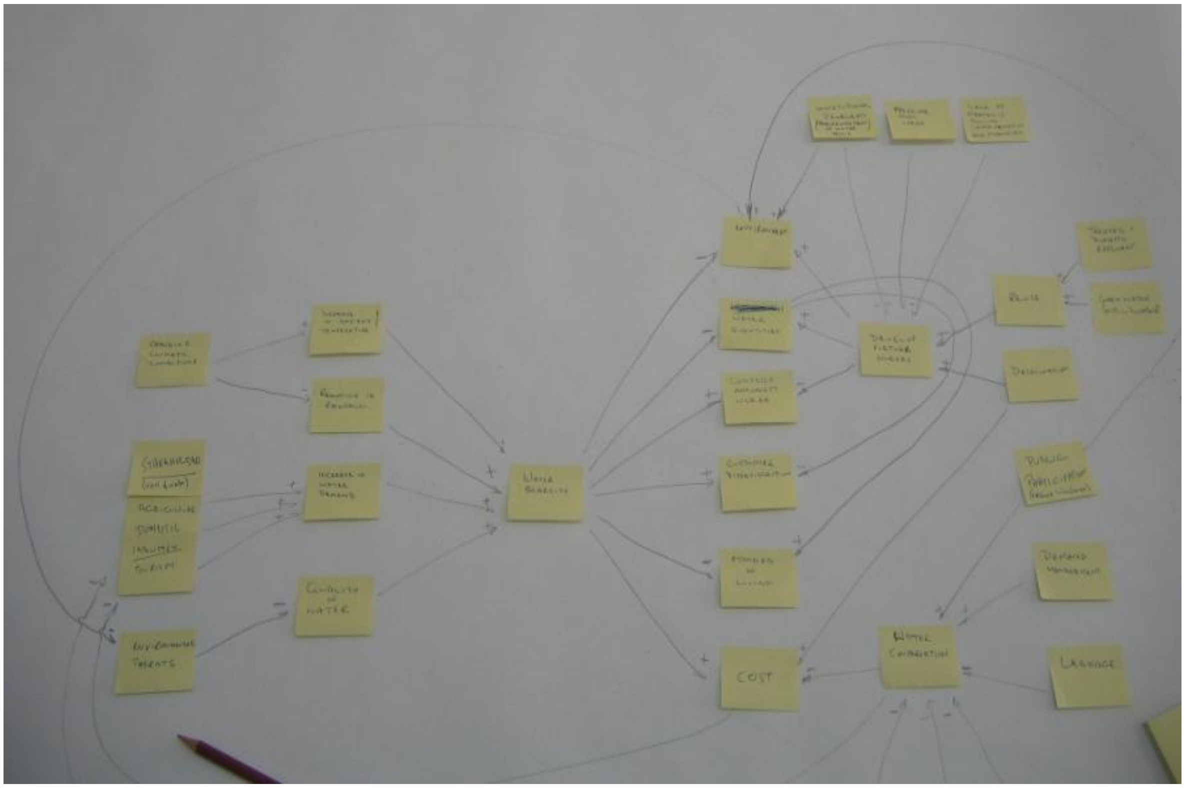

Table 1: Case Studies of Implementation of engineering for sustainability in different sectors (undergraduate course).

Main case studies	**Presentations**
Mining engineering	SNC-Lavalin, Golder
Energy, Agricultural engineering	Envint
Water, Highway engineering	Amec
Green infrastructure, Developments	Exp
Transportation engineering	Papadopulos Inc.
Pulp, paper industry	Domtar
Construction engineering	Dessau
Sustainability consulting	Dessau