World Sustainability Series

Walter Leal Filho
Susan Nesbit *Editors*

New Developments in Engineering Education for Sustainable Development

Springer

World Sustainability Series

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New Developments in Engineering Education for Sustainable Development

Springer

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Preface: Introduction to EESD15 E-Book

On the morning of 10 June 2015, approximately 125 delegates gathered on the campus of the University of British Columbia in Vancouver, Canada to open the 7th International Conference on Engineering Education for Sustainable Development (EESD15).

The conference opened with a keynote address from Jim Cooney, Professor of Practice in Global Governance at McGill University and a man instrumental in bringing sustainable development into aspects of Canadian and international mining practice. Delegates heard the inside story. EESD15 offered two more keynotes. Cynthia Atman, Director of the Centre for Engineering Learning and Teaching, University of Washington, shared results from some of the outstanding engineering education research investigations she has led over the years. And the closing plenary was generously given by Karel Mulder, Project Leader of the Education for Sustainable Development project at Delft University and the Chair of the first EESD conference, which was held at Delft in 2002. Karel's talk was reflective and provocative—the perfect close.

The University of British Columbia's Vancouver campus is well known for its sustainability infrastructure projects and, during EESD15, delegates were given walking tours of the Centre for Interactive Research on Sustainability (CIRS), the Bioenergy Research and Demonstration Facility, the Biodiesel and Clean Energy Research laboratory, the LEED Platinum "Nest", which is UBC's new student union building, as well as student-led tours of the campus.

Experts offered workshops on Corporate Social Responsibility and Sustainable Development, Environmental Ethics, Social Life Cycle Assessment and Life Cycle Costing, the 5-Step Methodology for Teaching Sustainability that is supported by CES EduPack (Granta Design) and Backcasting in EESD. There was also a special session devoted to delegates playing board games that can be used in the classroom.

One afternoon of the conference was held in downtown Vancouver where delegates participated in a Stakeholder Dialogue entitled: *A Dialogue on Accelerating Engineering Practice for Triple-Bottom-Line Sustainability*. And student posters presented engineering for sustainable development research projects.

And then there were the papers—73 were presented. The Session topics, many of which are represented in this book, included:

- Global Engineering,
- Assessing Programs,
- Assessing Student Performance,
- Curriculum Design,
- Change Agency,
- Project Courses,
- Comparing Programs,
- First year courses,
- Social Entrepreneurship and Innovation,
- Working with Others,
- Novel Teaching and Learning Techniques,
- Personal Growth and Life Long Learning,
- University Nudges toward Sustainability, and
- Sustainable Development in the Built Environment.

As has become the custom, the conference Steering Committee awarded a prize for best conference paper. ***The EESD15 Leo Janzen Prize for best paper was awarded to Scott Jiusto and Richard Vaz from Worchester Polytechnic Institute for their paper entitled: "Designing for impact: a model of community engagement for sustainable development"***.

This book fills the gap on publications related to engineering and sustainable development, and presents a set of papers that refer to both its theory and practice, as well as aspects of lifelong learning, and formal and informal pedagogies.

The EESD15 Conference chairs are grateful for the tremendous energy and support of the Keynote speakers, the Local Organising Committee members, supporting UBC staff members, the student volunteers, the Conference Steering Committee members, workshop and stakeholder dialogue facilitators, International Scientific Committee members and Conference tour guides.

We hope this book will be useful to all those interested in the connections between engineering education and sustainable development, and that it will encourage and catalyse further works in this field.

Germany — Walter Leal Filho
Canada — Susan Nesbit

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Comparing the Outcomes of Horizontal and Vertical Integration of Sustainability Content into Engineering Curricula Using Concept Maps

Elise M. Barrella and Mary Katherine Watson

Abstract

The goal of this project was to compare the conceptual sustainability knowledge of students at two institutions that differ in their approaches of integrating sustainability into curricula. One institution is a research-intensive university that has implemented a sustainability-focused course (vertical integration), and the second is a teaching-focused university that has woven sustainability into a variety of classes across its curriculum (horizontal integration). At both institutions, students beginning their capstone design experience created concept maps (cmaps) on the focus question: "What is sustainability?" Structure of student knowledge was analyzed using the traditional cmap scoring method, while specific content was evaluated using word clouds. Results support that students engaging in the curriculum with horizontal integration demonstrated broader, deeper, and more connected knowledge than students enrolled in the vertically-integrated curriculum. Furthermore, students participating in the horizontally-integrated curriculum demonstrated a more balanced understanding of sustainability, with the often-neglected social dimension being significantly represented in their cmaps, as compared to students from the vertically-integrated curriculum. Economic sustainability was a common weakness.

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Engineering education · Curriculum · Sustainability · Concept map · Integration

1 Introduction: Curricular Reform Strategies to Address Sustainability

For sustainable engineering to effectively contribute to global sustainability, engineering curricula must be updated to properly train sustainability-conscious engineers. Two common methods for effective incorporation of sustainability concepts into university curricula include horizontal and vertical integration. Horizontal integration is a strategy where sustainability concepts are incorporated into several courses across a curriculum, while vertical integration involves the addition of new sustainability courses into an existing curriculum (Ceulemans and De Prins 2010). Dissemination of a new course with sustainability content is essential for teaching students about fundamental concepts and principles related to sustainability (Peet and Mulder 2004). However, vertical integration alone may be insufficient because only teaching students about sustainability separate from core engineering concepts does not encourage them to incorporate sustainability into their professional designs and practices (Peet and Mulder 2004). Rather, integration of sustainability into existing courses may aid students in viewing sustainability in a systemic and holistic manner by demonstrating how sustainability and technical content can be blended to create sustainable designs (Peet and Mulder 2004; Ceulemans and De Prins 2010).

1.1 Sustainability Assessments

Cmaps are innovative assessment tools that can be used to assess student sustainability understanding. Cmaps are student-generated graphical tools for organizing knowledge in which concepts related to a particular knowledge domain are directionally connected using descriptive linking lines (Novak and Canas 2006). Students are provided with a focus question and asked to transcribe their internal knowledge into a cmap that can be easily reviewed (Ruiz-Primo 2000). Thus, cmaps allow students to explicitly reveal knowledge content, while also demonstrating how that content is mentally organized. Sustainability is a rapidly-evolving and complex knowledge domain, in which highly interconnected economic, environmental, social, temporal, and spatial concepts are very important. As a result, concept-map-based assessment tools are ideal for identifying concepts that students associate with sustainability, as well as quantifying the interrelationships between sustainability dimensions. However, practical methods for scoring cmaps are needed before concept-map-based assessment tools are widely applied (e.g., Besterfield-Sacre et al. 2004).

1.2 Project Scope

The goal of this project was to compare the impact of different strategies for integrating sustainability into undergraduate engineering curricula on student sustainability knowledge. The Georgia Institute of Technology (GT) has added a sustainability-focused course into their curriculum (vertical integration), while efforts to add sustainability concepts into existing courses (horizontal integration) is left to the discretion of the instructor. In contrast, James Madison University (JMU) has included sustainability and sustainable design as key elements that are woven throughout their interdisciplinary engineering curriculum. Concept maps created by upperclassmen at these two differing institutions were collected and analyzed to address the following research questions: (1) How do differences in sustainability integration strategies impact the *structure* of student knowledge? (2) What are the differences in the knowledge *content* of students from institutions with different sustainability curricula?

2 Background Information: Concept Maps

Concept maps (cmaps) can be used to capture the structure and content of student knowledge in a given domain. Several scoring methods are available to extract data from cmaps. As theoretically-grounded tools, cmaps are used as assessment strategies in a variety of fields, including sustainable engineering.

2.1 Function and Structure

Cmaps are graphical tools for organizing knowledge. Construction of a cmap is completed by enclosing concepts related to a central topic in boxes and using connecting lines, as well as linking phrases, to depict relationships between concepts (Novak and Canas 2006). The basic unit of a cmap is a proposition, which includes two concepts joined by a descriptive linking line. Propositions that include the cmap topic define the map hierarchies, and the level of hierarchy is defined by the number of concepts in the hierarchy. Cross-links, which are important for depicting connectedness, are descriptive linking lines that create propositions by joining two concepts from different map hierarchies (Watson et al. 2014).

2.2 Theoretical Bases

Use of cmaps is supported by cognitive psychological research in the area of semantic memory theory. Semantic memory refers to an organized database of concept-based knowledge, such as meanings, understandings, and images (Tulving 1972). Semantic memory theory posits that knowledge networks are formed by creating directed links between related concepts. Some researchers have proposed that networks are structured hierarchically with broad concept categories being divided into more specific sub-categories (Collins and Quillian 1970), while other researchers have rejected this assumption (e.g., Ruiz-Primo 2000). Nevertheless, interconnectedness within the structure is an important network characteristic, since it increases one's ability to access concepts (Turns et al. 2000) and is a key feature that differentiates expert and novice knowledge frameworks (Ruiz-Primo 2000). Since cmaps mimic the structure of internal semantic networks, student-generated constructs may be used to infer a student's domain understanding.

2.3 Use as Assessment Tools

Cmaps are an alternative to traditional assessment tools for characterizing knowledge content and structure. One significant challenge in using cmaps as assessment tools is identification of a robust scoring method (Besterfield-Sacre et al. 2004). Several scoring methods, including the commonly-used traditional approach, have been summarized elsewhere (Watson et al. 2014).

The traditional method (Besterfield-Sacre et al. 2004) involves quantifying the number of components in each cmap. For instance, the number of concepts, the number of hierarchies and highest level of hierarchy, and the number of cross-links are used to determine sub-scores for knowledge breadth, depth, and connectedness, respectively (Table 1). Some authors advocate for sub-scores being condensed into one metric using weightings for component sub-scores. For instance, Novak and Gowin (1998) propose that each proposition and example should receive 1 point, each level of hierarchy should receive 5 points, and each cross-link should receive 10 points. Alternatively, Bayram (1995) assigned one point for each proposition and cross-link, while each hierarchy was multiplied by its level (e.g., 2 points for a hierarchy with two levels). Novak and Gowin (1998) and Bayram (1995) each calculate the overall cmap score as the sum of weighted points. In contrast, Markham et al. (1994) argue that component sub-scores are more valuable when analyzed independently. Nevertheless, component-level scoring can provide an objective method for quantitatively scoring cmaps.

Table 1 Rubric for traditional cmap scoring approach (Besterfield-Sacre et al. 2004)

Knowledge breadth	Knowledge depth	Knowledge connectedness
• The number of concepts included in the cmap is counted • No consideration given to quality or correctness of concepts	• The number of hierarchies included in the cmap is counted • The highest level of hierarchy is recorded	• The number of cross-links, which create propositions using concepts from different hierarchies, is counted • No consideration given to quality or correctness of cross-links

2.4 Applications in Sustainability Education

Several authors have used cmaps to characterize student sustainability understanding. Segalàs et al. (2008) investigated the effectiveness of six sustainability courses by comparing student cmaps before and after course delivery (Segalàs et al. 2008). Evaluation of cmaps revealed that complexity of cmaps resulting from courses employing constructive and community-based pedagogies was higher than from courses using more traditional instructional strategies (Segalàs et al. 2010). Similarly, Borrego et al. (2009) analyzed cmaps before and after a green engineering course using the holistic scoring method and found that the comprehensiveness, correctness, and organization of student maps increased after course delivery. Use of cmaps as assessment tools were also used to monitor student learning in capstone engineering courses (Watson et al. 2013). Thus, cmaps are beginning to be applied as tools for studying student sustainability knowledge.

3 Research Methods

3.1 Student Populations

Student sustainability knowledge was investigated at GT and JMU for students beginning their capstone design experiences. Seniors (4th year) in Civil and Environmental Engineering (CEE) at GT were recruited to construct cmaps documenting their sustainability knowledge. GT has taken a largely vertical integration approach to incorporating sustainability into the CEE curricula, with primary exposure occurring in a required junior-level (3rd year) systems course. For comparison, juniors enrolled in an interdisciplinary engineering program at JMU were also invited to construct sustainability cmaps. JMU has embraced a horizontal integration approach, as sustainability is an integral part of their entire curriculum from the freshman introductory course through the two-year capstone design experience. Most of the students in the JMU sample had not yet completed the two required senior-level sustainability science and lifecycle courses. Additional information on the curricula at GT (Watson et al. 2013) and JMU (Nagel et al. 2013; Pierrakos et al. 2008) are available.

3.2 Concept Mapping Assessment

The concept mapping assessment was conducted as outlined by Watson et al. (2014). Before completion of the sustainability concept mapping task, students participated in a brief concept mapping workshop to familiarize them with the construction of cmaps using CmapTools. Afterward, students were asked to create a concept map on the focus question: "What is sustainability?". Students were provided with up to three hours to complete their cmaps at GT, although most students were finished after thirty minutes. Students at JMU were provided with approximately thirty minutes to construct cmaps and all students finished within that timeframe.

3.3 Concept Map Analysis

Three judges were trained to use the traditional scoring method. Judges practiced scoring approximately 10 cmaps and discrepancies were discussed to promote future interrater reliability. Krippendorf's alphas for the training sessions were at least 0.67, which is appropriate for exploratory research (Krippendorff 2004). Further details on scoring calibration are available (Watson et al. 2014).

After scoring calibration, judges scored cmaps generated by JMU and GT students. Two judges scored each submission. First, judges individually quantified traditional scoring parameters. Inter-rater reliability, based on Krippendorff's alpha, was deemed to be acceptable (Krippendorff 2004) for all parameters (Table 2). Discrepancies in scores were discussed by the judges and consensus scores were used in all subsequent statistical analyses. Since data was determined to be non-normal (Shapiro-Wilk test), non-parametric Kruskal-Wallis tests were used to compare cmap scores based on institution. Significant relationships were identified for $p \leq 0.05$.

In order to compare the students' depth and breadth of sustainability knowledge, the content of cmaps was analyzed using word clouds, a strategy used by others for content analysis (Huynh et al. 2013). Concepts were extracted from the cmaps and used to generate word clouds with Wordle™. For consistency, the extracted concepts were not modified in any way (e.g., spelling could have been corrected). Further, default settings were used for language (remove numbers, remove common English words, leave words as spelled) and a horizontal layout was selected for both GT and JMU word clouds. For each word cloud, the frequency of concepts was tallied using the show count function. Given the large number of words, only concepts with a count greater than five were recorded. Concepts were then coded in accordance with a four pillar conceptualization of sustainable engineering—economic, environmental,

Table 2 Inter-rater reliability for Cmap scoring

Parameter	Krippendorff's alpha	
	Vertical integration (GT)	Horizontal integration (JMU)
Number of concepts (NC)	0.999	0.999
Number of hierarchies (NH)	0.999	0.973
Highest hierarchy (HH)	0.980	0.845
Number of cross-links (NCL)	0.869	0.897

social, and technical pillars. Concepts that did not directly match one of the four categories or could easily be coded as more than one pillar were coded as “other”. The resultant word clouds and content themes are described in Sect. 4.2.

4 Results

A study was conducted to compare sustainability cmaps between student populations at institutions which initiated either horizontal (JMU) or vertical (GT) integration of sustainability content into undergraduate curricula. The structure of cmaps was analyzed using the traditional scoring approach, while cmap content was examined using word clouds.

4.1 Traditional Cmap Scores

The structure of JMU students’ cmaps was more complex than those constructed by GT students (Table 3). Specifically, knowledge breadth was greater for JMU students than for GT students, given that the median number of concepts was 23 and 12, respectively ($p \leq 0.001$). Similarly, JMU students demonstrated more substantial knowledge depth than did GT students, with the median highest hierarchy being 4 versus 3 for each group, respectively ($p \leq 0.001$). Even still, JMU students prepared cmaps that were significantly more interrelated in structure than those submitted by GT students, with the median number of cross-links recorded as 4 versus 2, respectively. Due to the broader, deeper, more inter-related structure of JMU cmaps, overall scores were nearly twice as high (*Med* = 120.98) as for GT cmaps (*Med* = 61.35) ($p \leq 0.001$).

Table 3 Comparison of traditional scores across institutions

Parameter	Horizontal integration (JMU) (n = 86)		Vertical integration (GT) (n = 93)		Kruskal-Wallis test	
	Mean rank	Median	Mean rank	Median	$\chi^2(1)$	p
Number of concepts	125.03	23	57.61	12	75.81	0.000***
Number of hierarchies	92.10	4	88.05	3	0.28	0.597***
Highest hierarchy	114.14	4	67.68	3	37.73	0.000***
Number of cross-links	107.80	4	73.54	2	19.92	0.000***
Total score	120.98	91.5	61.35	43.0	59.17	0.000***

4.2 Content Analysis

Visual and thematic analysis of the word clouds allowed qualitative comparisons of depth and breadth of content coverage (Figs. 1 and 2; Table 4). Visually, the word

Fig. 1 GT sustainability world cloud

Fig. 2 JMU sustainability word cloud

Table 4 Comparison of concept map content from word clouds

Dimension	Vertical integration (GT)			Horizontal integration (JMU)		
	#Distinct concepts	Frequency (count)	Frequency (% of total)	#Distinct concepts	Frequency (count)	Frequency (% of total)
Economic	8	99	11	6	119	12
Environmental	21	370	40	16	312	30
Other	13	166	18	17	175	17
Social	13	151	17	21	284	27
Technical	13	129	14	10	144	14

clouds illustrate a clear environmental theme in the GT concept maps, which is often expected of students' sustainability knowledge (e.g., Segalàs et al. 2010). JMU concept maps showed a more balanced conceptualization with greater emphasis on the social pillar.

Table 4 shows that GT students demonstrated unbalanced representations of sustainability with environmental concepts dominating the other categories in terms of both diversity of concepts and frequency. From JMU concept maps, the social dimension demonstrated the greatest diversity of terms amongst the four categories, although environmental concepts were included with greater frequency (30 vs. 27 % for social). For both GT and JMU concept maps, the economic dimension was least well represented, both in terms of number of concepts within that category (8 and 6 respectively) and frequency (11 and 12 % respectively).

5 Discussion

5.1 Structure of Student Knowledge

Examining cmap structure clearly shows that students completing a curriculum with horizontal integration of sustainability content displayed broader, deeper, and more inter-connected sustainability knowledge, as compared to students enrolled in a vertically-integrated curriculum. This finding aligns with previous publications that underscore the importance of blending sustainability content with existing engineering coursework (Peet and Mulder 2004; Ceulemans and De Prins 2010). Examining knowledge breadth, a group of sustainability experts was reported to include an average of 19.8 concepts in their sustainability cmaps (Coral 2009), as compared to medians of 12 and 23 for GT and JMU students, respectively (Table 3). Thus, JMU students demonstrated more expert-like knowledge breadth than GT students. Furthermore, the greater level of concept connectedness displayed by JMU students is especially significant, since connectedness of knowledge is known to increase student ability to access concepts and is a key feature that differentiates expert and novice knowledge frameworks (Turns et al. 2000; Ruiz-Primo 2000). Overall, data from the current and previous studies suggest that horizontal integration has a positive impact on students' sustainability knowledge networks.

5.2 Content of Student Knowledge

Examining word clouds suggests that horizontal integration of sustainability into undergraduate curricula may encourage development of more balanced sustainability knowledge frameworks, as compared to vertical integration. Notably, "environment/al" was frequently represented in all student cmaps, although students from JMU clearly included the term “social” more often than students from GT (Figs. 1 and 2). Further, JMU students distinguished between individual and community dimensions of the social pillar. Prior research on students’ conceptual understanding of sustainability has overwhelmingly suggested that students often emphasize the environmental dimension of sustainability, while largely neglecting social aspects (e.g., Watson et al. 2014). Interestingly, one study has proposed that social considerations, especially related to end-user safety and well-being, are often evident in student designs, even if cmaps demonstrate little knowledge of social sustainability (e.g., Watson et al. 2013). Authors cite that students may not recognize that many routine aspects of engineering design promote social sustainability, at least to some extent. Consequently, perhaps integration of sustainability content into the unique sequence of design courses at JMU contributed to students awareness of social aspects of sustainability. It is important to note that the majority of JMU students participated in a client-based sophomore design project and are exposed to identifying stakeholder needs and impacts over a project’s lifecycle during that course experience. The “equity” dimension of social sustainability remains a weak area for students’ conceptualizations and applications of sustainability knowledge, and the content of cmaps in this study did not indicate otherwise. Likewise, economic analysis could be further developed to enable appropriate and realistic trade-offs amongst the four dimensions. Nevertheless, the increased balance among sustainability dimensions demonstrated by JMU students is desirable, since promoting sustainability inherently requires an understanding of all inter-related dimensions (Davidson et al. 2007).

5.3 Limitations and Implications for Research

Several limitations are inherent in the design of this project. Foremost, only one institution exemplifying each integration strategy was investigated. Vertical and horizontal integration are two very broad strategies that can encompass a variety of educational interventions. For instance, a program with a different vertically-integrated sustainability course (e.g., more comprehensive, more active, emphasis on different topics) may have proved to be more or less effective than the GT case. Consequently, investigation of integration strategies across multiple institutions may provide more generalizable results.

Second, there were several differences between student groups in the current study that could have contributed to differences in cmap scores, beyond just exposure to different integration strategies. Specifically, students were in different stages of their academic careers (juniors at JMU and seniors at GT) and engaged in a non-discipline specific curriculum at JMU versus a CEE curriculum at GT. However, student academic development may have actually been more similar than expected, since both groups were entering their first comprehensive, independent design experience. Even still, junior JMU students demonstrated more comprehensive sustainability knowledge than senior GT students, despite completing fewer semesters of the prescribed curriculum. Despite these differences in student samples, it is expected that significant differences in student sustainability knowledge demonstrated in this study is due to inherent differences in the curricula of the two institutions. The methods and results of this study do not address how students' conceptualizations of sustainability translate to performance on the capstone design projects, which is an area for future research.

6 Conclusions

A study was conducted to evaluate the efficacy of horizontal versus vertical integration of sustainability content into undergraduate engineering curricula. Cmaps were collected from students in a horizontally-integrated, interdisciplinary engineering program, as well as a vertically-integrated, CEE program. The structure of student knowledge was analyzed using the traditional scoring approach, while specific content was evaluated using word clouds. The following conclusions were made based on the results:

1. Horizontal integration resulted in student cmaps with greater breadth, depth, and inter-connectedness, as compared to vertical integration.
2. Students participating in a horizontally-integrated curriculum demonstrated more balanced understanding of sustainability, including the social dimension, as compared to students from a vertically-integrated program. To some extent, economic sustainability was a weakness of both programs.

Results from this study align with previously-published suggestions that horizontal integration of sustainability is important for student development. If sustainability is only taught in isolation from core engineering fundamentals, then it is possible that students will view sustainability as an afterthought during the design process. Given that current undergraduate students will soon be responsible for local and global development projects that will impact both humans and the environment, it is important to equip them with the knowledge and skills necessary to engage in sustainable design.

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A New Program in Sustainable Engineering: A Platform for Integrating Research and Service into the Classroom Through Global Engagement

Rachel A. Brennan and David R. Riley

Abstract

Currently 2.5 billion people, over one third of the Earth's population, are affected by water scarcity and are without sanitation. The majority of humanity is concentrated in coastal communities: approximately half of the world's population lives within 200 km of a coast. In many developing countries, raw wastewater is discharged into coastal waters without being treated, in the belief that these discharges do not significantly affect the environment. In reality, these contaminants not only threaten human health, but also often contribute to the loss of marine animals which local peoples often rely on for food and income. In the future, continuing population growth and economic development will increase the demand for water and the severity of pollution. There is a clear and overwhelming need for sanitation and water purification in developing coastal communities, but it is not afforded by conventional, energy-intensive and chemically-intensive water treatment or fossil-fuel-based energy systems. In high-poverty equatorial coasts, the stable temperatures, steady winds, and predictable solar input greatly facilitate sustainable practices for water treatment and energy production. We have recently begun to develop a new cross-disciplinary program in Sustainable Engineering at Penn State that empowers coastal communities in the Caribbean to improve their quality of life and protect their natural resources. In this program, senior-level engineering courses train undergraduate and graduate students to design and deploy

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ecologically-designed wastewater treatment plants with renewable energy systems in collaboration with faculty-led research teams and community participants. These courses are strategically designed to be training and recruitment tools to help prepare the local student chapter of Engineers Without Borders (EWB) for the project, and to provide students at all levels with challenging, immersive, hand-on experiences that augment their research and education in sustainability. This work is significant because it is one of the first international, multi-disciplinary programs in Sustainable Engineering in North America, and utilizes a student outreach organization (EWB) to mobilize the resulting efforts to engage developing coastal communities with the assistance of practicing engineers. The longevity of this program is supported through cross-disciplinary research, course development, and mentoring of EWB projects containing interdisciplinary, multi-component systems. Future partnerships in the areas of wind energy, coral reef resilience, food systems science, economic development, and eco-tourism are planned to further enhance the program.

Keywords

Sustainable engineering · Ecological wastewater treatment · Engineers without borders

1 Introduction

Currently 2.5 billion people, over one third of the Earth's population, are affected by water scarcity and are without sanitation. The majority of humanity is concentrated in coastal communities: approximately half of the world's population lives within 200 km of a coast. In many developing countries, raw wastewater is discharged into coastal waters without being treated, in the belief that these discharges do not significantly affect the environment. In reality, these contaminants not only threaten human health, but also often contribute to the loss of marine animals which local peoples often rely on for food and income. In the future, continuing population growth and economic development will increase the demand for water and the severity of pollution. There is a clear and overwhelming need for sanitation and water purification in developing coastal communities, but it is not afforded by conventional, energy-intensive and chemically-intensive water treatment or fossil-fuel-based energy systems. In high-poverty equatorial coasts, the stable temperatures, steady winds, and predictable solar input greatly facilitate sustainable practices for water treatment and energy production. These issues show a present and growing need for engineers trained in a broad suite of sustainable water treatment and renewable energy technologies, and with an ability to work in interdisciplinary teams in complex international settings.

We have recently begun to develop a multi-disciplinary, collaborative, international initiative in Sustainable Engineering to train undergraduate and graduate students to meet the current and emerging global needs of society, while enabling research by faculty on topics with broad technical and scientific impact in the vital area of the water-energy nexus. This goal is directly in line with the mission of our college, which is to "nurture and train world-class socially-aware, globally-connected, diverse engineers, educators and researchers….to develop innovative solutions to the world's most pressing challenges through transformational interdisciplinary research". The program also aligns and supports several of the institutional thrust areas of our college, including: (1) **Innovative Engineering Education** through the provision of global engineering education and experiences; and (2) **Sustainable Water-Energy-Food Nexus** through water resources sustainability, management, treatment, and energy consumption.

Indeed, overcoming the crisis in water and sanitation has been identified by the United Nations as "one of the greatest human development challenges of the early 21st century" (United Nations Development Programme 2006). The timeliness of this program is also evident in that it addresses four of the Grand Engineering Challenges for the 21st Century, namely: providing access to clean water; managing the nitrogen cycle; making solar energy affordable; and restoring and improving urban infrastructure (National Academy of Engineering 2008). To meet these challenges, collaborative relationships between faculty, students, and professional engineers in a variety of disciplines are necessary to lead innovative research and bring it to practice.

The integrated program described herein is the first for our college, and enhances existing collaborative efforts between faculty in several engineering departments, as well as creates opportunities for robust collaboration with others across the University. This work is significant because it is one of the first in the country to develop an international, multi-disciplinary program in Sustainable Engineering, while utilizing a student outreach organization (Engineers without Borders, EWB) to mobilize the resulting efforts to engage developing coastal communities with the assistance of practicing engineers. To meet these goals, we aim to integrate our research programs, courses, and the local student chapter of EWB. This paper describes progress in the first year of the program with the initiation of a sustainable water treatment project in the island community of Roatán, Honduras, through the development of a new course in Ecological Engineering.

2 Project Location

Located 40 miles off the north coast of mainland Honduras, the island of Roatán is home to a diverse set of ecosystems, socio-economic conditions, and immersive learning opportunities. The key facets which justify the launch of this initiative in Roatán include:

- **Favorable conditions for success**: Isolated from complex economics of larger countries, island communities possess "micro grids" of energy, water, and economic infrastructure, and offer excellent opportunities to engage in the deployment of sustainable and resilient technologies;
- **Unique setting for sustainable technology deployment**: The warm temperatures, coastal winds, and solar availability on Roatán, coupled with high energy costs, offers a perfect setting for the proposed technologies. The local community is politically stable, English speaking, close in proximity to the US, and economically and socially diverse—factors which enable rich and fulfilling contributions by student teams;
- **Enhances and strengthens multiple existing and diverse activities**: The program introduces a global engineering component into existing courses and research infrastructure in sustainable energy and water technologies that can serve as a foundation for the engagement of additional disciplines in the future.

In future years, this initiative is expected to expand to enhance an existing university program in Mona, Jamaica. As the initiative gains momentum, we envision even broader partnerships with faculty, non-profit organizations, and industry partners working in other coastal communities to pursue further sustainable engineering applications that address critical energy and water challenges.

3 Course Integration

As part of our new program in Sustainable Engineering, a senior-level, elective course in Ecological Engineering was offered for the first time in fall 2014 with a focus on empowering real coastal communities in the Caribbean to improve their quality of life and protect their natural resources. In this course, undergraduate and graduate students worked in multidisciplinary teams to design ecological wastewater treatment systems with an emphasis on producing beneficial byproducts of food, income, and/or education for the targeted community. The team project was strategically designed as a training and recruitment tool to help identify and prepare student leaders of Engineers Without Borders (EWB) for the project.

The class of 23 undergraduate and graduate students was divided into four teams based on their background and interests, and half of them were tasked with designing a sustainable solution for restoring and protecting the Pensacola estuary on the island of Roatán, Honduras, while the other half were tasked with a similar project for a community in Jamaica. In Roatán, wastewater from individual homes is currently being dumped into the Pensacola estuary, where it flows untreated out to sea damaging the nearby coral reef. The instructor of the course (lead author of this paper), traveled to Roatán with one graduate student from her research group to survey the site and collect water quality data to support the project. Multidisciplinary teams of students then worked to design a passive, wetland-based, wastewater treatment system to remediate the area. They took advantage of proven ecological technologies and natural tidal forces to remove contaminants from the wastewater so that surrounding habitats are not further damaged.

The goals of this student design project were to: (1) reduce contaminant concentrations within the estuary to Honduran regulations; (2) provide beneficial byproducts from within the treatment system; and (3) educate the local community on the importance of treating wastewater and protecting their environment.

After completing a Site Investigation and evaluating potential technologies, the students formalized their strategies through a comprehensive Design Plan. Both Roatán teams converged on similar engineering solutions for treating the wastewater, including the construction of a septic tank, horizontal subsurface flow (HSSF) wetland, free water surface (FWS) wetland, and a stormwater channel. The two teams differed, however, in their development of value added projects for the community. The leading team proposed a variety of features for the site, including a bridge made out of locally recycled materials to traverse the estuary, an educational sign to describe the water treatment system, and an oyster aquaculture system at the mouth of the estuary to provide additional water quality polishing, as well as a protein and income source for the community. This leading design now serves as a template for EWB to remediate this and other estuaries with similar detrimental impacts in Roatán.

4 Assessment

In an optional online survey conducted at the end of the semester, students in the new Ecological Engineering class were asked to reflect on their learning experiences in the course compared to other courses taken throughout their time at university. The survey consisted of 50 randomized multiple choice questions, provided in both positive and negative voice, with five possible answers to select from: strongly disagree (SD), disagree (D), neutral (N), agree (A), and strongly agree (SA). Survey participants (n = 21 out of 23 enrolled) overwhelmingly liked the real-world application of the design project (76 % SA; 24 % A), felt that it enhanced their fundamental technical skills (29 % SA; 67 % A), inspired them to learn more than if it had been a theoretical problem (38 % SA; 62 % A), and believed that it was a better learning experience than a typical classroom activity (45 % SA; 50 % A). Working with a team made students more effective collaborators (14 % SA; 71 % A), contributed to their learning in the course (19 % SA; 48 % A), and enhanced their leadership skills (19 % SA; 62 % A). The international aspect of the project enhanced student learning (19 % SA; 62 % A), encouraged them to think about social impacts while creating engineering solutions (38 % SA; 52 % A), and inspired them to deliver a quality design for the community (33 % SA; 62 % A).

5 Significance

This work is significant because it is one of the first international, multi-disciplinary programs in Sustainable Engineering at our university to leverage a student outreach organization (EWB) to engage both developing communities and fundamental research activities. The program provides students with challenging, hand-on experiences that augment their research and education in sustainability. The program also provides an immersive learning experience including cultural, technological, collaborative, and leadership components, and demonstrates a scalable approach to the globalization of existing courses and research initiatives. The very nature of this project helps cultivate the characteristics of a World-Class Engineer, which requires that students be: solidly grounded; technically broad; globally engaged; ethical; innovative; excellent collaborators; and visionary leaders.

In future semesters, the Ecological Engineering course will include optional travel to Roatán for students to help build the water treatment systems that they collaboratively designed with oversight by practicing engineers. The longevity of this program will be supported by a team of faculty committed to cross-disciplinary research, course development, and mentoring of EWB projects containing inter-disciplinary, multi-component systems.

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Seeing Beyond Silos: Transdisciplinary Approaches to Education as a Means of Addressing Sustainability Issues

Edmond P. Byrne and Gerard Mullally

Abstract

Sustainability is a normative topic framed by disciplinary perspectives. This can be problematic as the tools that are used and applied to meta-problems and 'grand challenges' associated with societal (un)sustainability, and which may result in proposed 'sustainable solutions', are framed through the lens of the 'object world' disciplinarian. Traditional engineering education and practice has tended to frame problems in narrow techno-economic terms, often neglecting broader social, environmental, ethical and political issues; or what might be termed the social complexities of problems (Bucciarelli 2008; Mulder et al. 2012). This reductionist approach has sought to close down risk and uncertainty through deterministic modelling and design, resulting in frameworks/models which provide an air of misplaced confidence but which are incapable of accounting for (or recognising) unknowability, and can thus lead to behaviour which ironically, results in increased fragility, rather than promoting increased robustness or resilience. Researchers in the social sciences and humanities are inherently more comfortable and adept with dealing with complexity, uncertainty and unknowability. This paper is posited in this context, whereby chemical engineering and sociology students taking respective disciplinary sustainability/environmental modules were brought together to work on a common assignment dealing with some aspect of sustainability. This paper reflects on this collaborative exercise, including the experiences of the students themselves, alongside some challenges and successes. It concludes that

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transdisciplinary approaches to learning are not just desirable in addressing wicked and meta-problems when addressing challenges of (un)sustainability, but represent a *sine qua non* for building the social capacity in confronting these issues.

Keywords
Education · Transdisciplinarity · Complexity · Sociology · Engineering

1 Introduction

> Literary intellectuals at one pole—at the other scientists, between the two a gulf of mutual incomprehension—sometimes (particularly among the young) hostility and dislike, but most of all lack of understanding. They have a curious distorted image of each other. Their attitudes are so different that, even on the level of emotion, they can't find much common ground. It is all destructive. Much of it rests on misinterpretations which are dangerous.
> (Snow 1965)

It has been widely contended that any successful address of the 'grand challenges' that are posed by contemporary and modern society associated with its unsustainability, not only needs a global perspective, but a holistic non-reductive type of knowledge that can only emerge through a transdisciplinary approach (Max-Neef 2005; Hirsch et al. 2006; Nicolescu 2012; Lang et al. 2012). The 'object world' view of the disciplinarian expert (Bucciarelli 2008), built upon the dominant Cartesian paradigm of modernity not only represents the root causes of an unsustainable societal construct, but is also, by implication, wholly inadequate in addressing either the symptoms (e.g. climate change, and crises around energy, food, water, economic inequality and financial) or the root causes of these problems.

Moreover, the siloisation of the academy—whereby universities, as drivers of knowledge and understanding, merely seek to learn 'more and more about less and less' amid increasingly specialized and ghettoised silos of knowledge, only serves to further embed such a paradigm of reduction and separation (Morin 2008), resulting in an educated global population (and elite) who are neither able to either fully comprehend nor adequately deal with emerging crises. The result is engineers who are incapable of seeing the broader ethical context of their work (nor of seeing the rationale for developing such an awareness), including the absence of envisioning a normative or political dimension to their work. To the engineer who holds this limited self-perception, acting as a technological 'gun for hire' therefore, every object is a potential nail to this hammer, and every problem can thus potentially be reduced to a closed problem with a technological 'solution'.

Meanwhile as engineers get on with the business of (literally) constructing society, as ordained by their business or political masters, social scientists broadly content themselves with exploring the nature of reality, as (co-)constructed and mediated by humans, the interactions between human agents themselves, and at times between humans and the rest of their environment. The tools of their trade enable them to theorize, critique, deconstruct and reconstruct at will. But while they understand the recursive nature of iterative complex systems, these tools are not typically applied to the real techno-economic society that engineers and scientists help co-construct, and which is overseen by economists, policy makers and politicians. Indeed the dominant societal paradigm of reduction and separation is largely ambivalent, if not antagonistic to either the ideas or implications of a paradigm of emergent complexity. Meanwhile disciplinary silos remain firmly in situ while all only see value from within their own disciplinary silos. The upshot is that the potential for meaningful progress in the wake of emerging crises through transdisciplinary integration and insight is lost among practitioners who not only cannot speak the same language, but who in many cases are incapable of even recognising the existence of any other. This of course represents a very broad brush characterisation and simplification of the nature of the problem, but we would argue that it represents a useful and necessary caricature to help highlight the problem and ultimately provoke change. 'We need a kind of thinking that relinks that which is disjointed and compartmentalized, that respects diversity as it recognises unity, and that tries to discern interdependencies' (Morin 1999; cited in Hofkirchner 2009, p. 7).

2 Background and Rationale

Given the above assessment, and the common recognition that the only rational and intellectually honest way to address emerging societal crises associated with unsustainability was through transdisciplinary approaches, the authors concluded that this could largely only be meaningfully progressed through practical intervention. A key intervention point presents at the stage of professional and formative education. If C.P. Snow's chasm between the humanities and the sciences can ever hope to be breached, then contact at the critical stage of educational formation may be necessary whereby disciplinarians can at close quarters both see and appreciate the 'object world' views of the other and hence hopefully, find the space and opportunities to develop useful emergent 'complex thought' (Morin 2008) around issues of sustainability. One cannot reasonably hope to expect disciplinary practitioners, educated exclusively in hermitically sealed silos within a 'multiversity' setting, to spontaneously develop the required understandings, skills and competences to work productively together in tackling larger wicked problems at some unspecified later stage of their respective careers or lives if they are not exposed to each other during the formative years of disciplinary education. There is also a very powerful subliminal message being spun when the two groups come together; the conferred legitimacy that two academics, working together in trust, can confer on transdisciplinary work, undertaken within an ethos of openness, vulnerability and absolute good faith, sends a very strong message of affirmation to students and future graduates. Not only is working with sociology/humanities or engineering/science graduates a useful and interesting means to addressing complex and difficult issues, it is, the implicit message tells them, an absolute requirement. The other must not only be accepted, but necessarily embraced.

Of course, in order to get to this point in the first place, the two academics needed to build up trust in each other in addition to having shared understanding. While both had worked across the ‘divide’ with others in the past, the development of such trust, to enable a successful collaboration of this nature, could only emerge through a number of earlier interactions. For example, the authors worked closely together in organising a ‘Sustainability and Modern Society Seminar Series’ at their local university (UCC 2012), and together with another colleague, geographer Colin Sage, developed a transdisciplinary research initiative entitled ‘Sustainability in Society’, from 2011 (UCC 2011). The latter resulted in a transdisciplinary conference (‘Trans-disciplinary conversations on transitions to sustainability’) in 2013 (UCC 2013), and emerging from that, a subsequent book (Byrne et al. 2016). The authors have also collaborated in transdisciplinary related research leading to a number of publications (e.g. Byrne et al. 2013; Mullally and Byrne 2014; Byrne and Mullally 2014).

This provided both a context and platform from which to develop a joint collaborative exercise between students of a chemical engineering module (PE3011 Sustainability in Process Engineering) and a sociology module (SC3029 Sociology of the Environment) initially on a pilot basis, from academic year 2013-2014. The rest of this paper will provide details as well as reflections on this exercise.

3 Assignment Description

Students from two modules which ran concurrently were brought together for a joint assignment during 2014 by the authors of this paper. The modules involved were PE3011 Sustainability in Process Engineering (taken by students in the third year of their four year Bachelor of Engineering degree, as well as a number of visiting students, mainly from Germany and Brazil) and a sociology module SC3029 Sociology of the Environment (taken by third year students of the Bachelor of Arts degree, majoring in Sociology and other humanities subjects, including a number of visiting students, mainly from USA). While the devised assignment was compulsory for the engineering students and comprised 15 % of the assessment grade for the assignment, it represented a voluntary component of the module for the sociology students. Thus there was a smaller take-up among the SC3029 students, who were in a minority.

Given the potential for wide divergence and framings among the respective cohorts, it was decided that the assignment would be as general as possible. The initial and primary aim of the project was to get the engineering students and the sociology students to come together and to engage around a common theme of sustainability. It was thus decided to divide the joint class into groups, each comprising of three or four students, mixed between engineering and sociology students and also between local and international students. The class as a whole included 27 from PE3011 and 7 from SC3029 from which nine groups were formed.

3.1 Assignment Content

Given the diverse nature of the students involved and the aims of the assignment, the specification was purposefully left quite open ended. Essentially groups were asked to pick any aspect in relation to ‘sustainability’ and then to research, reflect upon and engage with it, both collectively and individually. The ultimate hope was that through a creative fusion of disciplinary ‘object world’ views, approached in an open spirit of enquiry, that both a broader context for some chosen aspect(s) of sustainability might emerge (driven by the sociologists perhaps?), alongside also some pragmatic pointers for intervention (driven by the engineers?). The potential also existed for a ‘car crash’ situation where conflicting frames and ‘object worlds’ would lead only to confusion and antagonism. However, we were willing to accept this as an outcome of this piece of ‘low stakes’ experimental classroom research. Nothing ventured, nothing gained! The following therefore represents part of the assignment specification given to students:

> Any aspect may be chosen by the group that relates to ‘sustainability’ to research and then reflect upon. The group reflection is open ended and can be directed as you best see fit. For example you might like to consider what this aspect or topic means (to yourselves or to society), how it has the potential to change the way we/you do things, consider how it can or might be achieved, what are its potential consequences, difficulties or problematic issues, why or how it is so powerful a concept, and so on.

Output comprised two parts. The first part (attracting two thirds of the available marks) involved a short group presentation to peers and lecturers on the module on the chosen sustainability related topic/aspect, followed by a group discussion plus questions and answers. The second part (attracting the remaining one third) involved a 400–600 word personal reflection on the exercise, including how the student felt the trans-disciplinary nature of the assignment worked out (or didn’t) in terms of for example, the learning opportunities and challenges it presented.

The groups met formally once a week for five consecutive weeks ahead of the presentations, with the lecturers present for feedback on their work. To get some ideas flowing and to incorporate a degree of commonality (as each of the groups were concurrently taking their perspective modules separately), a video was shown over the first two weeks. The video focussed on conceptions of progress, whereby it reflected on (un)sustainability in our contemporary world, in each of economic, social and ecological domains.

4 Student Output

The mixed groups worked very well together, with no apparent ‘car crash’ situations emerging. A wide range of topics were chosen to analyse, though three groups chose to look at issues around consumption. Meanwhile, just one group chose a topic which could clearly be related to technology, perhaps reflecting the nature of the groups, though of course all could have both technological and engineering implications. Table 1 displays the topics chosen by the respective groups.

4.1 Group Presentations

The group presentations were the first time that the lecturers saw how or to what extent the project succeeded in terms of the students from disparate backgrounds working together to produce authentic, emergent and novel ideas and proposals. By and large, it was a great success: each of the groups provided well researched, thoughtful and thought provoking presentations which displayed a strong level of engagement. Lively discussion followed the presentations among the presenters and the lecturers and their peers. While there wasn’t always a coherent narrative, or in a few cases an altogether consistent one, it was clear that the students engaged very well and in good faith, particularly given their different backgrounds. This was reflected in some of the lecturers’ comments on the grading sheets which included ones such as ‘*Interesting presentation—some good points though not always perhaps consistent’* to *‘Interesting take on food though apparently opposing views. Lacked any overview framework to map out perspectives*.’ Other presentations did display more coherence however, and attracted comments such as ‘*A nice angle on Fairtrade chocolate. Nice analysis/critique. Coherent and well presented.*’ All seemed to enjoy the experience, though the sociologists generally appeared less confident at the thought of presentation by Powerpoint (the ubiquitous mode

Table 1 Groups and topics chosen

Group	Chosen ‘sustainability’ related topic
A	Globalisation versus localisation
B	Consumerism—products, resources, environmental and social
C	Chocolate bars and sustainable consumption
D	Habits and their meaning for sustainable development
E	Consumerism
F	Biomimicry
G	Unforeseen and unintended consequences of sustainable development
H	Sustainability in food consumption
I	Sustainability and Ethics

chosen) than the engineers, they being more comfortable with text and verbal expression than the more visual (graphic and diagram) oriented engineers.

4.2 Individual Reflective Reports

The individual reflective reports provided students with an opportunity to reflect on the assignment. It thus provided some excellent insights on how the students engaged with the topic and each other. It also offered students the opportunity to elucidate on personal perspectives to a greater extent than was possible or evident in the group presentation. The result of this was twofold: (1) It provided evidence of some strong student engagement and learning during the assignment, producing some valuable insights and enhanced self-awareness, and (2) it showed that the students found the opportunity to engage with students of other disciplines to be an overwhelmingly positive and intellectually stimulating and rewarding experience. This was reiterated by the lack of any negative comments. A selection of relevant comments from the reflective reports demonstrates this (Table 2).

5 Student Feedback

Formal anonymous student feedback was also elicited on the assignment itself. Students were invited to respond to five questions (outlined below) which related to the learning outcomes of the PE3011 module as a whole and were asked to tick a respective box (Fig. 1). They were also asked some follow on questions (Table 3). 29 responses were received (including 24 PE3011 students) representing an 83 % response rate.

The five questions asked (labelled 1–5 respectively in Fig. 1) were as follows: To what extent did this assignment help you:

1. develop new and deeper understandings you'd previously overlooked or help broaden your perspectives?
2. think more critically?
3. enhance your level of understanding around sustainability/sustainable development?
4. better prepare you for the nature of your future career?
5. Overall, how do you think the exercise worked?

Figure 1 displays the collated responses to these questions. Given the small numbers involved and the lack of significant differences between (PE3011 and SC3029) responses, no differentiation is made between disciplinary groups. It is clear that there is strong agreement with all of the questions posed, with over three quarters indicating an 'above average' or 'excellent' response, with the sole exception that a smaller majority of students were less likely to believe the exercise would help them to significantly better prepare for their future careers.

Table 2 Some student reflective report comments

Comment	Context
"I think that the disciplines of sociology and engineering work very well together and found the whole experience very educational. It helped to broaden my own ideas on sustainability and helped me look at the issue from angles that I would not have necessarily considered before."	Irish female sociology student (Group H)
"I thoroughly enjoyed the interaction and working process of the assignment with a completely different discipline to that of chemical engineering. While different viewpoints were certainly brought up, I found that both disciplines complimented one another nicely. I found this assignment a valuable experience to my future work career not only from a sustainability perspective, but also the perspective gained from working with sociologists, i.e. a different discipline."	Irish male engineering student (Group F)
"In my opinion there are two interesting issues about the concept of sustainable consumption that became apparent during the presentations. Firstly, many of the other groups who challenged the issue of (un-)sustainable consumption put a strong emphasis on its environmentally destructive implications. This critique of present-day consumption is very appropriate but it is somehow one-sided as it does not challenge the dilemma that rising levels of consumption fail to deliver an improved level of human well-being in western societies. I think that focusing on the environmental impacts and finding solutions to mitigate them, reflects to some extent the engineer's approach, whereas challenging the underlying concept as such, without the necessity to find an alternative, the sociologists approach."	German male sociology student (Group I)
The concept of social and collective consciousness, suggested by the sociology student in our group was a very insightful and original slant on our whole presentation. Coming from an engineering and technical background, I felt as though this was a completely innovative and fresh approach to addressing the problem of unsustainability. By creating a consciousness or awareness which is held by all of society we can really begin to recognise problems and in our case recognise the habits that are keeping us from developing a sustainable future.	Irish female engineering student (Group D)
"I want to leave college with a well-rounded education in my discipline of "Environmental Studies". That's why I was so excited to be a part of this assignment that blended the social and technical disciplinarians. It took two completely different brain types and perspectives and proved how valuable both were in tackling the world problems that we currently face. After our group had decided on the topic, the engineers returned with a detailed outline of the inner workings of the living machine and the economical advantages. I, on the other hand, had not even thought of looking into the details of the design but remained excited about the bigger theme of modeling technology after nature. It was automatically clear that we were coming at the assignment from completely different angles."	US female sociology (environmental studies major) student (Group F)
"When it came to writing this personal reflection based on the group project undertaken by PE3011 and SC3029 students, it struck me how much I had learned about the topic we had chosen and, more importantly, a different way of thinking. As engineers, we sometimes suffer from narrow mindedness; things are black or white, right or wrong. Working with the sociologists opened my eyes to the fact that this seemingly logical way of thinking is not always the best."	Irish male engineering student (Group A)

(continued)

Table 2 (continued)

Comment	Context
"The work that the three Engineering students produced gelled really well with the Sociology that I brought to the group. Initially I had not expected everyone in all the groups to get along very well, but both the Engineering and the Sociology students were all very welcoming to each other. Individually the two subjects are two quite different disciplines that I had originally thought would hold no value for one another, but I was quite surprised and happy also, to see that a lot of insight can be gained from blending the two subjects into one. In my own opinion, bringing an Engineering perspective to the Sociology of the Environment module, sheds a new and interesting light on the problems that society is confronted with, and offers a different catalogue of conceivable solutions to these problems."	Irish female sociology student (Group D)
"Although areas of conflict may be an issue in trans-disciplinary subjects, this was not the case in our group. We worked as a group and agreed on what problems arose in the consumption and possible solutions that could be implemented in the future."	Irish male eng. student (Group H)
"Overall I really enjoyed this assignment as it was different to others encountered throughout the year. I also enjoyed working with students from another discipline; I felt that it challenged me as well as encouraging me to take on a different perspective."	Irish female eng. student (Group C)
"I thoroughly enjoyed this assignment. It was a great way to hear perspectives from an engineering point of view and to brainstorm what we can do together to make the world a more sustainable place. I was in awe at how much I learned from the engineers about ways they could contribute to sustainability. As a social work major and an activist, my favorite part of this assignment was coming up with ideas as to how we can alter our society to combat these environmental and social injustices. I have realized that we need engineers on our side. Activists can educate people extensively; but if the products are not made well, then the process is futile. We need engineers to create products that last. How can we slow down consumerism if there is planned obsolescence? When products are designed to fail, we waste more materials and natural resources."	US female sociology (social work major) student (Group E)
"As a group we had slightly different views regarding the topic. The sociology student had done a lot of work in the field of globalisation and felt that future technologies would allow this regime to prosper. Contrary to this my two engineering colleagues and I felt that the overuse of natural resources and over consumption of goods and services, as a result of globalisation, was not sustainable. We accepted each other's points of view but ultimately we could not come to a decision as to which regime was the best. Working with people other than engineers, on an assignment, was a new experience for me and I got to see the topic from a different perspective. Working with a variety of people is a big part of engineering so I feel that this particular exercise will be beneficial in the future, when considering stakeholders in certain projects."	Irish male engineering student (Group A)

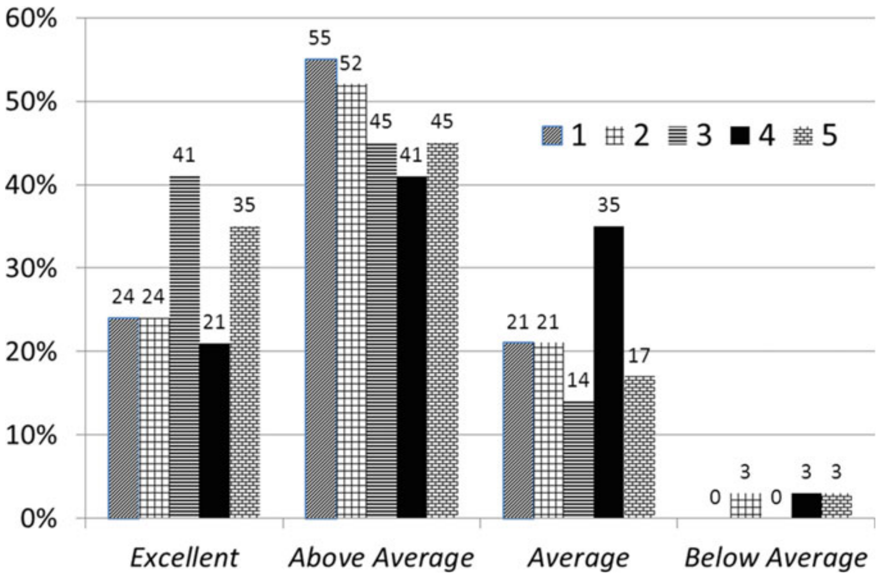

Fig. 1 Collated student feedback on transdisciplinary sustainability assignment

Table 3 Qualitative student feedback—selected comments

1. What are the key learning points *or* insights *or* rewarding aspects that you've taken away from undertaking this joint assignment?	Student background
"*It was an exercise for critical thinking, which was very enriching*."	PE3011
"*Learned that sustainability relates to everything, and should always be critically considered when undertaking any project*."	PE3011
"*I learned that group work from working within multiple disciplines, provides a much wider perspective on a given topic, and I found that this type of teamwork is very effective*".	PE3011
"*I really liked working with someone who came from a different faculty and has a different viewpoint on sustainability*." "*The best part of this assignment is how to work with people with different points of view*".	PE3011
"*I really enjoyed working with the engineers because they had great ideas about how to make products last. It was a good opportunity to hear their perspectives*."	SC3029
2. From a trans-disciplinary or international perspective or both, what aspect(s) of the assignment did you find most challenging?	Student background
"*Initially I found that working with sociology students was quite difficult as we came from very different backgrounds*."	PE3011
"*It was difficult to make a decision on what topic to cover as our viewpoints were a bit different*."	PE3011
"*There was so much to say and discuss. We had great fun discussing sustainability. Working in groups was beneficial because we got to teach each other*."	SC3029

6 Reflection

The assignment worked very well, in fact it exceeded our expectations in that there were no significant disciplinary ‘language’ problems, but on the contrary there was a willingness to learn and explore in a collaborative manner and in good faith by all parties. We would like to think that this was aided by a similar spirit on behalf of the authors, as we engaged on this experimental mission with an attitude of transdisciplinary openness, underpinned by trust built up over the past few years. This we would hope, engendered a sense of legitimacy among our respective students with respect to the assignment, helping to peel away any cynicism, or the potential for Snow’s ‘*hostility and dislike, but most of all lack of understanding*’ across a ‘*gulf of mutual incomprehension*’ (Snow 1965). Thus we will continue with and expand the exercise. For the 2014-15 iteration, the assignment was formalised as part of the assessment for SC3029, while it was also decided that the lecturers would mediate between the groups to help ensure that a range of different facets were chosen (other than consumption), or at that least different aspects could be chosen by different groups.

7 Conclusion

Despite CP Snow’s misgivings, there is significant cause for hope. The initial experience of this experimental exercise appears to demonstrate that, despite the rigorous siloisation of our educational system, that this is not a natural or insurmountable problem; where disciplinarians act in good faith and build up necessary trust, there is the possibility of having productive transdisciplinary ‘conversations’ around significant ‘grand challenges’ around the contemporary metaproblem of (un)sustainability. This is not to denigrate, nor to suggest a reduced need for disciplinary studies or perspectives; on the contrary, it demonstrates the value and necessity of disciplinary learning and ‘object worlds’ as pillars from which productive transdisciplinary knowledge can both emerge and be supported. The result can be a dynamic and energetic fusion of thought and action which is not just a nice optional extra, but is in fact nothing less than a necessary requirement if we are to hope to successfully address contemporary crises whose roots reside in unsustainability, while opening up the possibility of genuine human flourishing.

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Implementing a Collaboration Activity in Construction Engineering Education

Caroline M. Clevenger, Rodolfo Valdes-Vasquez and Moatassem Abdallah

Abstract

Collaboration skills are increasingly necessary in today's construction workforce. However, classroom activities that incorporate collaboration skills, ones involving interactive work among individuals towards a common goal, are underrepresented in many construction classes. This research documents and illuminates implementation of a team activity where groups of interdisciplinary students were asked to build a structure using the provided (paper and tape) resources with the objectives to create a structure that stands at least 4″ tall and supports as much weight (under textbook loading) as possible. Two rounds of activities were performed with differing levels of role definition provided to the students. Team interactions and performance were recorded, along with student self-assessments, and reporter observation. The implementation of this collaboration activity continues to provide valuable lessons, which informs the integration and assessment of collaboration activities in construction education.

Keywords

Construction education · Collaboration · Interdisciplinary · Cooperative learning

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1 Introduction: Collaboration in Construction Education

For purposes of this research, in the context of construction education, collaboration is the act of sharing or taking part in group decision-making processes concerned with equal participation and equitable power among a wide range of stakeholders from the owner and the professionals to the building users and representatives of the local community. Specifically, we adopt the definition of collaboration to be “an interactive process that engages two or more participants who work together to achieve outcomes they could not accomplish independently” (Salmons 2011). Collaborators should be prepared to listen to others, treat their ideas with respect and give one another equal decision-making power (Forsyth 2010). The goal of collaborative projects is to solve problems more effectively and produce better outcomes (Levi 2013). For instance, building delivery is not the result of one person’s contributions; rather, it is the result of the technical collective knowledge from different disciplines. To make the process easier, information communication technologies and virtual models can be used to provide a better understanding of the visualization of designs, models and communication among participants (Emmitt and Ruikar 2013). In the context of this study, the most pertinent communication level is the group because of the amount of information required in designing and executing construction projects.

A number of publications highlight the importance of effective teamwork in the construction industry (Krug 1997; Levi 2013). For instance, partnering was developed to address conflicting objectives among owners, contractors, designers, vendors, suppliers, and government agencies, all of which also increased litigation among these parties (Gransberg et al. 1999; Anvuur and Kumaraswamy 2007). Researchers report that the primary benefits of partnering appear unlikely to be realized extensively unless cultural changes in the industry occur, specifically manifested in the development, communication, and pursuit of common goals for projects (Dagenais 2007). The overall message is that design and construction activities need to move from a siloed to an integrated approach to improve performance and provide significant benefits for all project stakeholders.

Broadening the engineering and construction curricula by focusing on cooperative learning has been highlighted by several reform education agendas. Cooperative learning is based on the social interdependence theory that has been studied for more than five decades (Froyd et al. 2012), with the empirical and theoretical evidence supporting its efficacy (Felder et al. 1998; Springer et al. 1999; Prince 2004). In addition, more recent studies have begun to articulate the knowledge, skills, and habits of mind needed for students to perform satisfactorily in an interdependent world (NAE 2001, 2005; Duderstadt 2009). Need exists to develop new evidence-based teaching strategies that can be implemented in construction and engineering programs to facilitate and change student skills in collaborative enterprises (Borrego and Henderson 2014). In the absence of acquisition of such skills, future professionals are likely to be less than optimally prepared to contribute to the building of future infrastructure.

2 Background

Previously, the authors published findings comparing pilot implementation of two interventions intended to increase collaboration among construction students: one paper-based and one computer-based (Valdes-Vasquez and Clevenger 2015). High-level lessons learned included:

- Performance metrics for activity task performance should be integer-based to enable granular correlations about collaboration levels;
- In agreement with existing literature, diversity within teams appears to be correlated to the level of collaboration achieved;
- The learning environment (traditional paper-based versus computer-based) can impact the ability of teams to collaborate;
- Providing definition regarding individual roles and tasks during collaboration activities may or may not significantly impact team performance;
- Intra-experiment observation (a team reporter) is critical to studying collaborative activities.

3 Research Objective and Method

The objective of this research is to analyze an author developed in-class collaboration activity with distinct structured and unstructured implementations, analyze and compare results and evaluate potential impacts on students' collaboration skills as measured by metrics related to team performance and individual self-evaluation.

In this research, the authors chose to implement a paper-based collaboration activity with a group of students during fall 2014. Student participants were enrolled in an upper level course on sustainable design and construction. The course serves as an elective for upper level undergraduate and graduate students at the Colorado State University. Student enrollment consisted of twenty-seven students from construction management. The modified paper-based, as opposed to computer-based activity was selected for further implementation, due to ease of implementation since the selected objective of this follow-on study was to observe and analyze if structured (assigned) versus unstructured (unassigned) roles impacted team overall performance.

To perform the prescribed activity, facilitators provided the students with the following instructions:

4 Rules and Objective

Each group will build a structure with the materials provided the objective of which is to have the resulting structure stand and support as many textbooks as possible. Students may load the textbooks. The structure must hold the textbooks at least 4″ off the ground plane for at least 10 s. The structure must be free standing and cannot be taped to the floor, ceiling, or any other structures.

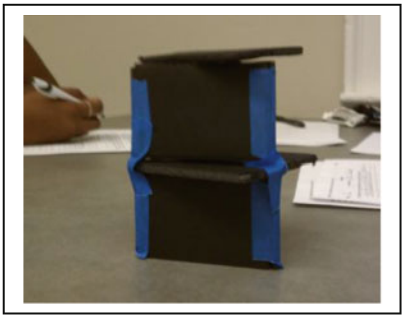
4.1 First Round (Assigned Roles)

1. Each member of the group will receive specific resources (papers, poster boards, tape) and will only be able to use their own resources when building the structure.
2. One student will not receive any resources, but may help to lead the project.
3. The group will have only 10 min to build a structure.
4. After the 10 min, the structure will be tested.
5. The group with the more resistant structure will be the winner (see rules above).
6. Students will complete feedback form#2.

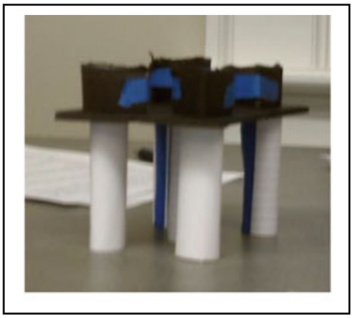
4.2 Second Round (no Assigned Roles)

1. The group will be provided with a bag of collective resources (papers, poster boards, tape).
2. The group will have only 10 min to build a structure.
3. After the 10 min, the structure will be tested.
4. The group with the more resistant structure will be the winner (see rules above).
5. Students will complete feedback form#2.

During the two rounds of the collaborative activity the authors collected team performance data as well as qualitative student self-assessment data using intra-experiment observation. Specifically, during these contests one student in each team was assigned to be a non-participatory "team reporter" to record observations about team members' interactions. Finally, after each round of the collaboration activity, all student participants completed a survey, and results were analyzed. The questions for these surveys were adapted and synthesized from existing surveys regarding collaboration (including Borden and Perkins 1999; Kane and Harms 2005; Ohland et al. 2012).



Sample A



Sample B

Fig. 1 Sample structure created by the students

5 Collaboration Activity Implementation

Five groups, each with four participants and one observer, completed both rounds of the collaboration activity. Figure 1 illustrates representative simple structures created by the student teams within ten minutes of receiving instructions. Figure 2 shows how students loaded these structures with textbooks to test their strength.

6 Results

Three types of data were collected after each round of the collaboration activity: quantitative team performance (how many books could the structure hold), team reporter observations, and individual participants' self-reported qualitative assessments. The following three sections summarize these data.

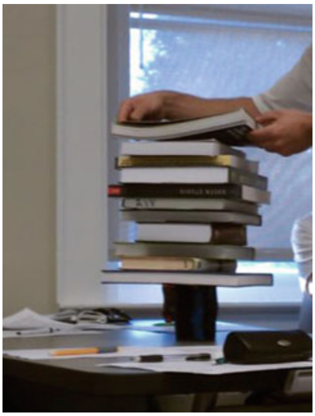


Fig. 2 Student team loading the team's structure to test its strength

Table 1 Team performance ranked according to demonstrated strength of structure under loading

Team	Round 1 structural loading achieved (no. of books supported)	Round 2 structural loading achieved (no. of books supported)
1	4	11
2	5	9
3	10	1[a]
4	5	0[b]

[a]Structure toppled while being loaded
[b]Structure collapsed

7 Team Performance

Table 1 ranks team performance (according to total books supported across both rounds) as assessed by loading each structure with textbooks one at a time by the student teams. This simple measure was used as a proxy for team performance relative to the stated objective of the activity.

While such a quantitative performance assessment metric (number of books) for the various teams was rather coarse, it proved interactive and informative. In fact, the authors noted that the act of loading the books on the structure, was, in itself, a potentially collaborative exercise- some teams involving numerous individuals as participants and coaches, while other teams chose to make the process individually oriented and independent. In future research, the authors hope to further study the collaboration that occurs at this stage of the exercise as well. Nevertheless, the "number of books supported" metric proved sufficient to rank team performance (see Table 1), and followed previous research findings that indicated that integer-based scoring, rather than binary (pass/fail) measures for such activities is useful for comparing collaboration achieved across teams.

8 Team Reporter Observations

The following are unordered lists summarizing comments noted by team reporters.

Team 1

- team did a good job of bouncing ideas around before they started to build
- ideas were extended to come up with a solution
- team used all of their resources
- everybody gave valuable input to come up with the final solution

Team 2

- members of the team worked well together and helped each other out during the construction of structure

- team thought through the design before beginning construction so there was less change in design while building
- good communication

Team 3

- open friendly atmosphere
- collective decision-making
- open to ideas from others
- group started working quickly

Team 4

- they collaborated a lot at the end to finish the project
- collaboration was evident when the time was running out also when a "break-through" was made
- poor communication vehicle for results
- made a plan and started early

Such results while illustrative, are not sufficient or sufficiently detailed to be informative. However, based on such comments and notes, the authors have determined that in future research, consisting of more rigorous assessment of student collaboration activities, trained researchers (as opposed to student peers) should be enlisted to act as third-party reporters in order to provide more consistent and informative documentation.

9 Individual Team Member Self-assessment

After each round of collaboration activity, all student participants were asked to complete a survey where they responded to fourteen statements related to collaboration. These fourteen statements are presented around the radar charts in Figs. 3 and 4. Specifically, after each round, students were asked to indicate the extent to which they "strongly disagree" (1) to "strongly agree" (9) with the statement based on their experience during the class exercise. Table 2 presents a summary of these results in numeric form, based on aggregated team averages.

Table 2 Team averages for self-perceived levels of collaboration by round

Team (by performance level)	Round 1 (assigned roles)	Round 2 (no assigned roles)	Combined average	Percent change between rounds (%)
1	8.21	8.43	8.32	+3
2	7.64	7.98	7.81	+4
3	7.36	7.51	7.44	+2
4	6.72	7.24	6.98	+8

Note for all teams, perceived levels of collaboration rose between round one and round two of the activity (see Table 2, percent change between rounds)

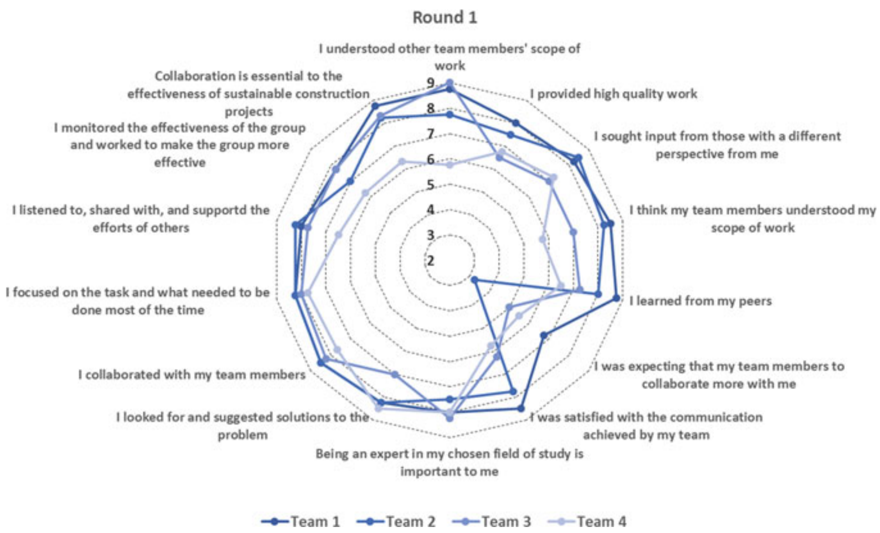


Fig. 3 Round one (assigned roles) self-assessment of collaboration by teams

Figures 3 and 4 compare team averages according individual question responses related to self-perceive level of collaboration achieved for each of the four teams according to round 1 (Fig. 3) and round 2 (Fig. 4).

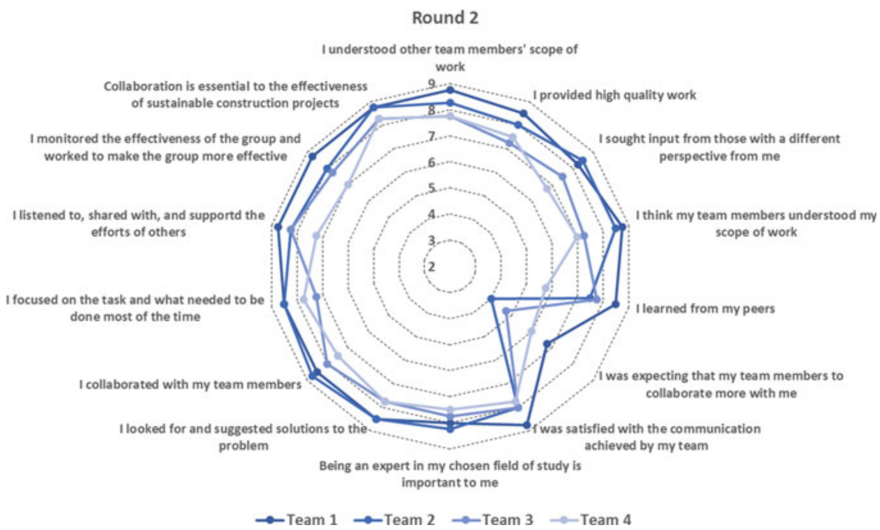


Fig. 4 Round two (no assigned roles) self-assessment of collaboration by teams

Two observations are supported by the data presented in Figs. 3 and 4:

- Teams with higher performance generally reported higher levels of collaboration across both rounds of data collected.
- The biggest self-reported changes between rounds across teams occurred in relationship to the following statements:
  - I understood other team members' scope of work
  - I think my team members understood my scope of work
  - I was satisfied with the communication achieved by my team
  - Collaboration is essential to the effectiveness of sustainable construction projects

In each of these cases, the biggest changes in level of agreement (>14 %) were reported by Team 4 (the worse performing team overall).

10 Conclusions and Future Research

Three preliminary findings are suggested by this research: (1) flexibility achieved through lack of assigned roles may improve collaboration level, (2) higher levels of collaboration may contribute to higher team performance, and (3) lack of understanding of the scope of work and poor communication may contribute to poor team performance. The authors acknowledge that significant limitations existed for this research including: the use of student peer team reporters; collection of self-reported data post (i.e., with prior knowledge of) team performance results; and possible transfer of inherent learning from one activity to the next which might impact (presumably improve) team performance. Nevertheless, the authors propose that the reported lessons learned serve as a valuable contribution with regard to implementing and assessing collaboration activities in construction engineering education. Specifically, the authors make the following recommendations for further and future investigation:

- Impact of assigned individual roles on team dynamics and resulting collaboration levels achieved within the context of construction work-flows;
- Changes in team dynamics, and collaboration levels achieved between design and implementation phases of work;
- Relationship of levels of self-perceived collaboration to levels of collaboration reported by outside observers;
- Specific correlations (using statistical regressions) between specific self-reported levels of collaboration and overall team performance.

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Multidimensional Sustainability Assessment of Solar Products: Educating Engineers and Designers

Bas Flipsen, Conny Bakker and Martin Verwaal

Abstract

Since 2008 the faculty of Industrial Design Engineering at the TU Delft hosts the minor Sustainable Design Engineering. The minor has been highly useful as a platform to pilot new ways of teaching engineering for sustainable development. Instead of having students make life cycle assessments and introduce them to straightforward checklists to improve their product designs, we challenge our students to develop a critical understanding of sustainability and use multidimensional assessments. Sustainability is not just about environmental benefits but also about useful products and added value. This paper describes our educational approach in the photovoltaics practicum (part of the minor). Our objective is to illustrate how such a multidimensional assessment works in practice and how it has helped students to develop a more critical, systemic perspective on sustainability. Students are asked to evaluate a PV-powered product on its sustainability by assessing the technology, usability and the environmental impact. To date, over 150 students have followed the minor, which gives us a large database of multidimensional assessments on a wide range of PV powered products. This paper describes the conclusions we have drawn on the validity of our approach. Our findings show that many of the currently available products with integrated PV systems are initially perceived as "green" but after assessing the product on multidimensional aspects students invariably reach a more nuanced perspective, with some products failing to pass the test. Students indicated how the multidimensional assessment has made them better equipped to see through the "greenwash" and give a balanced evaluation of the real value of solar cells integrated in products. The paper will elaborate the methods used in the multidimensional assessment in more detail, illustrated with student work.

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Keywords
Sustainability assessment · Multidimensional · Students · Solar products

1 Introduction

Since 1995 Design for Sustainability (DfS) is part of the curriculum of our bachelor and master studies at Industrial Design Engineering of the Delft University of Technology. Within the educational program the faculty hosts a minor on Sustainable Design Engineering since 2008. An academic minor is a university student's secondary field of study or specialization during their undergraduate studies. The minor has been highly useful as a platform to pilot new ways of teaching engineering for sustainable development.

Instead of having students make Life Cycle Assessments (LCA) and introduce them to straightforward checklists to improve their product designs, we wanted to challenge our students to develop a critical understanding of sustainability and use multidimensional assessments to back up their findings. Sustainability is not just about environmental benefit but also about useful products and added value. This paper describes our educational approach in one of the courses within the minor of Sustainable Design Engineering, the photovoltaics practicum. Our objective in this paper is to illustrate how such a multidimensional assessment works in practice and how it has helped students develop a more critical, systemic perspective on sustainability.

In Sect. 2 the pedagogical structure of the practicum is given illustrated by examples of student work. In Sect. 3 a review of the students' evaluations is presented and the paper ends with a discussion, conclusions and recommendations.

2 PhotoVoltaics Practicum

The solar energy industry is currently one the fastest growing industries in the world. With declining prices and increasing efficiencies, solar cells may become promising energy harvesters in consumer products. In this practicum our students are asked to disassemble and study a product powered by solar cells. The objective is to learn (hands-on) how these products are constructed, and to assess the practical, technical and environmental feasibility.

2.1 Approach

Students work in teams of 4–5 people. At the end of the ten week course the teams have to deliver a report and poster presentation. Together these two deliverables constitute the final grade.

Fig. 1 Examples of solar products used in the practicum: the Solio solar powered charger (Solio 2015), the IKEA Sunnan solar lamp (IKEA 2014) and the ETON Rugged rukus Bluetooth speaker (Eton 2014)

During the Photovoltaics (PV) practicum we ask the teams to assess a product with integrated PV cells e.g. a solar powered lamp, see Fig. 1. The assessment is based on three sustainability factors:

1. **Usability**, does the PV technology offer any added value and how does this reflect on the product's usability?
2. **Technological feasibility**, does the product function as it should under the intended circumstances?
3. **Environmental impact**, is there a positive energy return on energy invested?

The overall learning goal is to make the students aware that when a PV product fails on one of these three factors it cannot be regarded a sustainable product. E.g. if the PV cell in its use context is too small to comply with the power consumption of the products' main function, the product will be discredited and become a gadget. When a product is difficult in use, or is multi-interpretable it will probably end up in a drawer or in the garbage. When the environmental impact of the product is higher than the environmental gain during its life, the product will not contribute to a sustainable future.

2.2 Usability Assessment

In the first two weeks of the course students have to actively use and test the product in their own environment, the so-called "field trial". The students take turns in testing the product and have to record their findings in a diary or log, in which they describe memorable interaction moments and take pictures. Figure 2 shows such part of a diary of one of the student teams.

The students should write down their expectations of the product beforehand. During the field trial they should make note of the pattern and frequency of use

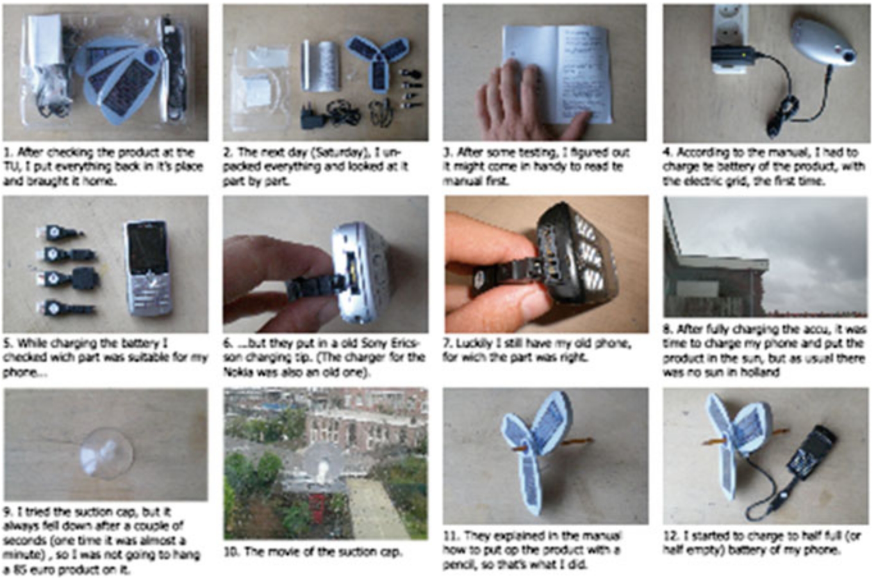

Fig. 2 Diary of one of the teams, who were assigned a PV-powered phone charger

(which have to be clocked), the ease of use and general functioning of the product, and their frustrations and feelings of satisfaction while using the product. Finally, they have to compare their preliminary expectations with their experience after use. An important realisation from the field trial is the context-dependency of PV products. In a predominantly cloudy Netherlands (the practicum takes place in early autumn) the students quickly learn that there's often not enough solar power available to make the PV products function as they should. Some excerpts from students diaries:

> …sunlight from 10:00 am to 07:30 pm. Even after 7,5 h of charging the lamp did not work

And:

> Day 1, 09.30 am. "Oh shit, I have to put that solar thing outside, or it won't charge."
> Day 1, 11.03 pm. "It doesn't work yet. Better luck tomorrow."

There were also positive experiences:

> 17 September 07.30 "the sun came up. The solar panel on the lamp could charge the batteries."
> 17 September 20:00 "I turned the lamp on. Bright light."
> 17 September 02:00 "I turned the lamp off. I was still able to read."

Table 1 The technological feasibility of the product-PV combination by calculating the EBR

$E_{in}/E_{out} > 10$	Feasible, PV system is over dimensioned, optimize the system
$1 < E_{in}/E_{out} < 10$	Feasible
$0{,}1 < E_{in}/E_{out} < 1$	Try to adjust parameters to make it feasible
$E_{in}/E_{out} < 0{,}1$	Not feasible

2.3 Technological Assessment

In weeks 3–5 of the practicum, the task is to determine the use context and energy balance of the PV-powered product. The students have to draw up a realistic use-scenario based on their field trial and other data at hand, e.g. from the product packaging, manual or the internet. Next, they have to calculate the Energy Balance (EBR) to find out if the harvested energy matches with the used energy over a realistic time-period. The EBR is calculated by taking the ratio of the yielded energy per day/week (E_{in}) over the energy demand of the product per day/week (E_{out}). This ratio shows if the harvested energy matches with the energy use of the product, giving the students a sense of direction on the technological feasibility of the product, see Table 1.

Students are given lectures on calculating the EBR, but also about irradiance basics, where the difference between potential harvestable light-power in indoor situations versus outdoor are explained, which varies between 0.1 and 1000 W/m^2 for respectively indoor situations and bright outdoor sunlight. They have to do their own tests and measure the PV-cell in question in out- and inside situations, and also in laboratory test-cabinets (Fig. 3).

To assess if the potential harvestable power and the power production of the PV cells matches a realistic use scenario, the students are given the task to disassemble the product, measure the solar cell characteristics and determine the power and energy consumption of the product's function. Furthermore the students have to identify all components and draw up an electronic schematic (Brain 2012) which shows the

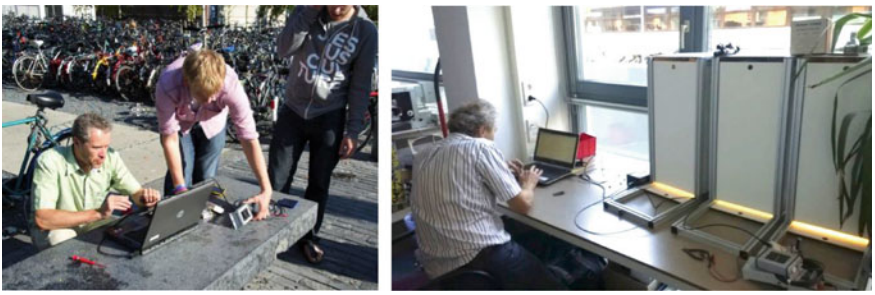

Fig. 3 PV test outside, and the laboratory test using closed PV-test cabinets

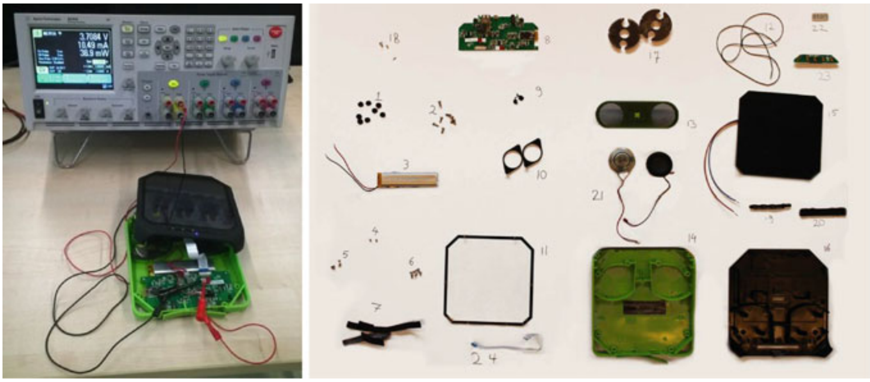

Fig. 4 Measuring the power production of the PV cells and the power consumption, and an overview of components of the Eton Rugged Rukus speaker

interlinked connection between the power consumer (the product's main function), the intermediate accumulator (battery) and the power producer (PV cells), Fig. 4.

When the students are finished with the lab sessions they have to test the technological feasibility by means of Energy Balance Matching (Kan 2006; Kan & Strijk, 2006), questioning if the harvestable energy over a certain period matches with the power consumption of the product in the same time period.

2.4 Environmental Assessment

Weeks 5–7 are used to do the environmental assessment, where students are asked to generate a Fast-track Life Cycle Assessment (LCA) of the product (Vogtlander 2012; Goedkoop et al. 2013; ISO 2006) and calculate the Energy PayBack Time (EPBT) of the product (U.S. DoE 2004; Peng et al. 2013; Sullivan and Gaines 2012).

During the disassembly workshop the product is torn down to single-material parts and, mostly electronic, components. All materials and components are documented in a Bill of Materials and Processes (BoMP), which includes the material type, weight, probable production process and origin of production; i.e. the Life Cycle Inventory (LCI). After inventorizing the students have to evaluate the potential environment impact of the product system over the total life cycle of the product. Students are asked to use the Cumulative Embodied Energy Demand indicator in MegaJoules and the Global Warming Potential in $kgCO_2$-equivalent as their main environmental impact indicator. The first indicator can also be used to calculate the EPBT. The second indicator is the mainstream indicator for companies to show their products' environmental burden. With the LCA students should determine the main contributors on the environmental impact of the product and make a comparison with a similar product which is powered by the grid or a low-voltage charger only, and that does not make use of PV cells.

The Energy PayBack Time (EPBT) is defined as “the amount of years it will take before a PV-system produces as much energy as could be produced by the current grid-mix, using the same amount of primary energy”, based on (Fthenakis and Kim 2011; Raugei 2013):

$$EPBT = \frac{E_{PP}}{E_{OUT}}$$

where E_{PP} is the primary energy input of the total PV system (module + components) during its whole life cycle [MJ_p] and E_{OUT} is the net annual primary energy savings (from the grid) due to electricity generation of the PV systems [MJ_p/yr].

2.5 Reporting

After the three assessments the student teams have to interpret all the acquired knowledge and bring this back to a scientific poster and report. Based on the findings from the field trial, lab work and the analyses they have to suggest options to improve the products’ PV system, clearly argumented with facts and figures.

3 Review 2011–2014

In the past three runs of the minor (2011–2014) 150 students have followed the same approach. This has given us a large database of multidimensional assessments on different PV powered products, and allows us to draw conclusions on the validity of our approach.

The objective was to give the student the ability to make a critical assessment on an initially perceived sustainable product by giving them tools to assess not only the environmental impact of the product but also on technology matching and usability. To give an impression on the results of the different teams over the years, an overview of quotes and calculations are given in Table 2 for four products from cohort 2011 to 2014 after performing the multidimensional sustainability assessment.

4 Discussion and Conclusions

Because this course was limited in time spent (2 ECTS, equalling 56 h per team member) there was, unfortunately, no time for very detailed analysis and proper redesign. Students had to use already acquired skills to assess the products properly. Amongst others the environmental impact is assessed by using an LCA, which was taught in one of the parallel courses of the minor.

Table 2 Multidimensional-assessment results of some of the products evaluated in 2011–2014

Product	**Solar Charger—group 5, cohort 2011** (Biet et al. 2011)
Initial perception	"The initial reaction to the product was that it's a "cool" device. For the most part this is due to the concept of charging a mobile device using solar energy." The expectations were "Long charging time before use, irregular usage because of alternating weather conditions, hard to position for optimum sunscreen, expecting to charge up my mobile phone and mp3 player."
Technology assessment	The Energy Balance Ratio of the product is approximately 1.89, "… when energy is only required for powering the common mobile devices like a mobile phone and a mp3 player, the XXXX is a feasible product."
Usability assessment	"Nevertheless after intensive testing/use of the product, certain downsides of using an unconventional power source for charging became evident. For example, when using the device on the first day (see diary below) it took approximately fifteen minutes before the mobile phone began to charge and almost three hours before the products green led blinked ones"; "The concept behind the XXXX device is a great idea. It provides the user with a great feeling of sustainable living. However, some frustrations arose. One of the typical causes of frustration is the need to reposition the device, every time the position of the sun changed, in order to obtain optimal sun exposure. The size and construction of the product also makes using it in public a little uncomfortable. The usage of the product when on the road can lead to rather much attention. […] The verdict for the XXXX is overall positive. However, the product is best suited for specific regions where the suns intensity is the greatest. Similarly, it is most suitable for people that do not mind interacting with their charger."
Environmental assessment	[note from the authors: in 2011 the LCA and EPBT was not introduced yet]
Overall conclusion	"It was reasonable to say that we all had fairly minimal knowledge about solar powered products before partaking in the PV practicum. The least amount of understanding was how effective the product would be and the electronics behind the device. After the field trial, despite the initial frustration of having to reposition the device for optimal sun exposure, we were surprised at effectiveness of the XXXX brand. The product was able to fully charge the attached mobile phone. […] Overall, it was concluded that solar powered products are a good concept and that they may be worth purchasing if you lived in a hot climate which experienced prolonged spells of intense sun exposure, for example in northern Australia. However, for those of us stuck in the cooler, more northern or southern parts of the world, it is most likely that solar powered products will not be efficient enough in our types of climates for a few more years to come."
Product	**PV powered garden light—cohort 2012** (Albargothy et al. 2012)
Initial perception	"All members of the group agreed that the concept of an outdoor reading light was slightly alien, although the product made sense as an outdoor entertaining light. […] Based on the assumptions mentioned above and the group's collective knowledge of PV products: it was expected that this product would deliver a slightly underpowered light source that although being ambitious would not be quite fit for purpose. Several members of the group also expected the product to have a limited lifespan and poor quality, leading to a short product lifetime, based on their experiences of XXXX's design."

(continued)

Table 2 (continued)

Product	**PV powered garden light—cohort 2012** (Albargothy et al. 2012)
Technology assessment	The EBR was calculated for two scenario and is in between 4 and 6.7, which means "the PV system is well suited to both usage scenario's."
Usability assessment	"Having considered the usefulness of the product, most of the group were surprised about the battery life from what seemed relatively short periods of charging, which was a commendable attribute of the system. […] …both the diffusion of the light provided for reading and the luminosity were not fit for purpose in the eyes of the project team […] In addition when attempting to read under the light, there was insufficient radius to read a magazine comfortably."
Environmental assessment	Calculated from an average use during june, july, august, the EPBT is approximately 25.9 years. "However if used more frequently, potentially in a commercial environment such as a bar or restaurant […] this product would have a repayment time of approximately 8.6 years. […] Both these scenarios would be unlikely however as the lifespan on the product's batteries is likely to be limited to around 2 to 3 years. Although replaceable, most consumers would probably not take the initiative to open up the product and replace these as it would involve unscrewing and disassembling some sections. It could therefore be suggested that the energy consumed in the manufacture of this product would never be repayed by a lot of users."
Overall conclusion	"Based on a usage pattern of 30 days per year during the summer months […] the product energy payback time would be approximately 26 years. Considering this figure against the lifetime of the batteries, and the difficulty a user might experience in replacing the batteries, it has to be concluded that this product is not environmentally friendly. This is an important point to note and the outcome that the project team reflected on most: although marketed to consumers as eco-friendly, these products often could provide more environmental damage than gains."
Product	**Solar LED String Lights—cohort 2013** (Buquet et al. 2013)
Initial Perception	"The overall expectation is that the product will work for a while but that the solar panel won't charge really fast. Also because the lights work already straight out of the box, the battery might be fully charged, which might influence the data. After all, until the battery runs empty we won't be certain if the solar charging works."
Technology assessment	The Energy Balance ratio is in between 1.75 on an autumn day and 11.9 during summer. This number "shows that the available input is sufficient to more than the required output. […] Probably the designer made a conscious decision here, since the user won't always have sunny days and still wants to use the product then."
Usability assessment	"I switched the product on, but then after two hours it was already a big disappointment"; "The XXXX solar lampions are a "fun-to-look-at" product, colourful and simple. They are, however, hard to assemble, don't have much functionality […] and they looked fairly cheap and poorly manufactured. This all together makes the current product into a bit of a disappointment."

(continued)

Table 2 (continued)

Product	**Solar LED String Lights—cohort 2013** (Buquet et al. 2013)
Environmental Assessment	The EPBT is in between 2.85 and 5.44 years. "If the quality of the product and the overall user experience is taken into the equation, one might conclude that the product will probably be discarded after a year or two. Therefore the energy payback time is too high to make this product profitable."
Overall Conclusion	"The solar cell works good when you charge it on a clear summer day and you want the LEDs to shine bright. Therefore its practical use is quite good, as it seems to be a summer product. Sadly if we look at what the real values are, technically, economically and environmentally, the product performs rather poor."
Product	**Solar lamp—group 12, cohort 2014** (Jackson et al. 2014)
Initial perception	"From our perspective, we were expecting this lamp to satisfy a number of purposes simultaneously. It will serve a utilitarian function as a desk lamp providing sufficient power on demand for a reasonable length of time (consistent with its ultimate solar limitations). It ought not to be a toy. […] Rightly or wrongly, some team members were expecting something special given it was his first solar product larger than a very small electronic calculator."
Technology assessment	"Our Energy Balance result of 1.7 suggests that this product is feasible as long as a user can comply with the charging requirements." [note from the authors: which is only when charged outside. Inside charging is not an option].
Usability assessment	"Collectively, we tested this product in two parts. Firstly, we tested charging it indoors, as we were ignorant of the instructions. We thought charging in a windowsill would have the same effect as charging outdoors, but it was far more convenient. Secondly, we tested charging outdoors. Of course, our initial expectations were disappointed only to be satisfied after complying with the manufacturer's recommendations." "The brightness achieved at full battery power closely rivalled conventional electric lamps. It was just frustrating when the unit would lose power and brightness. […]. It also became cumbersome to position the battery pack ideally, relative to the sun given that it is a square unit without any devices for attaching it to surfaces. The lamp unit was also not detachable. This limited potential functionality."
Environmental assessment	The EBPT for the PV panel and battery pack is 6.28–9.37 years, when it is charged outdoor under ideal usage scenario. "This analysis only really shows that the product is 'less bad' than the alternative. If we want to know if the product is truly sustainable we need to take the embodied energy of many other components, as well as transport and manufacturing energies. […] Once you start adding these things up, and considering that our usage scenario is optimistic, our true payback time would stretch to perhaps 20 years or more. This is beyond a reasonable expectation for the lifetime of the product."
Overall conclusion	"From this we can conclude that the PV cell is well matched to the battery voltage for outdoor charging. If we wanted to optimize the indoor performance, one option would be to adjust the batteries to a lower voltage so they would align well with the maximum power curve. This would be a waste, as the indoor power seems too small to bother."

The student teams consisted of different disciplines ranging from industrial design, mechanical and aerospace engineers to students with an art background. The structured approach in this course contributed to good teamwork and high-value results, which was well appreciated by most of the students attending the course.

Our findings show that many of the currently available products with integrated PV systems (lamps, chargers, household appliances, etc.) are initially perceived as "green" and sustainable. After the multidimensional assessment students however invariably reach a more nuanced perspective, with some products failing to pass the test and others, to some surprise, passing the test. From reflections in the final reports and our evaluation sessions with the students, the students indicated how the multidimensional assessment has made them a "better" engineer, more equipped to see through the "greenwash", and give a balanced assessment of the real value of solar cells integrated in products. The course was successful in reaching our goal to teach our students critical thinking and design by assessing a product from multiple dimensions instead of only one.

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Development of a Case-Based Teaching Module to Improve Student Understanding of Stakeholder Engagement Processes Within Engineering Systems Design

Carli D. Flynn, Mallory Squier and Cliff I. Davidson

Abstract

This paper introduces a case-based teaching module designed to increase student understanding of the importance of stakeholder engagement processes in the design of complex engineering systems. The teaching module makes use of a case study on past technology adoption and environmental injustices related to stormwater management plans in Onondaga County, NY. The module begins with a review of the history of events in the County, including social unrest when the needs of certain stakeholder groups were ignored. Students are then divided into groups, each representing an assigned stakeholder community. The students predict what engineering designs will most directly affect their stakeholder group and how each design solution may impact other groups. An assessment tool is used to gauge the students' perceptions of stakeholder engagement and engineering design after the teaching module. Results demonstrate that the module effectively increased student understanding of the complexities related to the engineering design process, particularly stakeholder engagement activities. The module also improved student motivation and interest in course material. These results provide insights for instructors seeking effective ways to bring stakeholder concerns into the classroom.

Keywords

Education · Engineering · Stakeholder engagement · Case-based learning

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1 Introduction

Engineers are now being tasked with understanding the broader social, economic, and environmental implications of their work (Allenby et al. 2009). This requires changes in the education of engineers to think holistically and incorporate a complexity of new constraints in practice (Davidson et al. 2007). It is unrealistic to expect students with little "real-world" experience to understand these complexities through traditional instructional methods. Instead, introducing pedagogical elements such as historical context, decision-making, and ethics into the classroom can aid in the development of "post-conventional" engineers. This term has been used to describe engineers who have a sense of autonomy in their work and see and treat engineering work as requiring complex decision-making and social responsibility (Nair 1997).

This paper proposes that case-based simulation modules can better prepare engineering students to appreciate the complex situations they will encounter on the job. For this study, a stakeholder simulation exercise on selecting management practices for stormwater control was developed to help civil and environmental engineering students learn to apply sustainability concepts and principles. The module makes use of active and collaborative teaching pedagogies within a learning cycle framework.

1.1 Context and Motivation for Module Development

The module was originally designed for the course Sustainability in Civil and Environmental Systems, a sophomore core course for Civil and Environmental Engineering majors at Syracuse University. When this study was conducted in the spring semester of 2014 there were 76 students in the class. The course encompasses a broad range of topics integrating sustainability into a traditional introductory environmental engineering course with the following primary instructional objectives:

(A) Introduce principles of sustainability and systems as applied to the natural and built environments;
(B) Provide skills necessary for quantitative assessments of civil and environmental engineering problems;
(C) Use principles developed in class to evaluate and solve complex open-ended environmental problems and communicate the results of the analysis.

The course material is primarily covered in lectures, or a combination of lecture and in-class problem solving activities. The course is divided into 4 topic areas: population, energy, water, and air. Within the water unit, topics include water contaminants, physical properties of water and the hydrologic cycle, municipal water and wastewater, and urban water management. The last topic covers green versus gray methods of controlling urban stormwater runoff.

1.2 Theoretical Background

Active learning methods have consistently shown an increase in student performance in undergraduate courses in science, technology, engineering, and mathematics disciplines (Freeman et al. 2014; Prince and Felder 2006; Prince 2004). Several researchers have suggested that active learning methods may be especially useful in allowing students to better understand sustainability principles (Huntzinger et al. 2007; Korkmaz 2011; Siller 2001). The case-based urban water stakeholder simulation module designed in this study employs several pedagogies to promote active student learning.

1.3 Case-Based Learning

Inductive learning begins with a context for learning rather than fundamental theories and concepts. Inquiry-based learning is an inductive learning method based on the constructivist theory of learning that knowledge is constructed by the learner. Students assume responsibility for the learning process by engaging in experiences and experiments to solve a problem. Inductive teaching strategies provide students with opportunities to engage in experience-driven learning within collaborative learning environments (Prince and Felder 2006). Case-based learning is a type of inductive learning method in which students are presented with the context of a case study with complex, ill-defined problems to consider. Case-based learning goes beyond the constructivist theory of learning in that it defines a model of cognition that can be turned to for advice and for predictions that can be simulated to test ideas, thus allowing students to draw productive lessons from a case and transfer their knowledge to future situations (Jonassen and Land 1999). Case-based methods have also been shown to be a preferred inductive learning style among instructors and students (Srinivasan et al. 2007).

To design case-based modules as effective inductive learning tools, the context of the case is described but the actual decisions made are withheld so students can inductively develop their own solutions to the problems presented (Lynn 1999). The following steps to structure case-based discussions have been suggested to optimize the student learning experience in case-based environments (Kardos 1979): (1) review of the case content, (2) statement of problems, (3) collection of relevant information, (4) development of alternatives, (5) evaluation of alternatives, (6) selection of a course of action, and (7) evaluation of solutions and review of actual case outcomes.

1.4 Learning Cycle-Based Instruction

The steps proposed for case-based learning closely follow several learning cycle models. For instance, Kolb's experiential learning theory, which asserts that experiences play a key role in the learning process, suggests that student learning occurs in two stages: *grasping experiences* (through a concrete experience phase and an abstract conceptualization phase) and *transforming experiences* (through a reflective observation phase and an active experimentation phase) (Kolb 1984). Based on this theory, Kolb postulates that complete learning occurs when students engage in all four phases of a learning cycle, and that instructors can promote complete learning by designing course materials to encourage students to complete all learning cycle phases (Kolb et al. 2001).

2 Module Design and Implementation

The module employed in this study was designed to make use of case-based learning methods within a learning-cycle-based instructional framework. The seven steps suggested for case study design by Kardos (1979) were used in the design of the urban water stakeholder simulation module, as summarized in Table 1.

Table 1 Module design components

Steps for case-based module development	Module features	Pedagogy elements
(1) Review of the case content	Mini lecture, videos and discussions of stormwater engineering design and Onondaga County context	Grasping experiences through concrete experience and abstract conceptualization
(2) Statement of problem	Problem statement: *As a member of a key stakeholder group in Onondaga County, what type of technologies or solutions would you consider and why?*	Case-based problem
(3) Collection of relevant information, and (4) Development of alternatives	Stakeholder simulation activity: student group discussion aided by floating facilitators	Student collaboration; transforming experiences primarily through active experimentation
(5) Evaluation of alternatives, and (6) Selection of a course of action	Environmental, economic, social and ethical considerations used to evaluate each set of proposals	Student collaboration; transforming experiences primarily through reflective observation
(7) Evaluation of solutions and review of actual case outcomes	Summary of actual changes to Onondaga County's stormwater management plans	Grasping experiences through abstract conceptualization

2.1 Case Selection and Context

Preparation for case-based learning is very demanding as instructors must be intimately familiar with the history and current state of decisions related to the case in order to actively respond to questions during the case (Kardos 1979). This case was selected based on the authors' expertise on sustainable urban water systems and depth of knowledge on stakeholder perspectives (Flynn et al. 2014; Flynn and Davidson 2015). The context of the case takes place in Onondaga County, located in Central New York. Onondaga County operates a combined sewer system and must provide a control plan to manage combined sewer overflows (CSOs). Most municipal CSO control plans in the U.S. make use of traditional "gray infrastructure" solutions, or CSO control technologies that either enhance or supplement existing sewer infrastructure, which tend to be large in scale and cost. Implementing only gray infrastructure systems for urban stormwater management is neither sustainable nor sufficiently resilient to accommodate climatic changes (Novotny et al. 2010; Pyke et al. 2011). Conversely, urban stormwater systems that include green infrastructure technologies are recognized as a more sustainable management approach. Onondaga County's original CSO management plans included multiple expensive and gray infrastructure technologies that were considered invasive by local community members. While all major regulating and regulated parties were directly involved in the project planning, several important stakeholder groups were not. Over time, the environmental injustices stemming from this exclusion led to the social unrest of many groups in Onondaga County, particularly the Onondaga Nation and the residents of the Southside neighborhood (Perreault et al. 2012).

2.2 Implementation of Module

The implementation of the module took place during a single 80-minute lecture period. Instruction began with grasping experiences through a mini lecture on why stormwater engineering design is both necessary and inherently complex. Early module content also described available technology options and the stakeholders that are affected by each option. Urban stormwater management issues were reviewed and local contextualization was provided with videos of recent localized flooding on campus and the surrounding neighborhoods. The module continued with a discussion of these issues and how the framing of water issues impacts the goals, system boundaries and specific solutions. Stakeholder engagement processes were introduced and a variety of different stakeholder groups involved with and affected by municipal stormwater management decisions were discussed. Students were then presented with the context of the Onondaga County case study. Recent changes to Onondaga County's stormwater management plans to include extensive green infrastructure technologies were intentionally left out of the module to elicit original student ideas as the module progressed.

The case-based simulation activity was designed to promote the active experimentation phase of learning, as students explored how they would advocate for particular engineering solutions while representing a certain stakeholder group within Onondaga County, and considered what consequences would occur if their solutions were chosen. Background on the case and on each stakeholder group was presented to the students and is shown in Table 2. The four stakeholder groups described in Table 2 were selected from the multiple stakeholders involved with this case. The class was divided into four equal groups, each representing one stakeholder group. Potential solutions using gray and green infrastructure were reviewed, as summarized in Table 3. Information on technology options was presented for the time period of 2007–2008, when green infrastructure technologies were acknowledged as a potential alternative to gray infrastructure technologies but not widely implemented. Students were then asked to answer the following question with their group: *As a member of a key stakeholder group in Onondaga County, what type of technologies or solutions would you consider and why*?

Table 2 Stakeholder goals and concerns

Stakeholder group	Primary goals and concerns
Onondaga County Government	Must meet consent judgment criteria to treat or mitigate 400 million gallons of annual CSO volume and decrease bacteria, phosphorus and trash loadings to Onondaga Lake using proven technologies in a cost effective manner
Engineering firms	Must design proven and cost effective stormwater management solutions to meet the needs of their customer (Onondaga County)
Southside residents	Several concerns: proximity of invasive infrastructure projects, localized and basement flooding, construction disruptions, aesthetics, recreation, health
Onondaga Nation	Lake is a sacred site; Onondaga Nation follows a vision of environmental stewardship and cooperative resource management; fish from Onondaga Lake was once a source of food

Table 3 Technological aspects of gray and green infrastructure

Technological aspect	Gray infrastructure	Green infrastructure
Materials	Human manufactured materials	Human manufactured and natural materials
Benefits	Single purpose technologies for stormwater mitigation and treatment	Multifunctional technologies with multiple environmental and social benefits
Distribution and capacity	Large capacity to centrally treat and transport stormwater	Varied capacities to treat and manage stormwater through a diffuse network
System integration	Concentrates stormwater and pollutants to be treated with chemicals	Complementary to existing infrastructure; systems-thinking design

Several possible considerations were provided to the students, including economic limitations and opportunities, political and community culture, current ecosystem conditions, current state of existing infrastructure, legal constraints, and current and future climatic conditions. Students were provided ample time to discuss the various technology options within their groups. A floating facilitator model was employed with four instructors moving from group to group during the discussion period to respond to student questions. Each facilitator had studied different aspects of this case over multiple years and was able to provide robust answers to student questions. After the discussion, students were asked to advocate for their technology selection and to provide support based on the goals and concerns of their stakeholder group. The class ended with an open discussion of the various proposals and a brief presentation of the actual solutions implemented in Onondaga County.

2.3 Formative Assessment Tool

A formative assessment tool was administered directly following the implementation of the module to provide feedback on its effectiveness as a teaching tool. The assessment also provided information on students' perceptions of their learning, as well as their overall enjoyment of the module activities and structure. The formative assessment tool included two parts. The first section used a three point Likert scale (Strongly Agree, Agree or Disagree) to assess student perceived level of understanding on several topics after the module; the second included two open-ended questions to elicit student comments on their satisfaction of the module.

3 Results

3.1 Formative Assessment Results: Part 1

Results for Part 1 are presented in Table 4. Previous to the implementation of this module, urban hydrology issues were covered in several lectures with specific examples of existing technological solutions. However, stakeholder concerns and stormwater issues in Onondaga County (i.e., the Syracuse area) were not directly addressed. Following the module implementation, 95 % of students agreed or strongly agreed that they had a better understanding of how course concepts apply to real world cases, and 96 % felt that the module helped them to better understand urban water problems in Syracuse, NY. Anecdotal evidence suggests that most of the students in the course are not from the Central New York area and therefore would be uninformed of local ongoing issues. This response is of particular importance to the instructors who encourage their students to relate course material to the world around them. Additionally, 86 % of students agreed or strongly agreed that they better understood stakeholder involvement in engineering decisions

Table 4 Evaluation of learning activities

Question	Disagree (%)	Agree (%)	Strongly agree (%)
As a result of today's activities, I have a better understanding of how concepts learned in this course apply to the real world	5	75	20
As a result of today's activities, I have a better understanding of how different stakeholders influence engineering decisions	14	59	27
As a result of today's activities, I have a better understanding of urban water problems in the Syracuse area	4	60	36
I enjoyed today's activities	25	57	18

following this module. This result is also notable, as increasing students' ability to understand the complexities of engineering decisions was a primary objective for the module.

3.2 Formative Assessment Results: Part 2

Of the students who completed the assessment tool, 23 included useful comments in the open-ended section. Two of the instructors categorized the open comments based on common themes and language that students used to describe their experiences in the module. The first open-ended question asked what the students enjoyed most about the class activity. These comments were classified into seven groups, with some comments being included in multiple groups, as shown in Fig. 1. Many students mentioned that they enjoyed working in groups and enjoyed learning about the various interests of the different stakeholders.

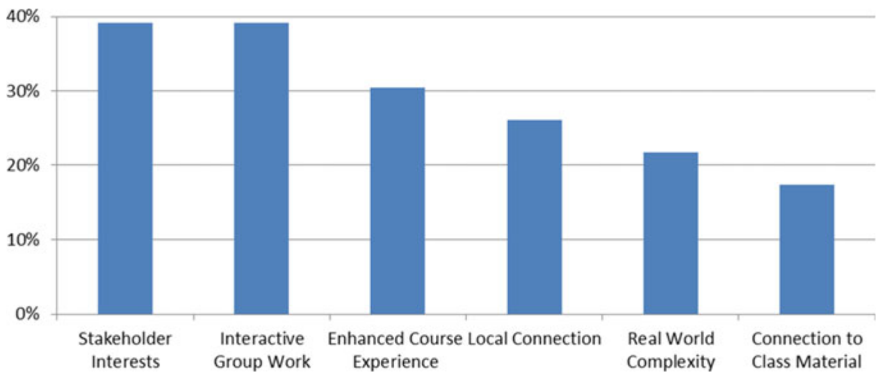

Fig. 1 Student responses to "*What did you enjoy most about today's activities*?"

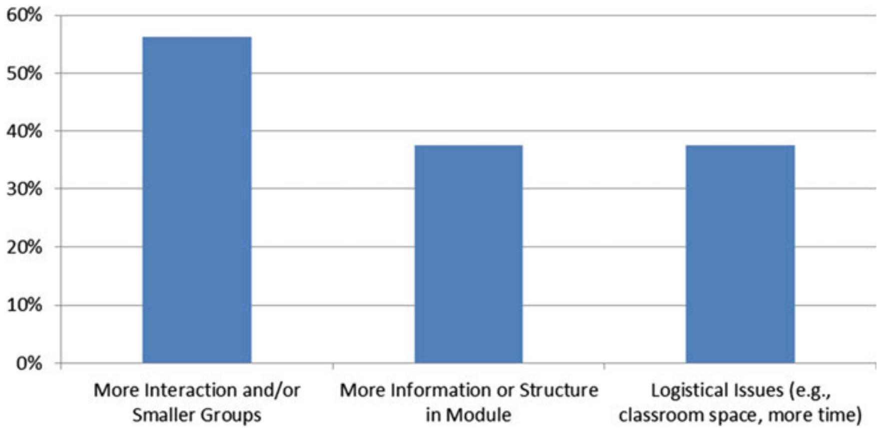

Fig. 2 Student responses to "*What suggestions do you have for improvement of today's activities*?"

Several comments from the first question of Part 2 also indicated an increase in student motivation to continue investigating stormwater engineering issues. Two such comments are included below:

> I thought the lecture was well done and I found it to be engaging, interesting and extremely useful. This was possibly the most useful lecture I have here at Syracuse and reminded me why I chose engineering.
>
> Maybe make this into a 2 day activity, so people can come to the next class with a little more knowledge and do some research to the problems and think more thoroughly on solutions.

The second open ended question of Part 2 asked what the students thought should be improved about the module. Sixteen useful responses to this question were classified into three groups, with some comments being included in multiple groups, shown in Fig. 2. Nine of the responses included comments on group size and limited interaction within the groups. Six students requested more structure to the module and more information. Just over one third of the responses included a comment on logistics of the class, including issues related to the classroom layout and time constraints.

4 Conclusions and Ongoing Work

In order to encourage active student engagement in learning of urban stormwater management practices, a case-based module was developed and implemented in a sophomore civil and environmental engineering course. Assessment results suggest that the module effectively increased student understanding of complex decision making processes required of engineers. The instructors observed high levels of student involvement and engagement in the material throughout the module, particularly during the simulation activity. Students enjoyed the collaborative learning activities and focus on a local engineering case study involving diverse stakeholder concerns. Several modifications will be applied to the module in response to student suggestions. For instance, additional stakeholder groups will be included, such as multiple engineering firms, environmental organizations, and a local business council, in order to allow for smaller student groups while also creating a more realistic simulation activity. Moreover, several student comments from the assessment tool suggested the need for additional reflective observation time. In future iterations, the module will be spread out over two lectures and one recitation period. An innovative classroom space will be completed within the college to allow for enhanced interaction of small groups within a large classroom setting. Some level of gamification is being considered for the simulation activity, which will take place during the second lecture period. Additional work on this module aims to further engage students with a local, real-world, complex situation both to forge better and more creative engineers and to enhance student learning in the classroom setting.

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Author Biographies

Carli Flynn is a Ph.D. candidate in the Civil and Environmental Engineering Department at Syracuse University. Her research makes use of interdisciplinary methods to analyze the development of sustainable civil infrastructure systems. Application areas include the adoption of green infrastructure within stormwater management systems, and engineering student understanding of rate and accumulation processes. She would like to thank the students who enthusiastically participated in the original implementation of the stakeholder engagement processes learning module.

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A Practical Approach to Integrating Research and Education: A Course Experiment from KTH, Sweden

Fredrik Gröndahl and Daniel Franzen

Abstract

In this study we evaluate a project-based learning course called Applied Ecology, within the master program Sustainable Technology at the Division of Industrial Ecology, at KTH—Royal Institute of Technology in Stockholm, Sweden. The case study in the course is focused on the effects of a relatively large Bay, "Burgsviken", situated on the island Gotland in the middle of the Baltic Sea, that has changed due to the eutrophication in the area. The eutrophication of the Bay has initiated bottom up processes of discussion and engagement among the stakeholders in the area, for the enhancement of the water quality and biological services of the bay, that would in turn improve fishing, swimming, biological diversity and tourism. There are several stakeholders involved in the project: a local non-profit organisation, farmers, entrepreneurs, authorities, permanent and seasonal inhabitants, researchers and others. The course is evaluated according to the methodology of Brundiers and Wiek (2013). Student evaluations have been conducted and analysed in relation to four phases: (1) Orienting phase, formulation of research question. (2) Framing phase, methodology and study planning. (3) Research phase, field study and other examinations. (4) Implementation phase, communication of the results with different stakeholders. The Applied Ecology course shares many of the positive features of other PPBL courses in the sustainability field—namely that it focuses on a real sustainability problem and that the student-centred learning approach and interactions between students and stakeholders make the student partnership in the project feel real, thus providing a practical insight of complex societal challenges. There are potential ways of improving all four phases of the

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course that were studied, but especially in the research phase and the implementation phase more efforts are needed. Feedback and reflections in the research phase could be improved by a clearer communication and to some extent changed pedagogical process through the course. All phases will be improved by increased communication before, during and after fieldwork between student, teachers and stakeholders.

Keywords

Engineering education · Sustainable development · Project and problem-based learning · Applied ecology · Course evaluation

1 Introduction

Engineers are key players in the development of a more sustainable society. In order to be the change agents that are so urgently needed they need to be equipped with a different set of competences than today (Clift 2006; Mulder 2006). They need to be able to envision, develop and implement sustainable solutions that respect the limitations of natural systems and promote human well-being (Svanström and Gröndahl 2012). This means that we also need to rethink how we educate engineers. Although Sustainable Development (SD) have been integrated in engineering education in many technological universities, the general level of knowledge in SD-issues is still very variable and in many programs, relatively poor. The students views of the SD-concept seems also to be biased toward technological and economic perspectives, excluding the social aspect of SD, and are also lagging behind in the understanding of how technical, ecological and economical knowledge may be integrated in order to solve real sustainability problems (Segalas et al. 2010).

One pedagogical approach to narrow the gap between intradisciplinary theory and transdisciplinary understanding of complex sustainability problems is the problem and project based courses (PPBL) (Lehmann et al. 2008; Brundiers and Wiek 2011, 2013). In PPBL-courses within the sustainability field, students are not only passive receivers of knowledge but active participants in projects concerning real SD questions in ongoing societal or research initiatives of sustainability challenges. Students are often active drivers of the research process from the problem description to the implementation of the results. The PPBL-approach aims to develop collaborative and transdisciplinary research skills, as well as to develop a capacity to analyse complex societal sustainability challenges. That said, some key barriers for success in these courses have been reported, such as how to identify and work with a “real sustainability problem” in courses often limited by short time frames and few possibilities to engage with different stakeholders. Other challenges include true transdisciplinary methodology and correct implementation of the results from the student-driven projects (Brundiers and Wiek 2013).

In this study we evaluate a pilot-version of a newly started PPBL-course called "Applied Ecology" in the Master Program Sustainable Technology held at the Division of Industrial Ecology, KTH Royale Institute of Technology in Stockholm, Sweden. The case study of the course is the sustainability problems attributed to the eutrophication of a Bay (Burgsviken) on Gotland, an island situated in the middle of the Baltic Sea. The problem includes different ecological, social, economic and cultural aspects.

Our objectives in this study are to,

- Evaluate the course from a student perspective, especially regarding their view of the course as research in a "real sustainability problem".
- Analysing the student opinions in relation to the four different phases of the course (orienting phase, framing phase, research phase and implementation phase), and suggest improvements of the course in these phases.

2 The Burgsviken Case Study and the Course Applied Ecology

The participants in Applied Ecology course includes both Swedish and International students in their first or second year of the master program. The students have various educational backgrounds from different engineer programs (energy and environmental, mechanical, industrial management, biotechnology, chemical engineer). The overall aim of the course is to increase the students' knowledge about ecology, ecological methods and how ecological knowledge could be applied in a broader context in relation to real sustainability challenges in our society.

The thematic sustainability issue in the course concerns the real problems of eutrophication in the Baltic Sea. Which have severe implications for the population around the sea both on a regional and local scale. The study area is located on the southern part of Gotland that is the largest of the islands in the Baltic Sea. The case study is focused on the effects of a relatively large shallow Bay "Burgsviken" that has shifted from an oligotrophic to a eutrophic ecological state since the 1970s. This change has resulted in a loss of ecosystem services from the Bay and as a result, the Bay no longer provides good fishing, swimming or yachting. In the Bay large stand of reed (*Phragmites australis*) cover the inner parts, and in the mouth and centre of the bay the sandy beaches are covered with organic matter from floating opportunistic filamentous red algae. In 2012 local stakeholders around Burgsviken decided to create the "project Burgsviken", a local initiative to save the Bay and restore the ecosystem service of Burgsviken. More than 50 local groups including the municipality, local companies and landowners are involved. Industrial Ecology, KTH are involved as an academic partner and in 2013 and 2014 we have used the Applied Ecology course and our students to help the project in Burgsviken to solve the sustainability problems of the Bay in close cooperation with the local initiative.

The pedagogic tools used in the course include literature seminars, lectures and excursions, but most central is the group work where groups of 3–5 students develop and conduct a study (student projects) of an ecological research question within the larger frame of the eutrophication problem of the Burgsviken Bay. The students form, plan, conduct and report the results from the study. The studies include the use of classical ecological field methods, but also some social, cultural or economical perspectives in relation to their question through the contact with stakeholders, interviews and literature studies.

The student's projects have mainly focused on the problems of reed, red algae and effects of eutrophication on the bottom fauna of the bay. The overall research question regards whether the extensive biomass of reed and algae in the bay caused by eutrophication may be harvested or collected and used for feed or bioenergy (biogas). Thus the problem may be turned into an opportunity and may help the bay to recover while creating new socio-economical values around the bay.

3 Methods

For the evaluation of the course we used two anonymous online student evaluations. The first evaluation (Evaluation 1) was a general basic evaluation including questions about general impression of the course, the contents and teaching, but also included some more specific questions such as the importance of the field work for the learning outcomes of the course, and how the course could be improved. This gave us a general picture of whether or not the course approach was well founded in order to present and work with "a true sustainability problem" (objective 1 above). The second evaluation (Evaluation 2) was structured according to an evaluation approach suggested by Brundiers and Wiek (2013) based on ideas in an earlier study (Talwar et al. 2011). The method uses an evaluative framework where the PPBL-courses are analysed in relation to four phases: orienting phase, framing phase, research phase and implementation phase. We use the core structure of this framework and formulate eight statements about the course—two statements for each phase—for the student to consider in Evaluation 2. Student opinions were collected in an online anonymous evaluation using a five graduated scale from 1–5, where 1 was described as "No I don't agree at all" and 5 was described as "Yes I agree completely". Values 2–4 were not described in words but were presented as intermediate choices in relation to their distance from 1 and 5. The students could also comment on the questions (Evaluation 1) or statement (Evaluation 2) and develop their answers in a text box after each question/statement. Some of these comments are used in the discussion as singular observations in relation to the quantitative evaluations. Here follows a short description of the four phases, as interpreted by the authors of this paper in relation to the course approach, and the statements formulated to represent each phase in the evaluation.

The orienting phase describes the formation and early presentation of the course and research project. The background to the project is presented and the learning objectives of the course. Statements 1 and 2 represent the orientating phase:

1. The Burgsviken project (central in the course) was presented as a sustainability challenge in the course. (S1 = *Sustainability challenge*)
2. One of the goals of this course was to contribute to the solution of the problem of eutrophication in Burgsviken. (S2 = *Course contribution*)

The framing phase is about delimiting different project tasks/research questions for each project group in the course. What should be each group's contribution, aspects and goals within the larger overarching sustainability issue? And what kind of methodology should be used for answering the question?

3. The methods used in your study were appropriate for the aim of the project to contribute to the information needed to solve the problem of eutrophication in the bay. (S3 = *Appropriate methods*)
4. The project task was interesting and most relevant for the Burgsviken project (given the limited time and resources of the field visit). (S4 = *Project task*)

The research phase in this course concerns especially the activities during the field visit at Burgsviken, where the actual work in the project is taking place e.g. meeting and working with stakeholders, conducting ecological inventories, estimations and interviews.

5. You got enough feedback on the methodological approach to solve your project task during the preparation of the study and during the field visit. (S5 = *Methodological feedback*)
6. During the course, did you have the possibility to reflect over the quality of processes and products of your project work? (S6 = *learning reflections*)

The implementation phase includes the presentation of each project task and the relation to the main sustainability question in the project (How can the negative eutrophication effects of Burgsviken be decreased?). How will the contributions of the students work be used in the Burgsviken area in practise or in further research, societal development or educational programmes?

7. The outcomes from your study will be reported/used/or saved and may be used for future research or societal needs in some way. (S7 = *Study usefulness*)
8. You took part in a societal/research project at the same time as you were participating in a university course for your own learning. (S8 = *Societal project participation*)

4 Results: Evaluation 1—General Opinions and Sustainability View

The general picture from the first evaluation was that the students had a positive view of the course for the three questions about: general content in the course (Fig. 1a), importance of the field visit for the learning outcomes (Fig. 1b) and

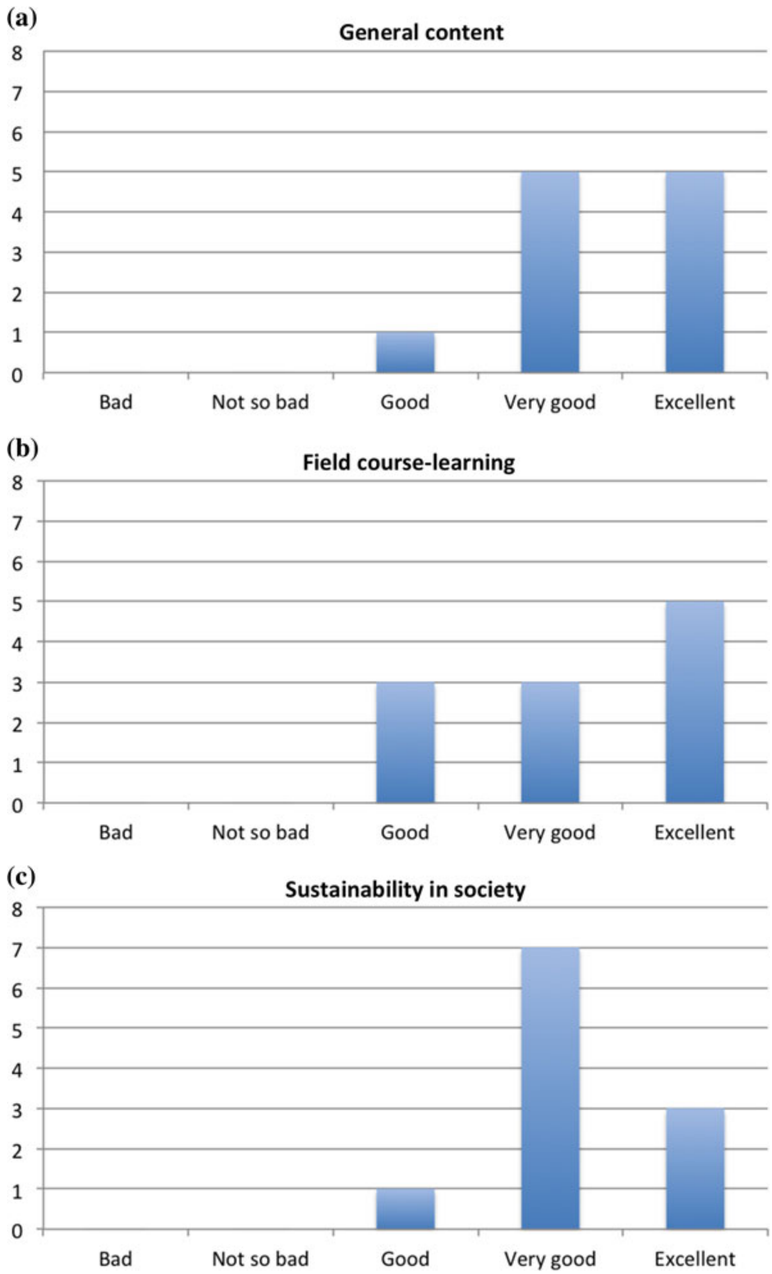

Fig. 1 **a** Looking at the course as a whole, are you pleased with the content of the course? **b** What is your opinion about the importance of the field course for the learning outcomes of the course? **c** How has this course managed to: increase your understanding of the integration of ecological theory, ecosystem management in practise and sustainability issues in society?

whether the course managed to increase the students' understanding of the integration of ecological theory, ecosystem management in practise and sustainability issues in society (Fig. 1c).

Figure 1a–c show the results from the student evaluation 1 in the course Applied Ecology 2014. The Y-axis shows the number of student answers graduated as: bad, not so bad, good, very good and excellent in response to the question.

5 Results: Evaluation 2—Evaluation of the Four Phases in the Course

Evaluation 2 had a response rate of 42 % (8 of 19 students). Figure 2 shows the results for the statements 1–8 (see methods) related to the four phases in the course described in a polar coordination diagram based on the mean value for each question (based on the 1–5 evaluations). Again the overall picture is positive for all phases with a mean value over 4.0 for all statements except for No 7 ("The outcomes from your study will be reported/used/or saved to be used for future research or societal needs in some way") that had a mean value of 3.6. The mean value of the first two phases (four questions) was generally very high with mean values over 4.2.

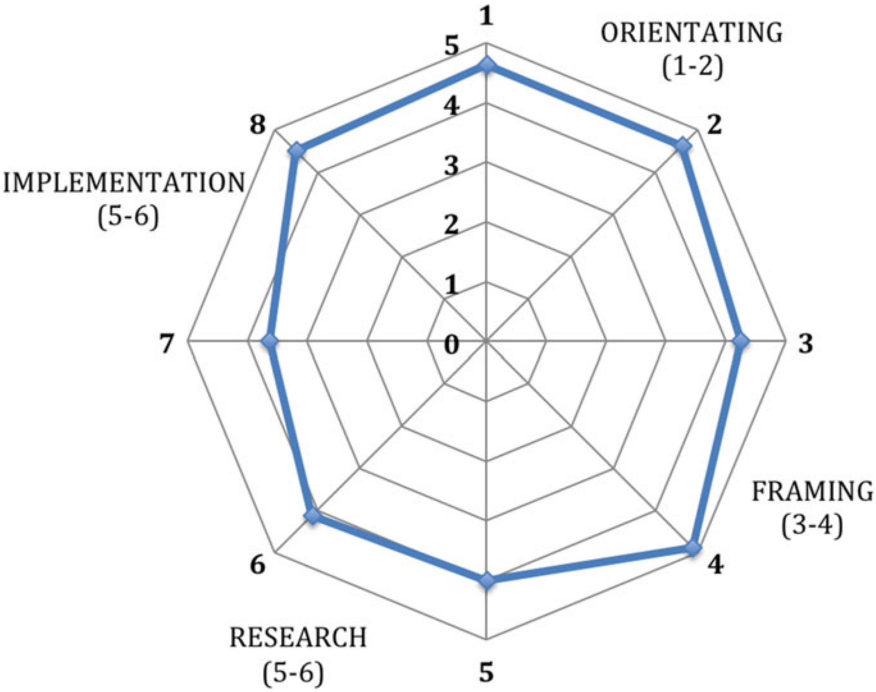

Fig. 2 Evaluation in a polar coordination diagram

The research phase had somewhat lower scores compared to the other phases (about 4.0).

Figure 2 shows the results from the evaluation in a polar coordination diagram. The mean value for each statement is marked in the diagram. S1 = *Sustainability challenge* S2 = *Course contribution* S3 = *Appropriate methods* S4 = *Project task* S5 = *Methodological feedback* S6 = *learning reflections* S7 = *Study usefulness*, S8 = *Societal project participation.* Values in the Orienting phase (S1 = 4, 6 S2 = 4, 6), Framing phase (S3 = 4, 25 S4 = 4, 9), Research phase (S5 = 4, 0 S6 = 4, 1), Implementation phase (S7 = 3, 6 S8 = 4, 5).

6 Discussion: Is the Case of Burgsviken an Appropriate Example of a "Real Sustainability Problem" that Could Be Used in Sustainability Teaching?

The main idea behind the course "Applied Ecology" was to increase the student's knowledge both in ecological theory and methodology but also to evaluate the finding from their project task within the wider context of the sustainability issue of understanding and improving the situation of the eutrophicated Bay of Burgsviken. The course evaluation shows that the students appreciate the general features and contents of the course and seem to experience the course as dealing with a "real" sustainability issue (see Figs. 1c and 2). One obvious strength in the course is that it at least partly takes place "outside the classroom" (Brundiers and Wiek 2011), where the core of the identified sustainability problem is located geographically. Students have close contact with different stakeholders and examine at least some minor part of the problems in situ. The Burgsviken case could also be described as a "wicked problem" (Brundiers and Wiek 2011), which means that the problems are highly complex including many ecological, socio-economic and cultural aspects, and could not be solved by a single technical or economic quick-fix. Looking at the response to a question about the positive aspects of the course several students underline the increased understanding of the sustainability problem due to the connection between theory and practice.

> To practically do something for real. To really see what we were talking about in theory, both about eutrophication, how it is to take samples, how reed may be harvested, and meet local stakeholders and others were very positive
>
> It was fun to have a practical course and to see how knowledge in ecology and ecosystem theories can be applied in real life.

We believe that a key mission of this course is to facilitate the students' understanding of their own project tasks in relation to the overarching general sustainability question. We find the challenge to bridge the gap between the student's own research and "the sustainability question in Burgsviken" as one of the most important missions for improving the course.

7 How Could the Course Be Improved in Relation to the Four Phases?

The 2nd evaluation also supported the view of the course as a good case of a real sustainability problem, showing high values (students agree to a large extent with statements) in all four phases. Although, the results give us also some ideas of how the course could be improved in relation to the four phases. The results indicate that the two last phases in the course process: the research and implementation phase could be improved for next year. This is also further indicated by some of the student comments regarding methods and feedback in the statements for the research phase.

> We didn't get so much feedback during the preparation of the study, but we got some good feedback and hints during the field visit
>
> The feedback was a bit unclear from times to times, but in the end it turned out good anyway.
>
> Maybe give some more directions about the field work and the report so we could start with it earlier - even though it might have been hard to do, since we didn't have such a good understanding about what was possible to do to begin with.
>
> To clarify and specify better, from the beginning, what the field visit and the project is about and which are the tools and the equipment available.

One idea of developing the work with methods during the course is to use participatory peer-review evaluation in a cooperation between students, teachers and different stakeholders, as suggested by Brundiers and Wiek (2013). Since there is limited time for the students during the course both for the planning of the fieldwork (6 weeks) and the actual research phase on Gotland (3–4 days). A possible solution would be to form a focus group including different stakeholders, which could be ready to give feedback to the groups already from the start of the course. The focus group could be used as early as the framing phase, to help the students formulate relevant and valid research questions and to give feedback on proposed methods. The group could continue the feedback during the research phase on Gotland and the implementation phase when students are writing the project reports (peer review) or presenting their results. In agreement with the review of other sustainability PPBL-courses (Brundiers and Wiek 2013), the implementation phase was identified as the least successful phase in the sustainability course process, by looking at the students' opinions for statement number 7—"The outcomes from your study will be reported/used/or saved to be used for future research or societal needs in some way"—which showed a relatively low mean value (3.6). This is also to some extent supported by comments from the students: *"The outcomes are too uncertain to use directly and the project too small to give a correct view of the problem, but the result could at least give a hint in the right direction."*

The implementation of the results depends on the quality of the contributions from the students during the course. This is highly dependent on the research question and whether results could be directly applied and may lead to a change in society. Here again the stakeholders and the suggested "focus group" could play a central part in the process of implementation. Actually engaging stakeholders in earlier phases of the course (discussed above) will probably increase the possibilities for implementation of the student's contributions to the project Burgsviken. This work will be strengthened and deepened if we could formalise our partnership with different stakeholders in the project (see Brundiers and Wiek 2013).

8 Conclusions

The Applied Ecology course shares many of the positive features of other PPBL courses in the sustainability field—namely that it focuses on a real sustainability problem and that the student-centred learning approach and interactions between students and stakeholders make the student partnership in the project feel real, thus providing a practical insight of complex societal challenges. There are potential ways of improving all four phases of the course that were studied, but especially in the research phase and the implementation phase more efforts are needed. Feedback and reflections in the research phase could be improved by a clearer communication and to some extent changed pedagogical process through the course. All phases will be improved by increased communication before, during and after fieldwork between student, teachers and stakeholders.

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Developing Global Preparedness Efficacy

Bhavna Hariharan and Sneha Ayyagari

Abstract

Increasing globalization and technological innovations have redefined the role of engineers in working towards sustainable development. The question of how to measure and evaluate preparedness of engineering students to meet these requirements remains an open question. This paper develops a performance indicator called Global Preparedness Efficacy (GPE) to measure the effectiveness of curricula that bring student engineers together with underserved communities in satisfying ABET criteria 3 h, which is "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context". This indicator measures ability to navigate the complexity and novelty of the problem space and enabling the creation solutions to the problem at hand consistent with the global socio-economic, political and cultural realities.

Keywords

Global engineering · Curriculum · Development engineering · Measurement

1 Introduction

Increasing globalization and technological innovations have redefined the role of engineers in working towards sustainable development. This is reflected in the creation and adoption of ABET Engineering Criteria 2000 which included six

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professional skills to prepare engineers who were more aware of how their profession, products and services are embedded in the larger global, socio-economic and political context (Shuman et al. 2005). The question of how to measure and evaluate preparedness of engineering students to meet these requirements remains an open question. This paper describes a theoretically derived metric global preparedness efficacy as one method to evaluate the effectiveness of a curriculum.

Responding to the need to prepare student engineers to collaborate with underserved communities, the Global Engineer's Education (GEE) program was implemented at Stanford University. The GEE curriculum offers students the opportunity to work with rather than for a community in rural India by understanding the problem space, practicing methods of ethical collaboration, and prototyping technologies to address sanitation and hygiene issues in the area. The curriculum fosters this collaboration through three unique curricular elements. Regular video calls with experts at the partner organization in India, the Environmental Sanitation Institute (ESI) allowed students to engage directly with community members. Readings and discussions from various disciplines encouraged students to consider the complexity of the problem space of sanitation and hygiene as they prototyped technologies. The course focused on the idea of designing with care by inviting students and community members to express their values and goals and incorporate each of these "care statements" into the final design.

These three curricular aspects allow students to engage with the community in a way that positions student engineers to incorporate their own values and ideas in context of local realities and knowledge. This approach is consistent with the work of Sheri Sheppard et al. who state in their book Educating Engineers: Designing for the Future of the Field that, "The shift from an outside to an inside perspective can be understood as a shift from engineering for "them" to engineering for "us". Although this new point of view may be disarming, at the same time it holds the potential to inspire new thinking, for a shift from an outside to an inside perspective highlights the complex social, physical and informational interconnections" (Sheppard et al. 2009).

The GEE course curriculum provides the opportunity for students to experience the challenges in collaborating with an underserved community globally and conceiving solutions to the challenges faced by the community that is mindful of and responds to the local economic, environmental, social, political, ethical and cultural conditions in a way that is safe. As such, students have the opportunity to examine subjectively daunting concerns they may have about bridging language and cultural barriers and connecting with the harsh realities that the underserved communities experience in a non-threatening environment. Knowing that their communities are real and the regular real-time connection with them also imposes an ethical responsibility on the students allowing them direct experience of real work conditions. As such, GEE serves as a good case to determine global preparedness efficacy of student engineers.

2 A Theoretical Understanding of Global Preparedness Efficacy (GPE)

The seminal work of John Dewey was selected above all the others because of his trans-actional worldview and his particular emphasis on learning through doing. He also explicitly focuses on learning as a result of interplay between the individual and the environment.

For Dewey, learning is a social process. It happens as a result of individuals interacting with the larger social environment in which they are situated. In fact, he went as far as to claim that education was a means of social continuity. Individuals learned from society and gave back to it, new knowledge that they discovered. Dewey believes it is an undeniable fact that all individuals grow up in a social medium.

Therefore, understanding learning by isolating the individual from the environment is fallacious: "As a matter of fact every individual has grown up, and always must grow up, in a social medium. His responses grow intelligent, or gain meaning, simply because he lives and acts in a medium of accepted meanings and values through social intercourse, through sharing in the activities embodying beliefs, he gradually acquires a mind of his own. The conception of mind as a purely isolated possession of the self is at the very antipodes of the truth… the self is not a separate mind building up knowledge anew of its own account" (Dewey 1969–1990).

2.1 Dewey's Trans-action Model, Experience and Learning

His views on learning and education stem from his trans-action worldview. It is a perspective "where systems of description and naming are employed to deal with aspects and phases of action, without final attribution to 'elements' or other presumptively detachable or independent 'entities', 'essences', or 'realities', and without isolation of presumptively detachable 'relations' from such detachable 'elements'" (Dewey and Bentley 1949). A trans-actional perspective considers a system holistically without attributing intention or will to individual entities. Entities derive their meaning from the context in which they are embedded. They are neither given predefined wills or intentions, nor are they looked at in isolation from the context in which they are embedded.

In the case of GEE, students considered the complexities of the sanitation and hygiene space from a holistic perspective by analyzing multidisciplinary views on the topic. The course focused on the broader perspective of designing with care and working with communities, allowing students a perspective through which they could approach and overcome discontinuity events.

A discussion of Dewey's idea of learning begins with understanding his concept of Experience. Experience for Dewey is an active-passive process. It has an active component where individuals act on their environment. Individuals experience the consequences of their actions in the complementary passive phase. He describes that learning occurs "[w]hen we experience something we act upon it, we do something with it; then we suffer or undergo the consequences. We do something to the thing and then it does something to us in return: such is the peculiar combination [of experience]" (Dewey 1969–1990, p. 163).

Learning is the creation of continuities and relationships between actions and their results and consequences. To learn from experiences, it is necessary for the individual to "continue into the undergoing of consequences, when the change made by action is reflected back into a change made in us, the mere flux is loaded with significance, we learn something." By moving back and forth between actions and the undergoing, it is possible to learn about the connections between actions and their effects: "Under such conditions, doing becomes trying; an experiment with the world to find out what it is like; the undergoing becomes instruction—discovery of the connection of things" (Dewey 1969–1990, p. 164). According to Dewey, a learning experience has two complementary components, namely active doing and undergoing. Consistent with the trans-actional point of view, learning is a combined experience of an individual actively acting on the environment (whereby the individual can alter and change the context or respond to a stimulus or problems in a given environment) while simultaneously the environment acts upon the individual.

When working with underserved communities, the students, researchers, and instructors often encounter completely novel contexts. Initiatives that bring together students and underserved communities are usually trying to bridge social, economic, linguistic, political, geographic and cultural differences. As such it is very common that the undergoing is unexpected. In fact, in an NSF sponsored study, a book published by Gary Downey captures the experience of a Professor at University of Denver at Colorado who decided not to pursue international engineering work because she felt "depressed to know that the large body of knowledge in the development area was not readily accessible or available to engineers either in their curricula or their international practice." She acknowledged that the disconnect between the values and experiences of community agendas, NGO partners, and student engineers made it difficult to "honestly assess their own practices and their unintended consequences" (Downey and Beddoes 2011, p. 162).

2.2 Applying Zimbardo's Discontinuity Theory

An explanation for these aberrant experiences of undergoing can be found in Philip Zimbardo's Discontinuity Theory. It investigates and proposes a model of how individuals adapt to aberrant experiences in their lives. He defines discontinuity as "a violation of the expectation in any domain of functioning highly valued self" (Zimbardo 1999, p. 345). It is an event that proves to be disruptive to the normal flow and pattern of everyday life.

Experiencing a discontinuity "involves an awareness of a noticeable deviation from an expected normative standard of how one usually feels, thinks, perceives, or acts—in those areas that figure into the calculation of one's global self" (Zimbardo 1999, p. 351). It implies that the discontinuities are felt in cases in which a highly valued self-image of the individual is threatened. It is only the disruption of patterns to which an individual is deeply attached, or holds in high regard as an essential character trait, that creates experiences of discontinuity. The nature of discontinuities is such that they are disruptive enough to cause an individual to seek an explanation for the experience in an attempt to restore either the previously experienced sense of normalcy or a renewed sense of self.

Zimbardo's theory offers nine types of "violations of expectations" (V.O.E) as sources of discontinuity, "each of which typically elicits characteristic affective reactions" (Zimbardo 1999, p. 351). The V.O.E are misfortune, good fortune, magic, miracle, humor, horror, natural disasters/cosmic perturbations, social deviance, aesthetic value violation (Zimbardo 1999, p. 351–352). It is reasonable to expect that any student working in a cross-cultural context in the developing world will encounter such violation of expectations. It is natural to imagine that differences in culture, economic status, belief structures and personal histories will lead to discontinuities.

According to Zimbardo's discontinuity theory, discontinuities can lead to inquiries that lead to new understandings, but they may also result in confused or biased behavior that can have less desirable outcomes. The experience of discontinuity is one of uncertainty, in which confusion about the expected behavior of learning and teaching results in the inability to proceed with the project. The discontinuity is overcome when a new course of action or renewed action is restored. From a Deweyan perspective, discontinuities are experiences of aberrant undergoing where active doing is lost and can be potential learning experiences if the active doing is restored.

3 Defining Global Preparedness Efficacy

Using the Dewey-Zimbardo framework described above, it is possible to look at student experiences when participating in project-based course that enable engagement with underserved communities. The metric is being developed with an aim to measure the ability of students to navigate the complexity and novelty of the problem space and enabling the creation solutions to the problem at hand consistent with the global socio-economic, political and cultural realities. Identifying the number of discontinuities encountered and identifying whether or not they were converted to learning experiences (as indicated by renewed action) could serve as a good measure for global preparedness. Global Preparedness Efficacy is defined as the ratio of resolved to total discontinuity events. This would imply that the closer the ratio to 1, the better the students were prepared for global engagement.

3.1 Calculating GPE

To calculate GPE, a necessary step is to determine whether discontinuities could be coded from student journals. A coding scheme to identify discontinuities and renewed action was developed using the method shown in Fig. 1. This meta-framework for generating a coding scheme (MFCS) was developed by studying two emotion-coding schemes: Intimacy Coding Scheme and the Specific Affect Coding System (SPAFF) (Hariharan 2011).

The first step in the process, as shown in Fig. 1 was to recognize the key concepts from the theory underlying the interactions of interest. Dewey's Learning Theory and Zimbardo's Discontinuity Theory were used to delineate the transition from discontinuity to learning experiences. As described previously, experiences of discontinuity are those where active doing stops and a shift to learning experience happens when active doing is restored or there is engagement in renewed action. Thus discontinuity and renewed action emerged as the key concepts. They were defined as follows:

- Discontinuity: Drawing from Zimbardo's theory, discontinuity is experienced when a highly valued expectation/belief is violated. In the case of the student practitioners, these discontinuities are likely to come from their assumptions about the community practitioners and their expertise in engineering design.
- Renewed Action: Action that comes after a discontinuity has been understood and overcome has been called renewed action. The naming is deliberate to differentiate it from merely resuming the same action that was being undertaken prior to experiencing a discontinuity. Renewed action implies acting out of having understood and contextualized the discontinuity.
- Vulnerability: Expressions of emotions, reflections and at times statements made in the third person about the topic under discussion. These were representative of the student practitioners' transition from discontinuity to renewed action. The

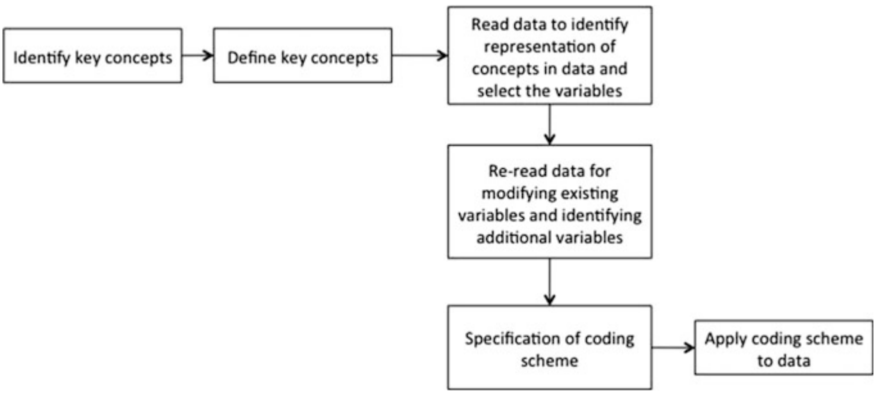

Fig. 1 Meta framework for generating a coding scheme (MFCS)

feeling of exposure resulted in these expressions being collectively called "vulnerability".

The next stage was reading the data to identify how discontinuity and renewed action in the vulnerability were represented in the data.

3.2 Identifying Discontinuities

On reading through the data, it became apparent that discontinuities were at times explicitly expressed. In other cases, they were implied in expressions of struggle and in a few cases expressions of joy. The most obvious representation of discontinuity was as an expression of surprise or concern as shown in the following example:

> We also discussed our reactions to the assigned readings for the week. All of us were very taken back by the readings and had never thought of safety as an issue linked to toilets (Student 614).

Discontinuities were not always explicitly expressed. They were also implied in texts that spoke of the struggle or joy that the student practitioner had experienced. In such cases, the discontinuity was coded as the event upon which the student practitioner was reflecting on. For example, one student wrote, *"Even though we met for 2 h, we did surprisingly little*" (Student 514). This statement in itself was not the discontinuity. The students were prototyping a bike-powered fan to improve ventilation in the toilet space.

3.3 Identifying Renewed Action

Following identification of discontinuities in the data, evidence for renewed action was sought. These were statements that expressed the student practitioners' understanding of the discontinuity and their intention to re-engage in active doing. For example, the two instances of discontinuities presented in the previous section were associated with the following renewed action:

> Discontinuity: We also discussed our reactions to the assigned readings for the week. All of us were very taken back by the readings and had never thought of safety as an issue linked to toilets.
> Renewed Action: *If we can create a toilet that is good enough to have very close to the school, so students don't have to venture too far to use the bathroom. Also, making sure people, not only are, but feel safe, is something important to me. Because we are most influenced by our earliest experiences, having things tailored to children and young girls especially would be something that I'm*

> *interested in.*
> Discontinuity: Even though we met for 2 h, we did surprisingly little.
> Renewed Action: *However, we realized some key aspects—we needed to buy a chain delinker, and we needed to build a stand for the bike so that one could pedal in a solitary position.*

In both instances of discontinuities above, we see that a discontinuity has been understood and there is an indication of how to move forward. However, not all discontinuities were, associated with renewed action. Discontinuities that had associated renewed action were called "resolved discontinuities" while those that did not have renewed action were called "unresolved" discontinuities. Since representations of both key concepts were found in the data without modification of concepts, discontinuity and renewed action were chosen as the variables of the coding scheme.

The instances of vulnerability associated with the examples of discontinuities and renewed action presented above shown below.

> Discontinuity: We also discussed our reactions to the assigned readings for the week. All of us were very taken back by the readings and had never thought of safety as an issue linked to toilets.
> Vulnerability: *This was an issue discussed in the context of sub-Saharan Africa, but we are all curious as to whether or not this applies to the village we are working with as well.*
> Renewed Action: If we can create a toilet that is good enough to have very close to the school, so students don't have to venture too far to use the bathroom. Also, making sure people, not only are, but feel safe, is something important to me. Because we are most influenced by our earliest experiences, having things tailored to children and young girls especially would be something that I'm interested in.
> Discontinuity: Even though we met for 2 h, we did surprisingly little.
> Vulnerability: *We were crippled by a lack of adequate tools, as well as inexperience with disassembling bike parts. All we managed to get done, in terms of prototyping, was separate the rear-wheel of a bike. It sounds really minute, now that I think of it, but the process was a lot more complicated.*
> Renewed Action: However, we realized some key aspects—we needed to buy a chain delinker, and we needed to build a stand for the bike so that one could pedal in a solitary position.

A second reader independently applied the coding scheme to verify that the three variables (discontinuity, vulnerability, and renewed action) were clearly defined and properly represented the data. The collective of discontinuity and associated vulnerability and renewed action (if it existed) were labeled as a discontinuity event. The coded data were put into tables as shown in Table 1 to enable easy retrieval for future use.

Table 1 Example of coding scheme

Discontinuity	I was very taken back by the Geographies of Danger paper, in which issues of girls specifically facing the danger of rape when going to the bathroom in sub-Saharan Africa
Vulnerability	This was extremely alarming for me, as safety has never been an issue that I would consider when going to the bathroom
Renewed action	Several of the girls noted that in female bathrooms, girls often socialize, but in dorms where there are "gender-neutral" bathrooms, this socializing does not necessarily happen. For our toilet design, it might be interesting to think about how to cater the toilet to each specific gender using it so that both are comfortable

4 Discussion

The presence of 130 discontinuity events shows that the GEE course made it possible for the students to experience the reality of working across cultural, social, economic, linguistic and geographical differences. GEE is a good setting to measure GPE because the curriculum allows students to experience the hurdles that they would encounter in field settings. The high number of resolved discontinuity events (107) indicates that GEE was also able to make what could potentially be an overwhelming experience of aberrant undergoing into a learning environment.

The difference in number of discontinuities observed in 2013 and 2014 can be attributed to two main reasons. The number of students in the class in 2013 (when the course was first offered) was 8 while in 2014 the class size was 11. The total number of journal entries written in the 2013 offering of the class was 65 while in 2014 the number was 269. This discrepancy is attributable to the fact that in 2013 the course was offered as credit/no credit while in 2014 the course was offered for letter grade with journal entries contributing to 25 % of the total grade.

When looking at the data for individual students for 2014, there was a wide variation in number of discontinuities encountered. The range of the data was 17 (2 and 19 being the highest and lowest number recorded). A possible explanation for this large range is that there was no given format or structure for journaling. The students were simply asked to take note of their activities with regard to the course and reflect on it. This is an avenue for improvement and questions about providing prompts for the journals is being discussed and researched.

5 Implications and Future Work

The primary purpose of this research was to describe the development of GPE as a metric to evaluate global engineering curricula. In addition, the paper describes a coding scheme used to determine GPE and how it was used with data collected in the GEE course. The data showed that GEE had a high GPE. Further research is required to study what aspects of the GEE course contribute to satisfying ABET criteria 3 h that is the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (Shuman et al. 2005).

Studying the causes of discontinuities across the data set can assist in making curricular innovations. Another application of the coding scheme is to monitor student experience and progress throughout the course. Regular coding will allow instructors to monitor what causes individual students to encounter discontinuities.

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Sustainability Science in Practice: Discourse and Practice in a University-Wide Transition Initiative

Jean Hugé and Tom Waas

Abstract

'Sustainability science' (Kemp and Martens 2007; Hugé 2012) is an increasingly popular concept, drawing scholars and students towards inter- and trans-disciplinary approaches that are commonly believed to embody the best solutions to solve the challenges of rapidly a changing world. While the enthusiasm generated by the concept is to be welcomed, its implementation and operationalization are challenging. If it fails to deliver, it risks to trigger disillusion and discouragement and it may come to embody nothing more than semantics and 'loose words'. Engineers are—at least perceived as—the quintessential problem solvers in academia, but global change as well as the realization that any scientific endeavour cannot be performed in a societal vacuum forces engineers to reconceptualize their role in society as well as their research philosophy. Tangible processes are needed to turn this analysis of the current situation into actions for a more sustainable future. Sustainability assessment (SA) is such a process that may turn the initial enthusiasm for the broad concept of sustainability science into actions that lead to more sustainable engineering research and teaching. The objective of this paper is to identify the strengths and weaknesses of SA in a university-wide transition exercise, focusing on the views of the academic community in engineering faculties at the University of Ghent, Belgium. Drawing on the application of sustainability

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assessment processes on various systems (energy systems, development cooperation projects), and on the real-life experience of the bottom-up ‘Transition at the University of Ghent, Belgium’-initiative, we use a discourse-analytical approach to sustainability assessment (Hugé et al. 2013). Acknowledging the variety of discourses, frames and worldviews embodied in sustainability science is a key step in creating actor coalitions that may trigger positive change in academic institutions. We will propose a qualitative evaluation of existing and planned concrete transition activities, building on recent insights in the field of ‘sustainable higher education’ (Beynaghi et al. 2014) in order to provide recommendations on how to implement sustainability science in engineering faculties.

Keywords
Sustainability science · Transition · Sustainability assessment

1 Introduction: What Kind of Knowledge Do We Need?

Generating and managing knowledge is essential to realize the ambition of sustainable development as a strategy to guide decisions. A decision-guiding strategy gains its legitimacy through the knowledge that forms the base of the strategy itself. This knowledge should be able to deal with complexity, uncertainty and multiple legitimate value-laden viewpoints—as these are key context-defining features of any sustainability issue (Andersson 2008; Hugé 2012).

1.1 Complexity

Sustainability issues are intrinsically linked to each other and the many interactions between social and natural systems are of high and increasing complexity. Complex issues concern a web of related problems, lie across or at the intersection of many disciplines and the underlying processes interact on various temporal and scale levels (van Asselt and Rijkens-Klomp 2002). Complex issues involve a large variety of technical and scientific input as well as important value-laden and ethical aspects (Andersson 2008). Indeed the interplay between environmental processes and human activity, and the values underlying the perspectives on this interplay are key in any sustainability issue. Complexity applies to systems showing deep uncertainties and a plurality of legitimate perspectives (Funtowicz et al. 1999). Studying sustainable development consequently entails studying non-linear causal networks, emerging issues and recognizing limitations in understanding (Ostrom 2009).

Complexity is present at various levels: First, the intrinsic complexity of multidimensional societal challenges is creating an ever-growing need for information and debate (Funtowicz et al. 1999). Complexity is closely related to the ever-increasing size and pace of information flows that submerge decision-makers. In other words, today's world is arguably 'messier now than it was in earlier decades' (Rosenau 2005). Rosenau (2005) speaks of 'fragmegration' (a neologism combining fragmentation and integration) to denote today's world's complexity and identifies eight complexity-enhancing forces ranging from microelectronic technologies to authority crises and to economic globalisation.

Secondly, the institutional complexity arising from the new realities of multi-level governance networks blurs the boundaries between the responsibilities and competences of 'classical' jurisdictional entities such as the nation-state and—new—players such as regions, stakeholder groups and multilateral organisations. Complexity is now also a defining feature of sustainable development governance (Jänicke 2007). This means that in order to understand the sustainability of complex systems, multi-level nested frameworks are needed (Ostrom 2009). As 'the price of increased complexity is pervasive uncertainty' (Gibbons 1999) we will now delve deeper into the latter.

1.2 Uncertainty

The context into which 'knowledge for sustainability' needs to be generated and used in order to cope with global change is characterized by inherent uncertainty. Uncertainty is a key feature of sustainability (Boulanger and Bréchet 2005), which is by definition a future-oriented concept. Uncertainties have become more significant in recent times because of the growing scope, complexity and hazardous consequences of human activities. Complex systems such as ecosystems and social systems are very difficult to predict). The interactions between the socio-economic system and the environment are mostly characterized by strong uncertainty as global sustainability problems have no historical precedent (Faucheux and Froger 1995). In order to deal with uncertainty, a learning approach and a high adaptive capacity are required.

1.3 Values and Multiple Legitimate Viewpoints

Within the interpretational limits of sustainable development, many legitimate viewpoints exist (Hopwood et al. 2005), which often reflect particular values. Values are beliefs about goals in life that are desirable for an individual or for society (Andersson 2008). Values lead to different perspectives, which differ between various actors. Some values are shared by almost everyone while others are cultivated within certain social groups (Andersson 2008). These perspectives reflect personal agendas as well as particular political, cultural or historical sensitivities and materialize for instance through differences in emphasis regarding the dimensions of sustainability. Decision-making for sustainable development hence not only requires scientifically valid knowledge but also knowledge that is acceptable to various societal actors (Runhaar 2009). Hence stakeholder input is needed to provide knowledge (Runhaar 2009). Blanchard and Vanderlinden (2010) also refer to these multiple viewpoints from a disciplinary point of view: scientific disciplines have become so specialized that coherence is lost. 'No perspective is wrong by its own measures, however, they are all incomplete without the other perspectives'. Knowledge for sustainable development needs to propose solutions to deal with these legitimate alternative viewpoints.

The recognition of the importance of the three context-defining characteristics described above has consequences for knowledge generation for sustainable development. It has even led to the emergence of 'new' forms of science, which we group under the heading of 'science for sustainable development'.

2 Sustainability Science

Sustainable development's normative character and its long-term horizon result in specific demands for science (Funtowicz and Ravetz 1993). A new concept of science, different from disciplinary, normal science seems to be necessary (Müller 2006). In the context of sustainable development 'knowledge creation' is far from the rational, cognitive and technical procedures of science as previously understood. Instead knowledge creation is perceived as a process or practice. Post-modern perspectives embrace an awareness of multiple 'knowledges', situated specificities, discourse and narrative analysis and complexities of actor-institutional interactions' (Grist 2008). Types of knowledge for sustainable development then include:

- diagnostic knowledge (with regard to the causes leading to 'un-sustainability);
- explanatory knowledge (with regard to the interactions between social activities and sustainability impacts);
- orientation knowledge (with regard to normative justification arguments);
- knowledge for action (with regard to finding solutions to 'un-sustainable' situations).

Knowledge for sustainability needs to analyse a system's deeper-lying structures, (diagnostic and explanatory knowledge), it needs to project into the future (orientation knowledge), it needs to assess the impact of decisions (explanatory, orientation and action knowledge), and it has to lead to the design of new strategies for solutions (knowledge for action) (Waas et al. 2010). We use the term science here in its broadest interpretation, as 'the state of knowing', referring to a contextually useful ordering of information flows.

Science for sustainable development is sometimes used as a generic term to describe science performed in a solution-oriented context of social relevance (Müller 2006) characterized by complexity, uncertainty and the importance of values. Scholars have proposed specific terms and initiatives describing its characteristics:

Table 1 Characteristics of science for sustainable development

Intra- and inter-disciplinary research
Co-production of knowledge
Normative and positive inputs
Systemic integration
Exploratory character
Recognition of own limitations and assumptions
Learning-oriented perspective
Production of socially robust knowledge
Attention to system innovation and transition

mode 2 science (Gibbons et al. 1994); post-normal science (Funtowicz and Ravetz 1993); sustainability science (Boulanger and Bréchet 2005; Kemp and Martens 2007). Despite differences in formulation, these approaches essentially describe the same content; and given the fact that 'sustainability science' is most probably the best known term (as exemplified in the homonymous journal http://link.springer.com/journal/11625), we use this throughout this contribution.

'Sustainability science' is defined as an integrative science aiming at the integration of different disciplines, viewpoints and knowledge types (Kemp and Martens 2007). Sustainability science is an 'evolving process of knowledge construction requiring co-operation between disciplines to arrive at a shared understanding of issues at hand' (Blanchard and Vanderlinden 2010). Hulme and Toye (2006) speak of 'knowledge communities' instead of disciplines. They argue that what matters is consensus on aims and methods within the community. Furthermore as knowledge will always be provisional and incomplete in its descriptive aspects, as well as depending on changing normative expectations, sustainability science needs to be reflexive, i.e. sensitive to the way in which knowledge was generated (and hence what the underlying uncertainties are for instance). In summary, sustainability science builds on both normative and positive inputs: the new scientific paradigm is no longer exclusively based on 'objectivity', but also incorporates normative elements (Luks and Siebenhüner 2007). Alternative problem framings are an essential element of sustainability governance and can lead to 'out of the box' thinking and to the realisation of innovative solutions to respond to complex societal challenges (Table 1).

3 Operationalizing Sustainability Science in a University: The Operationalization Challenge

Following this reflection on the specificities of the context in which sustainability science is to be applied, the main question of interest for universities is how to move from analysis to action. The ready-made answer is to turn to the multi-interpretable process of sustainability assessment. Sustainability assessment, defined as an umbrella process aimed at operationalizing sustainability as a decision-guiding strategy, through the identification of the future consequences or current and planned actions, is often presented as the key process to 'make sustainability happen'. Products, processes and organizations, policies and projects can be assessed on their sustainability content and impact, and many different methods exist (Ness et al. 2007). Similarly sustainability assessment frameworks have been developed specifically for academia (see Waas et al. 2010 for an overview).

However, one should be careful about the interpretation of what exactly is assessed, especially in the field of sustainability in higher education (SHE). Universities have a critical role to play in creating a sustainable future, as they educate many of the professionals who lead, manage, and teach in our society Moreover, they can be sustainability innovators through research activities, and act as models for the community. Yet studies show that while many efforts to incorporate sustainability within higher education exist, it is rare to find a university that has fully embraced the sustainability imperative (Wright and Wilton 2012).

To date, most of the efforts have been focused on: (1) sustainability and education (curricula/teaching), and (2) sustainability and management, in particular the environmental management of institutions (e.g. water and energy use, waste management) (Waas et al. 2010). The integration of sustainability (in one way or another) into the third pillar of academia—research—has been comparatively neglected. This is not due to a lack of attention devoted to research strategies, it can be attributed to the difficulties of grasping what sustainability means for existing and new research initiatives, both fundamental and applied.

4 The Ghent University Transition Initiative

Ghent University is one of the largest Belgian universities (41,000 students, 9000 staff members and 117 research units spread over 17 faculties) and includes two engineering faculties: the Engineering Faculty and the Bio-Science Engineering Faculty. Since 2012, a group of frontrunners consisting of professors and students has initiated a bottom-up process to foster sustainability at the university. This process has been strongly supported by the Environmental Coordination Unit and has ultimately been actively supported by the main governing bodies too. This initiative, known as 'the Ghent University Transition Initiative' is now a think tank as well as an open network, and it has produced two 'Memorandums' (in March 2013 and October 2014). The transition approach to sustainability presents societal transformation as the interplay between different levels: the landscape level describes the exogenous drivers, the regime describes the current state of affairs and the niches are innovative spaces and initiatives that can trigger changes at the regime, and eventually landscape level. The approach has been initiated by Geels (2002) and is now used e.g. in Belgium and in the Netherlands by policy-makers to understand and manage transitions towards sustainability. The 'University of Ghent Transition Initiative' chose this approach to link the wide range of—often small scale—sustainability initiatives (niches) with the bigger picture of change towards sustainability at the university-level, and to propose integrated actions towards sustainability at different levels. Figure 1 presents the transition multi-level perspective as proposed by Geels (2002). Figure 1 is a schematic outline of a sustainability transition, showing how niche innovations can be taken up by the dominant socio-technical regime (which consists of six dimensions (science, culture, policy, industry, markets, technology) and can hence modify that regime, which is also influenced by meta-level landscape developments. At the University of Ghent, transition pathways were developed for various modules (energy, water, teaching, mobility and transport etc.). We focus on the transition pathway that was developed for *research* and will subsequently reflect on the implications for engineering faculties.

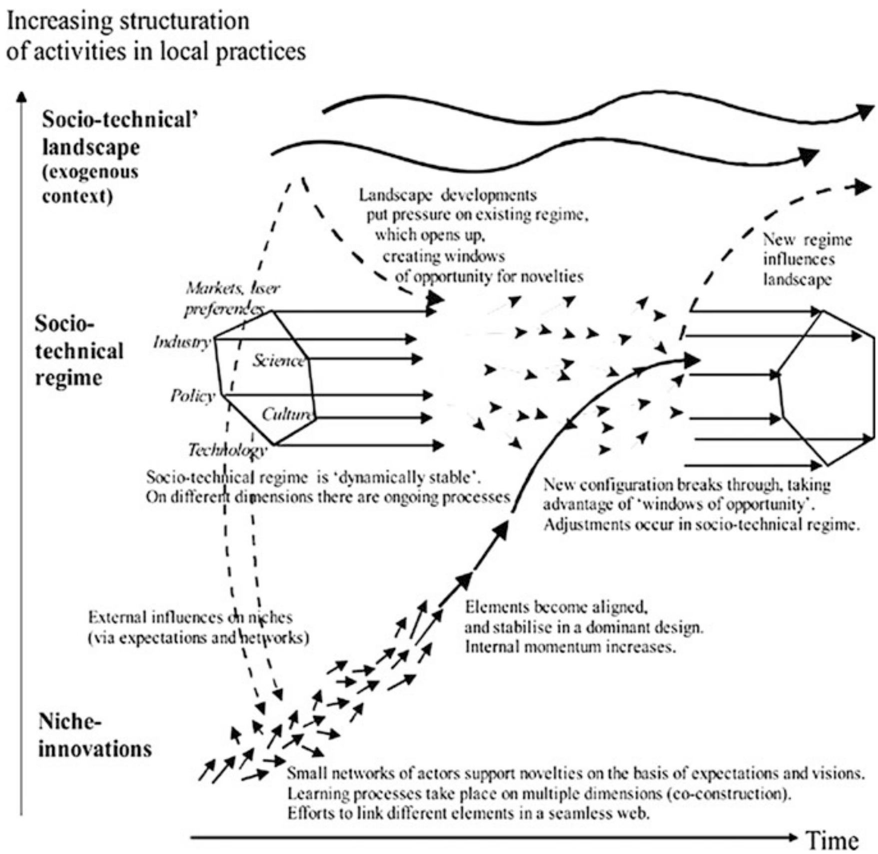

Fig. 1 The multi-level perspective on transitions (Geels 2002)

5 Transition Approach Applied to Research

Based on numerous participatory roundtable exercises held between 2012 and 2014, the following transition path for research was developed at the University of Ghent. Starting with an analysis of the situation in 2012, a stepwise transition path is proposed with 2020 as time horizon.

6 Discussion

6.1 Sustainability, Consensus and Academic Freedom

There are multiple reasons why universities encounter difficulties to grasp the concept of sustainability in research. The first one relates to the intrinsic multi-interpretability of the concept of sustainability, illustrated by the well-known weak versus strong sustainability discussion (Hopwood et al. 2005). The second reason pertains to the key issue of academic freedom. Steering research in a particular direction, even if that direction is presented as 'consensual' sustainability, inevitably raises questions about the independence of the researcher and the fear of limitations that could be imposed on academic freedom. The third objective relates to the specificity of every research tradition and the very interpretation given to 'science for sustainability'. Applied science can have positive effects on sustainability, without consciously following a self-reflexive, multidisciplinary approach, while the implications of fundamental research for sustainability are often impossible to predict. But given these caveats, how can university staff assess if they are on the right track towards incorporating sustainability in research, in order to 'implement' sustainability science? And how does one find a balance between the imperatives of fostering sustainability and maintaining academic freedom? We propose a stepwise approach.

6.2 Proposed Approach Towards Sustainability Science in Universities

The approach that is proposed here is currently being implemented at the University of Ghent, and aspects of this stepwise approach are also being applied at the University of Limpopo, South Africa. Feedback and comments on this proposed approach are welcomed, as the current state of affairs does not yet allow a systematic evaluation due to the ongoing character of the described transition initiatives.

Step 1: Initiating university-wide open discussion about what sustainability means with regard to the various roles of universities (teaching, research, societal service, facility management…) (e.g. the University of Ghent Transition Initiative).

Step 2: Combine university-wide and faculty-specific transition pathways for sustainability in research (cf Fig. 2) (e.g. the ‘campus as a living lab’ idea, entailing the conduct of academic research on proving new technology that advances sustainability on campus through operations).

Step 3: Mapping existing discourses on sustainability, and on sustainability in research, in each faculty. This can be done by using the Q methodology (Sylvestre et al. 2014) which allows to map discourses and subjective perspectives in a systematic and transparent way.

Step 4: Identify areas of consensus in the discourse mapping (Hugé et al. 2013). Start from these consensus areas (e.g. ways to define sustainability, options to realize sustainability in research) to develop pilot projects and/or pilot incentive mechanisms to support sustainability in research.

Step 5: Evaluate the success of these ‘niche’ initiatives in light of a multi-level, long-term sustainability transition strategy.

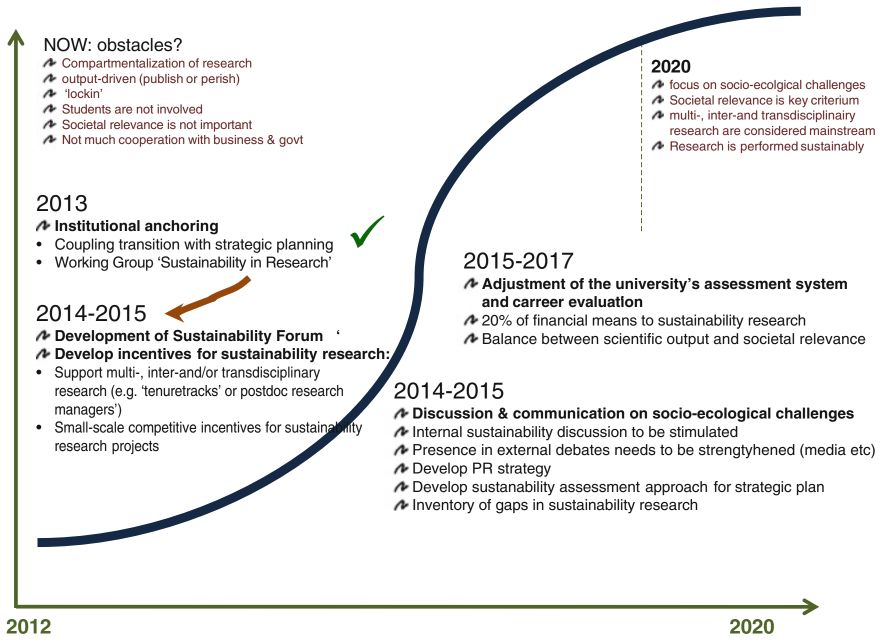

Fig. 2 Sustainability transition path for research at the University of Ghent (*Source* Memorandum for sustainable development, University of Ghent, 2014) (X axis: time, Y axis: increasing structuration of activities in local practices)

7 Conclusion and Steps Forward

While the approach presented here is yielding promising preliminary results, the empirical analysis of its potential success is still in progress. Linking strategic sustainability transition goals with niche experiments in challenging areas such as academic research is a necessary step towards the operationalization of sustainability science. Engineering faculties have a key role to play, both in actively shaping the discourses and perspectives regarding sustainability, and in learning from other discourses. Finding a balance between the awareness of the importance of sustainability in research and the need for independent academic research is certainly possible. Mapping discourses to identify areas of consensus will lead to practical ways of turning sustainability science into practice. Knowledge communities might arise from such an approach, which well then lead to the acknowledgement of alternative framings of sustainability issues and to the development of inclusive solutions. Ongoing research on discourse mapping methodologies can support sustainability transition initiatives by depolarizing debates and by providing the basis for common—interdisciplinary—approaches towards sustainability science.

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An Edible Education in Sustainable Development: Investigating Chocolate Manufacturing in a Laboratory-Based Undergraduate Engineering Course

Alexander V. Struck Jannini, Christian M. Wisniewski, Mary M. Staehle, Joseph F. Stanzione III and Mariano J. Savelski

Abstract

Green engineering, sustainability, and sustainable development are topics of great import to all engineering disciplines. To introduce students to these topics, hands-on experiments were developed for inclusion within a multi-disciplinary freshman engineering course. In these experiments, students learned to produce chocolate truffles and, ultimately, challenged to analyze and optimize the sustainability of the process with a cradle-to-gate and social life cycle assessments. Student analyses incorporated waste management strategies, overall energy and material consumption calculations, carbon reduction strategies, the use of engineering software, and the importance of fair trade in this industry. Eighty-nine freshman engineering students at Rowan University completed the experiments. Pre- and post-tests were used to evaluate the effectiveness of the course on increasing student knowledge of sustainability, of sustainable development, and of the impact engineers can have on socioeconomics. Preliminary results indicate that the course was effective in enhancing student knowledge and awareness of the social and environmental implications of chocolate manufacturing. A complete analysis and description are presented in this paper.

Keywords

Education · Sustainable development · Chocolate · Undergraduate course

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1 Introduction

The continued use and depletion of non-renewable resources warrant critical efforts to drastically improve the sustainability of current manufacturing processes. In response, engineering communities have begun discussing ways to increase the sustainability of current manufacturing processes and everyday lifestyles. This process, also known as sustainable development, is used to determine ways of meeting the needs of the present without compromising future generations to meet their own needs (Brundtland 1987). This broad definition has allowed sustainable development to be implemented in several different fields. Sustainable development is now embraced by companies, governments, social reformers, and environmental activists, who each have their own interpretation of what sustainable development means (Giddings et al. 2002).

For engineers, sustainable development is defined to include process development. Aspects that are often discussed in regards to sustainable development in an engineering setting include the conservation and improvement of natural ecosystems, minimizing the depletion of renewable and non-renewable natural resources, waste prevention and management, and the improvement of technologies (Hesketh et al. 2004). Mathematical and computational tools have been developed to model the impact of such aspects on industrial processes. One such modeling tool is a Life-Cycle Analysis (LCA). An LCA is defined as an evaluation of all inputs and outputs of a process to determine the environmental impacts that are associated with it (Guinée et al. 2002). An LCA can include, but is not limited to, all stages of a manufacturing process, including the extraction of resources, the production of raw materials, the product processing, the use of the product, and its disposal (Guinée et al. 2002).

With the increased interest in sustainability and sustainable development, pedagogical researchers have developed methods of incorporating sustainability into engineering curriculums (Perdan et al. 2000; Fenner et al. 2005; Elnashaie et al. 2013). Recently, a team in Malaysia discussed methods of implementing sustainable development into chemical and biological engineering curricula, using both centralized and decentralized approaches. The centralized approach involved adding sustainable development concentrations to the major, and adding new courses that related to sustainable development engineering. The decentralized approach involved changing the structure of the "core" courses so that they focused on aspects of sustainable development. Although there has been significant research to incorporate sustainable development into engineering curricula, there has been considerably less research in incorporating LCAs into engineering education. Evans, Galvin, and Doroodchi developed two LCA example problems that can be used in a chemical engineering curriculum. The two examples, an investigation in which method is better to use for drying hands and a study on the proper location for a manufacturing plant, can be used in first year engineering courses (Evans et al. 2008). They found that student feedback to the exercises was favorable, and that they showed increased appreciation for the viewpoints of others, and a willingness to apply their own interpretations based on assumptions. Another example of LCA incorporation into an engineering curriculum involved biodiesel production. This project involved first year engineering students creating biodiesel, and then performing an LCA to compare its production to that of traditional petroleum-based diesel (Farrell and Cavanagh 2014). Their assessment showed an increased conceptual understanding of the LCA process and an average gain of 55 % in knowledge about LCA's.

In this paper, we briefly describe experiments for use in an introductory multi-disciplinary engineering course that focused on sustainable development of chocolate manufacturing. Specifically, the experiments focused on producing chocolate truffles while exposing students to engineering concepts such as waste and waste management, energy requirements, and physical property measurements. Chocolate manufacturing was chosen not only to keep student interest high, but also because of negative socioeconomic factors surrounding the industry. The cocoa production sector has been tied to child trafficking for decades (Nagle 2008). More recently, child labor has grown in West and Central Africa (where the majority of cocoa is farmed) due to a demand for larger profits (LaFraniere 2006). Child slavery and its ties to cocoa harvesting is not frequently considered by chocolate consumers, and as such can stimulate important discussions on social responsibility in manufacturing. Since the course was an introductory course, the experiments also incorporated aspects of general engineering education, such as working individually and in teams to solve engineering problems, designing and conducting experiments, and also analyzing and interpreting data (Accreditation Board for Engineering and Technology 2013). The experiments also required the students to conduct an LCA on the chocolate manufacturing process, prompting them to discuss ways to minimize food waste, to lower energy consumption, and to use sustainable, socially beneficial raw products. The purpose of this paper is to convey our preliminary results that indicate students gained knowledge and awareness of the social and environmental implications of chocolate manufacturing.

2 Experiments

Experiments were developed to teach students about sustainable development and chocolate manufacturing processes. The course was designed to be a multi-disciplinary course that introduces students to engineering through active learning activities, i.e. project-based team laboratory experiments (Farrell et al. 2001). Therefore, the experiments were designed to tie together introductory engineering concepts and the sustainable development objectives. The experiments had students work in multi-disciplinary teams in order to complete the objectives of each lab. The first and seventh experiments were held in a standard computer lab, while the second through sixth and last experiments were held in a food-grade laboratory that contained cooking equipment and food-grade raw materials. Conducting most of the experiments in a food-grade laboratory enabled the students to gain good manufacturing practices and obtain hands-on practical lab experience, all while being able to sample their chocolate truffles.

The first lab of the semester had students conduct research on LCAs and the chocolate manufacturing process. Students used online resources, such as the journal databases provided through library services. The second lab of the semester guided students to create chocolate ganache domes using couverture dark chocolate (chocolate made with extra cocoa butter) and heavy cream. Students measured the mass of raw ingredients in the beginning of the experiment, and then measured the mass of the ganache domes. Students were to see that the masses did not match, and to speculate why that was the case using a mass balance. Using mass balances was also reinforced through an exercise in which students calculated the nutritional information of their ganache domes from the nutritional values of the raw ingredients.

The third experiment introduced students to the tempering process of chocolate and energy balances. Tempering chocolate is the process by which chocolate is heated and agitated in order to recrystallize the fats and oils. Through this process, chocolate gains qualities such as sheen and brittleness that are considered desirable in chocolate products (Afoakwa et al. 2008). Students were tasked with manually tempering chocolate and using watt-meters to determine the energy requirements for the process. Energy requirements included the energy needed to boil water, the energy needed to melt chocolate, and the energy needed to maintain an elevated temperature. The fourth lab of the semester introduced students to a tempering machine, which controls the temperature of the chocolate automatically, reducing the likelihood that the chocolate will overheat. (Overheating at any point requires reinitiation and repetition of the tempering process.) Students compared the energy requirements for the tempering machine to that of manually tempering. The fourth lab also asked the students to conduct a statistical analysis on chocolate truffle products consisting of a dark chocolate ganache center enrobed in tempered milk chocolate. Students were asked to find the average and standard deviation of the ganache centers before and after enrobing. Students saw that their standard deviation increased after enrobing. This gave students insight into which processes in chocolate truffle manufacturing require extensive waste management and which require quality by design considerations.

The fifth experiment introduced the students to developing and utilizing empirical relationships. Students were given three chocolate samples of various cocoa percentages (33.4–90 %) and one sample of unknown cocoa percentage (70 %). The students were asked to determine the cocoa percentage of the unknown sample using several techniques, including: developing correlations based on melting point and absorbance in olive oil at 615 nm, and a taste test. In the taste test, a student would rate sweetness and bitterness on a scale of 1–10, with 1 being very little and 10 being very much. Students were then asked which test they felt was the most accurate and why. The sixth experiment was another investigation into energy requirements. This time, students had to find the energy required to melt various

Fig. 1 Sample truffle products made by students for the final lab. Students were allowed to choose from a variety of chocolate (white, milk, and dark) and were given the liberty to use extra ingredients (sprinkles, graham crackers, peppermint candies, etc.)

chocolate products. White, milk, and dark chocolate varying from 54 to 90 % cocoa were used. To determine the energy required to melt the chocolate, students added boiling cream to chopped chocolate in increments and used a simplified heat transfer equation to calculate the heat transferred to the chocolate based on the volume of heavy cream required to melt the chocolate.

The seventh experiment was developed to introduce students to sustainability software. Students were given a tutorial on SimaPro® and then tasked with finding life cycle inventory (LCI) data for different raw ingredients that were found in common chocolate products. The LCI data was then used in the final experiment of the semester.

For the final experiment, students were required to produce their own chocolate truffles. Each team created a unique, final chocolate truffle that would appeal to consumers and also meet sustainability requirements, such as low energy usage and waste management. The students were also asked to consider social awareness (i.e. socially responsible manufacturing of raw ingredients). An example of final truffle products is shown in Fig. 1. Teams were evaluated on their implementation of these different areas with a team presentation, where they were charged with presenting their chocolate truffle to a panel of instructors who acted as a chocolate manufacturing plant management team that was interested in all aspects of producing their delectable, including taste. Students were graded based on the information that they presented and their answers to questions provided by the panel. The taste of the final truffle product was not considered as part of their grade.

3 Assessment

In order to gauge student learning of sustainable development, assessments were used both at the beginning and at the end of the semester. The assessment instrument consisted of two parts: a Likert-Scale survey used to determine student opinions, and a multiple-choice/true-or-false section used to determine student learning.

In the Likert-Scale portion of the assessment, students were asked to agree or disagree with a set of statements. Using this scale, an answer of "1" means the student "strongly disagrees" with the statement; alternatively, a response of "5" means the student "strongly agrees" with the statement. Students were asked questions in regards to sustainability concepts and socioeconomics. Six statements from the Likert-Scale portion are shown in Table 1, along with the percent increase of the average response from pre-semester to post-semester. The results of these six statements are shown in Fig. 2. A two-tailed paired Student's t-test was used to determine if the post-assessment data was statistically different from the pre-assessment data. For five of the six statements, it was determined that the post-semester assessment data was significantly higher than that of the pre-semester assessment ($p < 1 \times 10^{-3}$). Question 4 saw no significant change ($p = 0.325$). While we would have liked to have observed a significant decrease in this answer, we consider it to be still desirable that the students generally disagree with this statement, since due to variation in the manufacturing of individual entities, nutrition labels are not 100 % precise. Overall, we found that the students were more confident in their knowledge of sustainable development, socioeconomics, and the engineering role in these areas.

For the multiple-choice/true-false section of the assessment, students were asked questions regarding similar aspects to those discussed in the Likert-Scale portion. Sample questions can be seen in Table 2. Table 2 also contains the percent increase of correct responses from pre- to post-semester responses. Figure 3 shows the percent correct responses for the questions shown in Table 2. A two-tailed, one-sample Student's t-test was used to determine whether there were significant changes between pre- and post-semester responses. While we observed a significant increase in Questions 1, 3, and 4, Question 2 did not have a significant difference

Table 1 Six representative questions from the Likert-Scale assessment, and the percent increase in the average response for each question

Number	Statement	Percent increase (%)
1	I know what a life cycle assessment (LCA) is and what it is used for	196
2	I know what a social life cycle assessment (s-LCA) is and what it is used for	212
3	I know where mass and energy are lost in the production of chocolate truffles	205
4	Nutrition label on food are 100 % precise	6.19
5	It is important that chocolate manufacturers use renewable energy resources during production	13.4
6	Engineering plays an important role in the everyday production of chocolate	8.69

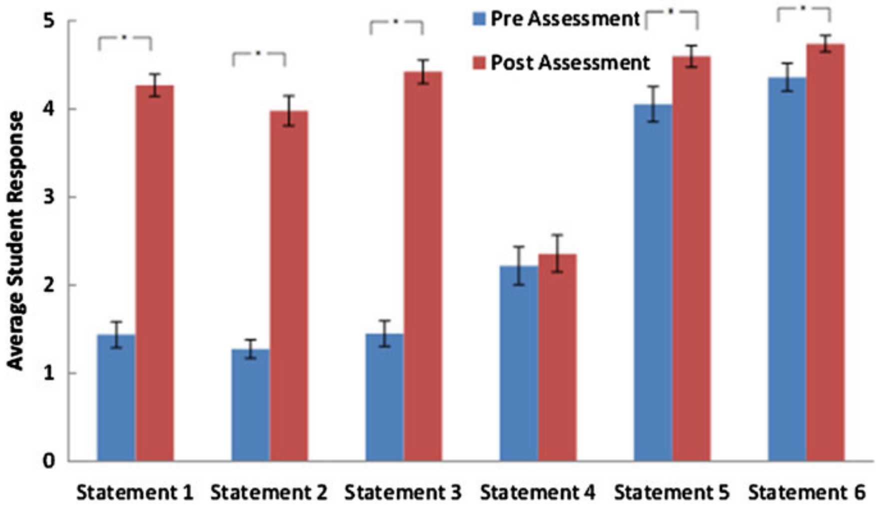

Fig. 2 The results of the Likert-Scale assessment. The statement numbers correspond to the statements in Table 1. The *error bars* are 95 % confidence intervals. The *asterisk* indicates that the pre- and post-assessment data is statistically different, with a p-value <0.05

between pre- and post-semester results. This differs from the results of the Likert-Scale portion of the assessment for this topic. From the Likert-Scale results, it would seem that students feel confident in their ability and knowledge of sustainability and sustainable development, but from the multiple-choice/true-false section, the results show that students are not able to correctly define sustainability as it relates to engineering. Another interesting finding from the multiple-choice/true-false section is that students had a high percentage of correct responses in the pre-semester test for Question 1. We hypothesize that this is due to the wording of the question and its possible answers. The correct response for this question was the only possible answer that contained the word "assessment" in its answer. Therefore, we think that students most likely determined it to be the correct response by the process of elimination.

Table 2 Sample questions from the multiple-choice/true-false portion of the assessment

Number	Question	Percent increase (%)
1	A life cycle assessment (LCA) is	14.0
2	Sustainability, as it relates to engineering, can be defined as	1.4
3	The majority of cocoa beans come from	80.2
4	Chocolate bars come in many varieties (e.g. milk, dark, or white). What is it that makes them different?	48.3

Included is also the percent increase of correct responses

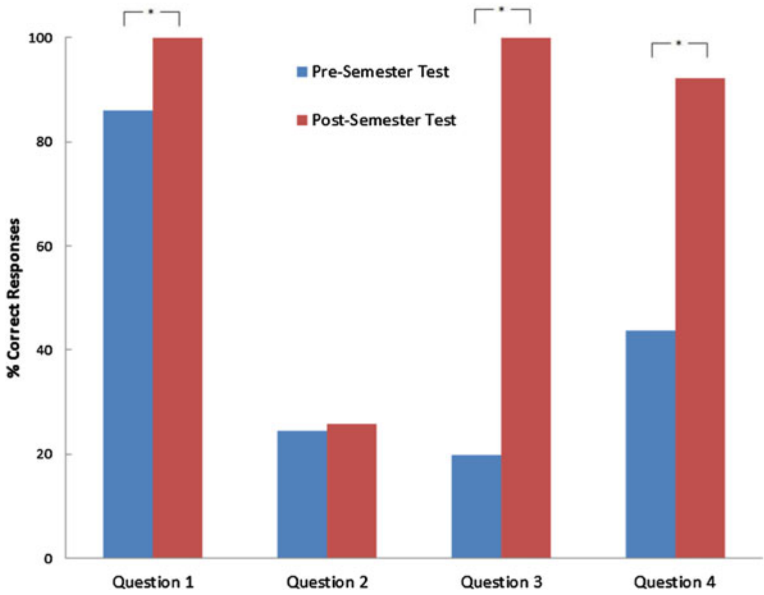

Fig. 3 The percent of correct responses to the multiple-choice/true-and-false section of the assessment. The questions correspond to Table 2. The *asterisk* symbol means that the pre-semester and post-semester results were considered statistically different, $p < 0.05$

4 Conclusions and Future Work

To increase engineering students' knowledge about sustainability and socioeconomics, eight experiments were developed for use in a lower-level multidisciplinary undergraduate lab-based course. These experiments focused on an area where socioeconomics concerns are important in the manufacturing of the product: chocolate truffles. To measure students' opinions and their gain in knowledge, an assessment was used at the beginning and end of the semester. From the Likert-Scale assessment data, it is evident that students felt more confident about their knowledge in sustainability and sustainable development topics, including the use of an LCA. The multiple-choice/true-and-false section demonstrated that the students' knowledge increased about sustainable development, socioeconomics, and related engineering concepts. This portion of the assessment also showed that while students had a high confidence in their knowledge of sustainability, they were unable to properly define it in regards to engineering. The inclusion of more time spent discussing sustainability and sustainable development with regards to engineering and editing experimental handouts to include more about these concepts are recommended to increase the effectiveness of the course at increasing student knowledge of global sustainable development.

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Author Biographies

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Design and Early Development of a MOOC on "Sustainability in Everyday Life": Role of the Teachers

Matty Janssen, Anna Nyström Claesson and Maria Lindqvist

Abstract

Universities all over the world have developed Massive Online Open Courses (MOOCs) to attract students and explore new ways of learning. The MOOC "Sustainability in Everyday Life" (SiEL) is currently in its design and early development stage at Chalmers University of Technology. It aims at developing the MOOC participant's capacity to appreciate the complexity of sustainable everyday life by developing skills such as systems thinking and critical reflection on the information flow in public media. This paper aims at sharing first experiences regarding the design and early development of the SiEL MOOC and identifying the role(s) of the teachers and its features during the course design and early development based on these first experiences. An action research approach was used to reach these aims, and the teachers' narratives about these first experiences were used as data source. Three distinct processes (pedagogical, production and interaction) and six roles (owners, teachers, learners, designers, developers and negotiators) were identified. The teachers' roles and the processes and activities taking place during the design and early development are closely linked to each other and need to be carefully considered in order to guarantee a successful MOOC design and development process.

Keywords

Massive open online course (MOOC) · Sustainability · Course design · Teacher role

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1 Introduction

1.1 Background

Universities all over the world have engaged in the development and implementation of Massive Open Online Courses (MOOCs) in the past few years. MOOC participants can be of all ages, have diverse educational background, have an interest to learn more about a topic outside of the formal university education system, and be located anywhere on the world. The number of sign-ups varies from MOOC to MOOC, but there are numerous courses with more than 100,000 sign-ups, and the largest course so far exceeds 250,000 sign-ups (EdX 2015).

Very recently, at the end of 2014, Chalmers University of Technology started the development of its first two MOOCs. As one of these two courses, "Sustainability in Everyday Life" (SiEL) was chosen after a university-wide call for proposals earlier in the year. The course is going to be published on the EdX platform under the name ChalmersX. There are several reasons why Chalmers decided to start this development and to choose this course (Janssen and Stöhr 2015):

- Branding of the Chalmers name by bringing one of its main strategic goals, sustainable development, to a digital platform with a global reach,
- Opening up higher education to a global audience, and
- Building up experience at Chalmers in developing, implementing and evaluating MOOCs.

The development of the SiEL MOOC is done by a large development team. This team consists of the authors of the SiEL MOOC proposal (henceforth called the teachers, also the authors of this paper), and several support members that take care of course design and pedagogic support, technical production, implementation on and support of the EdX platform, marketing and documentation. Furthermore, other teachers at the division where the authors of the MOOC proposal reside (the division of Environmental Systems Analysis (ESA) at Chalmers) are involved in providing course material. This paper will exclusively address the SiEL MOOC, and focus on the role and perspective of the teachers involved during the design and early development of the course. Thus, the aims of this paper are: (1) to share first experiences regarding the design and early development of the SiEL MOOC; and (2) to identify the role(s) of the teachers and its features during the course design and early development based on these first experiences.

The paper will continue with a description of the concept of the course. This is followed by a literature review regarding the role of the teacher in a MOOC. This review forms the basis for formulating several questions regarding the role and perspective of the teachers in this course. This is followed by reflections of the teachers about their motivations and first experiences so far. These reflections are then used to answer the formulated questions, and conclusions are made.

1.2 MOOC Design and Early Development Process

Although age distribution and the educational background of future MOOC participants are unknown, we attempted to define a target group including the minimum prerequisites. Helpful in this is the concept of the "informed citizen" that is defined by the European Union as the 15-year old student passing the final national tests in compulsory school (European Union 2015). Therefore, the prerequisite for the course is the knowledge gained during compulsory school.

The design of the course follows the pedagogical idea represented in Fig. 1. Five different topics related to sustainability were chosen based on their importance with regards to sustainability, and their occurrence in Swedish, Dutch, German and French media. These so-called "hot spots" are used to introduce the MOOC participants to the complexities of sustainability in everyday life. The hot spots used in the SiEL MOOC are: energy, food, climate change, globalization and chemicals. A more detailed view of a hot spot is given in Fig. 2. The course introduces each hot spot with a 15-min introductory lecture. This level aims at being a teaser and an introduction to the topic that gives some preliminary answers, but also generates questions and further nourishes the participant's interest. The second level consists of a set of mini-lectures of 5–7 min which further develop different aspects of the hot spots and add more detail to the introductory lecture. The aims of these mini-lectures are: (1) to increase the knowledge about the hot spot; (2) to show a simplified complexity by relating the hot spots to each other thus creating a level of systems thinking; and (3) to put the hot spots into the context of everyday life. It needs to be pointed out that the MOOC participants are assumed to be at the knowledge level of an university freshman at this second level (Fig. 2). The course is concluded with a final exam in which the participants are tested on their ability to make sustainable choices in everyday life situations. The possibility to construct this exam in the form of a game has been explored.

The learning outcomes of the SiEL MOOC aim at developing the participant's capacity to appreciate the complexity of sustainable everyday life by developing skills such as systems thinking and critical reflection on the information flow in public media. Furthermore, the course aims at giving the participants a sense of empowerment that enables them to move towards a more sustainable way of living (citizen stewardship).

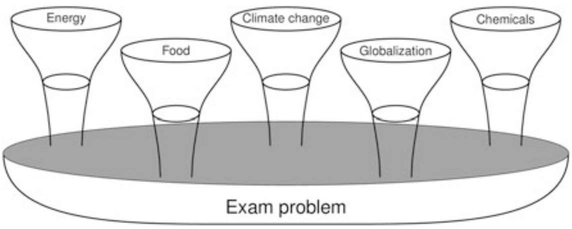

Fig. 1 The pedagogical idea used to design the SiEL MOOC

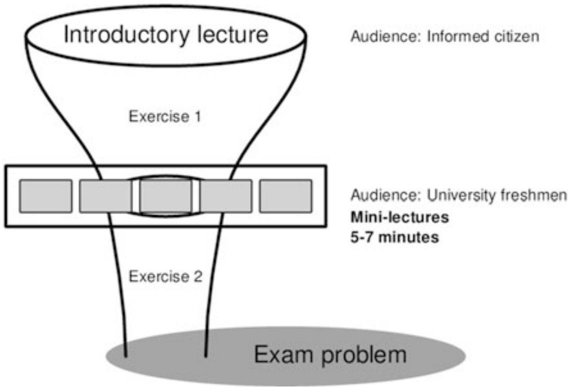

Fig. 2 Detailed view of a "hot spot" in which one of the selected topics is used to introduce the MOOC participants to the complexities of sustainability in everyday life

1.3 Literature Review

In recent years MOOCs have received a lot of media attention. While many MOOC developers believe that MOOCs are worth this hype, neither does a large majority believe that MOOCs deserve the formal credit of an educational institution, nor do they believe that it will be given in the future (Kolowich and Newman 2013). With the increased media attention, the existing MOOCs have also been scrutinized more heavily. For instance, skeptics remain doubtful about the educational value of MOOCs or question if MOOCs can give participants a satisfying learning experience (Kellogg 2013). Margaryan et al. (2015) analyzed the instructional design quality of 76 MOOCs based on First Principles of Instruction (Merrill 2002), and found that while most MOOCs are well-packaged and well-organized, the instructional design quality is low. This indicates that there is room for improvement regarding the design and development of MOOCs. MOOC design was identified, among others, as a research theme by Gašević et al. (2014). There are already examples of research in this field, see e.g. Guàrdia et al. (2013) who described ten MOOC design principles. It seems however that this research field is currently more focused on approaching the research problematic from a learner's perspective, and seems less concerned with the role and perspective of the teacher during the design and development of a MOOC (Ross et al. 2014). Nevertheless, a few studies were found in the literature that focus on this particular topic.

One study that focuses on supporting teachers in the description and design of MOOCs was published by Alario-Hoyos et al. (2014). In this study the so-called MOOC Canvas was developed which defines eleven interrelated issues of logistical, technological, pedagogical and financial nature that are addressed through a set of questions, and offers teachers guidance during the MOOC design process. In the MOOC Canvas the eleven issues are arranged under an available resources category and a design decisions category. Currently, the MOOC Canvas has only been applied to MOOCs about subjects related to technology and education, and requires validation by applying it to MOOCs that address other subjects. Ross et al. (2014) looked more closely at the role of a MOOC teacher and worked to demonstrate that paying attention to the complexity of the teacher's experience and identity might ultimately be essential to the success of the MOOC as a new educational format. The authors described their experiences in teaching a MOOC and indicated that perhaps the most difficult issue they dealt with was to what extent they needed to take responsibility for what was happening in the MOOC. Another important issue related to the role of the teachers in this MOOC was their presence and visibility. The authors conclude by saying that "we need a richer and more robust conceptualization of the teacher within the MOOC" (p. 67).

2 Research Method

The investigation into the role of the three principal MOOC teachers during the design and development of the SiEL MOOC was done using an action research approach. Action research is grounded in experience, and is action-oriented and participative (Reason and Bradbury 2001). Furthermore, Baskerville and Myers (2004) argue that action researchers need to be participant observers, and that a collaborative team is involved in reasoning, action formulation, and action taking. To the authors' knowledge little action research into MOOC design and development and the role of the involved teachers during this has been done. One study found in the MOOC literature where an action research approach was taken to study MOOC design described the MOOC design process, and participant engagement and experiences but did not focus on the role of the teachers (Vivian et al. 2014). Therefore, we chose to use the action research approach because, besides being the designers of the SiEL MOOC concept (see Figs. 1 and 2) and authors of this paper, we are all involved in the MOOC design and development.

Based on the literature review and on the aims of this paper, we sought to answer the following questions pertaining to the design and early development process of the MOOC and the role of the teachers:

1. What actions did the teachers take to initiate and make progress during the design process?
2. What have the roles of the teachers been during the design process?
3. How did the teachers manage to engage and to convey their ideas to the project group and their colleagues?

The data for answering these questions were provided by means of the teachers' narratives about the design and early development process of the MOOC. The narratives were written in chronological order describing and reflecting on meetings and other activities (workshops, seminars) that took place over a 9-month period, from early May 2014 until early February 2015. Due to the teachers' different backgrounds and tasks during these activities, different perspectives of the same activities were described in these narratives. The narratives were then analyzed and systematically reflected upon in order to answer the formulated questions.

3 Summary of the Teachers' Narratives

During the analysis of and reflections upon our narratives (i.e. the teachers' narratives), we realized that the different activities we were engaged in may be grouped into three different types of processes, namely, the pedagogical process, the interaction process and the production process (Fig. 3).

3.1 Pedagogical Process

The pedagogical process is our exploratory journey in the world of MOOCs and has been (and most likely will continue to be) very creative. We have received a lot of useful input from the other stakeholders involved (the MOOC development team, our colleagues at the division of Environmental Systems Analysis (ESA) at Chalmers) in the MOOC design and development process, e.g. on the peculiarities of running a MOOC, and on the topics of the mini-lectures that are part of each hot spot. Nevertheless, we ourselves put in the largest effort creating the pedagogical concept of the MOOC by evaluating different options. This happened during very open and dynamic sessions in which we brainstormed, discussed, and generated and structured our ideas. Many of the main elements in the course design were conceived during these sessions, e.g. the hot spots, trying to give the participants a sense of empowerment, citizen stewardship and the overall course learning outcomes. An example that reflects this creative environment is the evolution of the hot spot from the MOOC proposal up to its current form (Fig. 4). As shown, the fundamental premise stayed the same but the details of the design evolved to become more transparent, including the evolution of the MOOC participant through the course. Furthermore, we have been learning how to shape these ideas within the setting of a MOOC. The products of this process are intellectual goods for which we have a strong feeling of ownership and, consequently, about which we are rather unwilling to make compromises.

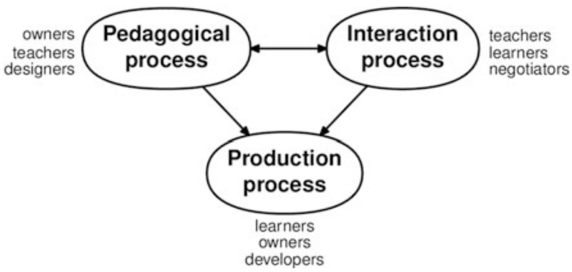

Fig. 3 Classification of processes taking place during the MOOC design and early development and the roles of the teachers in these processes

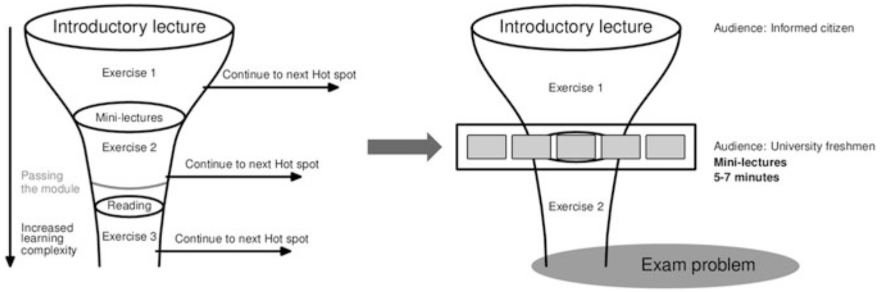

Fig. 4 Evolution of the design of the hot spots used in the SiEL MOOC, from MOOC proposal on the *left* to its current form on the *right*

3.2 Production Process

The production process has for us been characterized by informing and being informed, and by generating ideas. We have for instance had speaker training and one of us coached the speaker for one of the introductory lectures. However, we are currently only in the beginning stages of production. So far, the introductory lecture on globalization and the so-called teaser (the promotional video for the SiEL MOOC that will be on the EdX course website) have been recorded. Our interaction with the production team has been smooth, supportive and cooperative. Other practical topics that we addressed were the use and capabilities of the EdX platform, the use of social media (Facebook, Twitter, Google+, Instagram) for the promotion of the course and during the course, and the different formats that can be used in the design of the mini-lectures. In this process, we also have a sense of ownership with regards to the actual content of the recorded material. For instance, during the preparation of the teaser we argued with the production team about the story board where our ideas were not in complete agreement. We ended up finding a good compromise. Our colleagues at the division of ESA at Chalmers are instrumental in this process because several of them will record introductory lectures and mini-lectures.

3.3 Interaction Process

The interaction process is the process where we needed to make the other members of the MOOC development team and our colleagues at the division of ESA like our pedagogical ideas and go along with them. For instance, in the very early stages (before our MOOC proposal was chosen) we were asked to further clarify the aims and goals of the MOOC in an interview. Another important example was the introduction of the MOOC to our colleagues who, despite a healthy amount of skepticism and scrutiny, were positive about it. In both cases we were (more or less) promoting our ideas. Other activities were attending a one-day seminar about

MOOCs organized by the Chalmers Library where we learned about other MOOC initiatives in Sweden, and presenting the SiEL MOOC and our motivations and first experiences at the KUL conference at Chalmers (Janssen and Stöhr 2015). Within the interaction process we have also negotiated about several aspects that are part of the MOOC, see for instance the example about the teaser story board (in the previous section on the production process). Negotiation has also been a part of creating the content for each of the hot spots and will probably also be a part of motivating our colleagues to use one format or another for their mini-lectures. This process is about listening and being open-minded in order to improve an original idea where necessary. We need to guarantee that, for instance, the person doing an introductory lecture or mini-lecture has ownership of his or her idea and feels enthusiastic about what he or she is doing.

3.4 Interaction Between the Processes

The three identified processes are interlinked, that is, each process interacts with the other two processes (Fig. 3). The production process receives inputs from both the pedagogical and interaction process, whereas the latter two processes provide inputs to one another. The outcomes of the pedagogical process have been direct inputs to the production process, for instance, by coaching an introductory lecture speaker. They have also been used to inform the stakeholders about the MOOC design and development process, for instance, informing our colleagues about the SiEL MOOC. The outcomes of the interaction process have been inputs for the production process, for instance, the result of the discussion about the teaser story board. They have also been used to improve our pedagogical idea of the MOOC via feedback from our colleagues. The production process could provide inputs to the other two processes, but in this case these would most likely indicate the limits on the capacities of the production team (budget, man hours, etc.). These limits have so far not been reached.

4 Roles of the Teachers

4.1 Definition of the Teachers' Roles

The interaction between the identified processes affects the roles we, the teachers, play in each process, and we have tried to identify these roles (Fig. 3). We identified six roles that we have had during the design and early development of the MOOC so far: owners, teachers, learners, designers, developers and negotiators. Our role as owners is thanks to the strong sense of ownership we have for the pedagogical idea of the MOOC and the sense of co-ownership for the course material that is developed by ourselves, our colleagues and the production team. We act as teachers when we explain our pedagogical idea for the MOOC and when we inform and interact with others regarding our ideas about the course. We are learners when we are exposed to others' ideas about MOOC design and development or learning new skills that are needed during the production of the MOOC. We are designers when we are brainstorming and generating ideas for the course design or about specific content, and we are developers when we are involved with the hands-on development of the course material. Lastly, we become negotiators in order to enthuse all others that are involved with the MOOC design and development.

4.2 Teachers' Roles in the Identified Processes

In each process we assumed a different set of roles, and there are overlaps between these sets of roles (Fig. 3). Taking the roles of owners, teachers and designers in the pedagogical process helped us to create and design a very clear and transparent pedagogical idea that we felt strongly about and that we were able to successfully communicate to the other stakeholders involved. The roles we have had in the interaction process enabled us to inform, to receive and process new knowledge and to communicate with the other stakeholders such that we were able to find compromises if needed. The roles we took up in the production process enabled us to develop our own ideas for the content in collaboration with the other stakeholders. The roles we have during the production process will be defined with more detail once more introductory lectures, mini-lectures, and other course material such as the exercises and the exam problem have been developed.

In both the pedagogical and production process one of the roles was to facilitate interaction with the other processes: we acted as teachers in the case of the pedagogical process, and as learners in the case of the production process. This helped us to engage the other stakeholders and to clearly convey our idea about the MOOC. Furthermore, in both these processes we took up the role of owners, reflecting a keen motivation to translate our pedagogical ideas into high-quality course material. Our role as teachers is apparent in the pedagogical and interaction process, and as learners in the production and interaction process. This reflects both the importance of the interaction process itself and our willingness to inform the other stakeholders and to be informed by them. Our roles as designers, developers and negotiators are specific to the pedagogical, production and interaction processes, respectively. These are more specialized roles that are needed in these processes.

4.3 Importance of the Teachers' Roles

Our assumed roles during the design and early development of the MOOC have been instrumental in a so far smooth overall process. Our ability to switch between these roles, or combinations of roles, has apparently contributed to this. Furthermore, our strong feeling of ownership has driven the design and development of the course to a great extent. The roles through which we have interacted with the other stakeholders are of high importance and have guaranteed good and sufficient communication.

5 Conclusion

This paper is an exploration of the roles of the teachers during the design and early development of the “Sustainability in Everyday Life” MOOC at Chalmers University of Technology. We thus have not included the complete design and development process of this course. Nevertheless, this preliminary study gives some insight into the roles of the teachers involved. The teachers’ roles and the processes and activities taking place during the design and early development are closely linked to each other and need to be carefully considered in order to guarantee a successful MOOC design and development process.

Work in the near future will focus on including the remainder of the design and development process in our assessment of the teachers’ roles. This will include the design and development of exercises for the assessment of the knowledge gained by the MOOC participants and how this fits into their learning process. Furthermore, we will evaluate the MOOC once it has been given for the first time. We will also compare the design and development process of the MOOC with this process for on-campus courses in order to identify elements that may strengthen each process. We will also explore the use of material developed for the MOOC in on-campus courses.

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Understanding Impacts: Community Engagement Programs and Their Implications for Communities, Campuses and Societies

Scott Jiusto and Richard F. Vaz

Abstract

As universities increasingly involve engineering students in sustainable development work through community engagement, challenging questions arise regarding how to effectively serve the interests of both academic and non-academic participants. To date the literature on community engagement strategies such as service learning, project-based learning, and community-based research has had more to say about student experience than about implications for the university more broadly, or—critically—about impacts on community partners and community wellbeing more generally. While the potential for "real world" impact animates student learning and makes engagement meaningful, broader impacts can be hard to conceptualize and assess; arguably the more potentially consequential the impacts, the more they are likely to be mixed and hard to understand. This paper presents a simple model for thinking about community engagement program design and assessment at various scales of impact, across both academic and non-academic communities. We illustrate the model with examples drawn from a program operating in Cape Town, South Africa, where students confront a paradoxical challenge: nowhere are engineering insights and contributions more desperately needed than in the burgeoning urban informal settlements of the developing world that are home to 1/7th of the world's population, but the sustainable development strategies and cultural assumptions that academics carry with them often come undone in the social, environmental, economic, and institutional maelstrom that typically prevails in these areas. How then, if at all, are we as educators, engineers and/or community development practitioners to engage with students and community partners to advance sustainable development in such environments? How do we plan for

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and measure program success (of what? for whom?) in a context especially prone to failure of things built and relationships nurtured? How in short do we foster engagement that is thoughtful, collaborative, resourceful, respectful, hopeful, resilient and beneficial to all concerned?

Keywords
Community engagement · Sustainable development · Project-based learning · Assessment

1 Introduction: Models of Engagement Between Academia and Communities

Universities and colleges have been rapidly expanding programs that engage students and faculty with communities of various kinds in order to engender new forms of education, new insights into complex social-environmental challenges, and new forms of societal contributions from academia. While community engagement programs seek impact by promiscuously mixing education, research, action and social roles (all involved can be educators, learners, planners, creators), programs are typically informed by conceptual entry points that emphasize either (1) *student learning* (e.g., service learning, experiential learning, project-based learning, faculty-led international study), (2) *faculty research* (e.g., Community-Based Research, Participatory Action Research, etc.) or (3) *community development* (e.g., Asset-Based Community Development). With such diversity in program considerations and perspectives and a rapidly evolving landscape of initiatives, there is growing interest in how to better conceptualize and assess the impacts of such programs.

Most analysis to date has focused on student development in areas such as knowledge, skills, attitudes, and identity (e.g., Bielefeldt et al. 2010). In contrast, far less is known about program impacts on organizations that partner with universities and less yet on wider social impacts (Beckman et al. 2011). Such impacts are hard to assess both in real time, when insights may be critical to modifying goals and methods and nurturing collaboration, and retrospectively, when there are typically few resources available to tease out causal connections amid myriad overlapping outcomes, some of which continue to evolve long after the program ends. While formative assessment during and summative assessment after project completion may therefore be difficult, this should nonetheless not obscure the value of thinking explicitly and strategically about intended outcomes *prospectively,* when designing (or redesigning) a program, if one hopes to maximize common cause among partners and the potential for achieving meaningful outcomes.

At one end of a spectrum of engagement are service learning programs that Stoecker et al. (2010) criticize as proceeding from a "charity" orientation that typically puts individual students to work in communities, sometimes with little preparation and operating from an institutional perspective that can reify strong, imperialistic notions about the nature of social problems: “educated” individuals (students) discharge the academy’s social responsibility by educating and thereby empowering others (community members). While of some potential value to individuals, the “doing for others” discourse underlying such approaches can in fact be disempowering and belie a dominant concern with *student* outcomes.

At the other end of the spectrum are programs that take community development as their fundamental basis, prizing much deeper commitment to local participation and community action and impact than has been characteristic of most academic research (Stoecker 2012; Stoecker et al. 2010; Beckman et al. 2011). Academic and community partners are increasingly turning to project-based approaches to “sustainable community development,” a term we use broadly to mean strengthening the capacity of local individuals, organizations and agencies to improve the social, environmental, and economic health and vitality of “their” place and prospects for future well-being.

Despite growing interest in such programs, educators and local partners have few models to help think about how projects might positively (or negatively) impact participating organizations and through them wider aspects of community life (e.g., through changes in policy, programs, networks, built environment, etc.). In this paper we propose a conceptual model to fill this gap and illustrate its application using examples from a program operated in Cape Town, South Africa by Worcester Polytechnic Institute.

2 Thinking About Community Engagement Impacts

As a point of departure, we borrow from Stoecker et al. (2010) who offer a simple model of community impacts developed with participatory action research (PAR) practitioners. The model frames impacts at four scales—*individual relationships, organizational partnerships, community* and *system*, the latter being wider social systems that shape how communities develop. They argue that impacts should broaden over time, as community engagement efforts move from an initial focus on *research* and planning to *action* in the form of programs, structures or other outcomes with wider potential for impact. *After effects* can broaden impacts further, as when a successful program in one community informs policy or efforts elsewhere in areas such as public health, safety, economy, or environment.

Table 1 and the discussion below broadens this model to: (1) consider impacts on both *academic* and *community* sides of the engagement, as impacts are by design intertwined and often surprisingly symmetrical; (2) consider impacts first as a guide to program planning and aspiration, valuable even if assessment processes are weak and/or yield unclear results; (3) elide the distinction between research and action that doesn’t apply meaningfully in the case study nor in how many communities think about the value of engagement; (4) credit more fully than do Stoecker et al. (2010) impacts at *individual* and *organizational* levels for both their intrinsic value and diffuse but real potential for meaningful immediate impacts and “after effects;”

Table 1 A model of potential community engagement impacts

	Community Actors *(Academic Actors)*	Potential Impacts Communities ←-------------------------------→ Academics
System-Level Impacts	Political leadership structures Social movements Media and opinion leaders *(Higher education system)*	Policies and policy discourses changed/strengthened Strategies diffusing to other communities Institutional and financial resources flowing toward positive outcomes Proliferation of collaborative engagement models
Community Impacts	Key groups: children, ill, entrepreneurs, elderly, etc. Built environment *(The university community)*	Social programs operating successfully Social cohesion and decision-making enhanced Community sustainability enhanced Built environment improved Health and well-being enhanced
Organizational Impacts	Community, Non-Profit, Government, Business, Cultural, Educational Orgs *(Academic dep'ts, units…)*	Strategic planning and project development capacity Ability to collaborate and foster participatory processes Assets & Resources: ideas, data, reports, money, programs, facilities Networks, reputation and influence
Individual Impacts	Co-researchers, community leaders, local professionals *(Students as individuals & in teams, faculty advisors)*	Cross-cultural learning & empathy Confidence and sense of efficacy & contribution Project development strategic thinking and competencies Teamwork insights and skills Communication skills Professional development & asset accumulation Personal growth in realms deemed important by each individual

and (5) similarly, to be less dismissive of program outcomes that may fall short of systemic impact but that for many students and community partners can be vital learning and skill development experiences and tangible, meaningful forms of participation. Thus, while we strongly support strategizing that aims to grow impacts over time and space, as suggested by the large arrow in Table 1, we also fully appreciate the beneficial outcomes that can occur at all scales of engagement.

3 Applying the Impacts Model: A Case Study Discussion Based in Cape Town, South Africa

The Cape Town Project Centre (CTPC) was established by Worcester Polytechnic Institute in 2007 as part of the university's Global Projects Program. Each year, about two dozen students participate in the CTPC to complete interdisciplinary research projects (WPI 2015). The projects are a general education requirement intended to help students better understand connections between scientific and technological advance, social issues, and human need through an intensive problem-solving experience. Most projects are completed off campus at one of 40 project centers where multidisciplinary teams of three to five students address project challenges posed by local agencies, typically NGOs, non-profit community organizations, or government agencies. The projects "belong" to the sponsoring organizations which, along with WPI faculty advisors, guide the students and afterward advance project outcomes as they see fit. Key learning objectives for students involve critical thinking and writing, research skills, collaborative problem solving, and appreciation of the project's social and cultural context. The program includes a two month preparation term and two month field term, and students earn total credit equal to 4.5 courses.

Whether at home in Worcester or in London, Bangkok, Washington, Cape Town or elsewhere, the Global Projects Program (GPP) has student learning as its primary aim, achieved as students advance the interests of local organizations by serving in a junior consultant/project developer capacity. The program has expanded rapidly, involving over 750 students—more than 70 % of all WPI juniors—in the program for 2015–2016 and drawing on faculty from across the campus. With few exceptions, the program has not been closely linked to faculty research agendas nor aspired to independently advance community or system scale impacts outside academia or the purview of the sponsoring organizations.

The CTPC, on the other hand, has evolved to explore the potential for such wider impacts largely through projects related to sustainable community development in informal settlements, also known as squatter camps or slums (Jiusto and Hersh 2009). Student teams have built the center's understanding of issues and potential responses in such overlapping areas as housing and community centers, roads and storm water, energy, social entrepreneurship and micro-enterprise, with particular aspirations to system scale change in the areas of water, sanitation, and hygiene (WaSH) and early childhood development (ECD). Most fundamentally, the CTPC as both a social enterprise and an educational program is designed to support collaborative learning and coordinated action by community members, civic organizations, government and academics to gradually transform community conditions and create new models for informal settlement upgrading practice and policy (Elmes et al. 2012).

To these ends, the program has devised a strategic approach to student and community development called Shared Action Learning (SAL), drawing on PAR and Asset-Based Community Development strategies (Jiusto et al. 2013). SAL emphasizes the porous and necessarily improvisational nature of working with residents in poor communities, and recognizes that strong social, cultural and ecological factors often render unworkable "standard" approaches to community development, including engineering approaches that fail to deal effectively with the deeply social nature of infrastructure (Jiusto and Kenney 2015). Students are forewarned that informal settlements are difficult places to work due to social and cultural differences among key actors, intense contestation over power, resources and decision-making, and an ambiguous legal environment. It is easy for projects to fail to meet the hopes and expectations of diverse participants and stakeholders, and for success to be partial or fleeting.

Where the academic inclination might be to study such a difficult situation and draw insights that can be applied later by others, residents whose participation is ethically and strategically essential to "community engagement" are often impatient with planning processes not tied closely to action advancing their own welfare and that of the community (though the distribution of benefits among direct participants and a wider community is a perennial subject of discussion and some tension). Local activists, non-profit organizations and government also share an interest in action, yet each comes from a distinctly different institutional perspective. With limited resources and few successful examples to draw upon, a "learning by doing" approach is often unavoidable, but can spark community consternation ("Why are we being experimented on?") and fear among government and NGO professionals that trying and failing can be more threatening than doing nothing. Students and faculty can bring distinctive insights and assets, as well as liabilities, to navigating such a complex environment; in turn, the challenge these projects present can help both academic and community participants develop new, highly transferrable insights and skills.

4 Analysis of Individual Scale Impacts

The CTPC's core animating engagement is between WPI students and community "co-researchers": residents with demonstrated commitment or capacity for community service selected by local partners to work with students and share a unique learning experience. Immediately surrounding this core is a typically more professional cadre of WPI faculty advisors and staff of local organizations and agencies who simultaneously support students and co-researchers but who also potentially experience personal learning and growth themselves. The goodwill many people feel toward students and the collaborative model can foster a particularly rich environment for mutual learning across social, cultural, disciplinary, and sectoral realms. U.S. faculty can learn much from co-researchers, social movement activists, local professionals and politicians as they collectively struggle to "make something happen."

A recent alumni study found that participation in WPI's off-campus project program strongly fostered long-term impacts related to professional achievement and personal development (Vaz and Quinn 2014). On average, students participating in the CTPC report higher levels of challenge and accomplishment than students in the program overall. A total of 184 participants over seven years rated the intellectual challenge, their level of effort, and the educational value of the experience an average of 4.9 on a scale of 1–5, with similarly high ratings for gains in critical thinking, communication, and project management. These findings are corroborated by consistently high ratings given to the written work of CTPC students by program reviewers. Most Cape Town students reflecting on the experience in real time and after returning home express deep gratitude for the experience, in particular describing lessons of strength, resiliency, positivity, and even love taught them by the community members and professional staff they worked with.

Evidence of impacts on local individuals is far less systematic, but the program is designed to support community co-researchers by involving them in determining project goals, means, and implementation, and also expressly asking them about areas of personal growth and learning they would like to explore. Participation is formalized in a letter asking co-researchers to guide and teach students and faculty, as well as be active learners and project developers and representatives. At program's end, they get a certificate of participation and often other professional and personal development assets (e.g., a revised CV or an online and printed “profile” of the individual prepared by students).

These positive results emerge despite—or perhaps because—the projects are hard, often dealing with intractable and controversial problems (e.g., water and sanitation) with local partners that may struggle to work well together and to sustain initiative. Failure is an ever-present possibility, and the way forward often murky. It is notable, then, that in most cases the end of the project period is characterized by an outpouring of positive emotion and sense of accomplishment. Strong connection between co-researchers, local partners, students, and faculty is the norm. Community participants usually feel some mix of *pride* in what has been accomplished; *empowerment, momentum and new capability* to make directed change; *cross-cultural learning, demystification and confidence* when engaging with others from different social, racial or national backgrounds; *teamwork with local colleagues;* and often unanticipated, even cathartic *personal growth*, strongly echoing the same kinds of personal growth as students.

For local actors, this sense of growth and empowerment is certainly more fragile than for students, and it is not uncommon for individuals to later lose momentum and feel the sense of possibility ebb in the face of ongoing challenges. The daily grind of living amid poverty and crime, of facing jealousies and suspicions that may arise due to project participation, and the inevitable gaps in experience, resources and support can all sap follow-through, as can flaws in the advice and strategies that students and faculty proffer. While most community members have been eager to work with the program in follow-on years, the sense of loss that is the flipside danger to embracing hope is an ever-present possibility to recognize and ameliorate to the extent possible. Despite these risks, local actors generally credit the experience as advancing their potential as community leaders, job seekers, learners, etc. The apparent depth of empathy and cross-cultural engagement noted above is unusual in relatively short study abroad programs in the developing world (van ‘t Klooster 2014).

5 Analysis of Organizational Scale Impacts

Broader impacts emerge through relationships with local organizations that propose project topics and collaborate with faculty to guide student/co-researcher teams. These groups also contribute centrally to executing projects and supporting community follow-through. CTPC partners include local NGOs such as the Community Organising Resource Centre, a Shack Dweller International affiliate; the Informal Settlement Network social movement; over a dozen City of Cape Town agencies; and more informal community-based organizations (CBOs) such as the Maitland Garden Village Green Light Project. All have different perspectives on what they can contribute to and gain from program participation.

While many city agencies initially proposed "academic-oriented" projects that fit a mental model of internship or research oriented programs (i.e., projects heavy on students collecting and analyzing data and preparing a report for, say, stormwater management in a community), many now value the CTPC's more grounded, action-research orientation (e.g., developing a stormwater plan by designing and building channels with co-researchers, working out in the process systems combining formal and informal engineering strategies). Jiusto and Kenney (2015) demonstrate how such action-oriented, student-community work on stormwater or other engineering concerns can lead also to peer-reviewed publications that speak to academics and practitioners. City agencies that can be risk averse may use the program strategically to test new approaches to vexing problems. The city can represent the effort as one of students and community: success can be shared, failure owned by others. But because the relationship is one of truly *working with* rather than *researching about* local government, staff often devote considerable effort to sharing insights into institutional dynamics in South Africa and strategizing together how to overcome impediments to healthier, more sustainable communities. These insights inform not only project design and execution, but faculty scholarship and the evolution of the CTPC.

Community organizations, on the other hand, generally value tangible outcomes—a crèche (i.e., preschool/daycare), WaSH facility, or youth program, for example—that benefit the community and/or group members themselves. Community organizations are usually shoestring operations or micro-enterprises looking for support and nurturing to become more sustainable. Organizational decision-making processes and resource considerations are perennial challenges. Individual co-researcher and small CBO impacts often overlap; the CTPC benefits from their deep insights into community life and the learning that comes with trying to understand the challenges that social and profit-based entrepreneurs face, and how in two months the program might advance their aspirations and thereby in some measure community wellbeing.

In our experience, the richest sustained organizational impact occurs between our academic organization and the small non-profit organizations that serve but do not necessarily reside within a poor community. The most compatible of these organizations: (1) work on compelling and important issues that resonate with students and faculty; (2) have experience working with students and devote significant time to guiding them; (3) embrace a "learning by doing" development strategy; (4) have young staff members who can benefit professionally and personally from the relationship. The relationship between the CTPC and core NGOs is so symbiotic that our core community development strategies overlap and are pursued together, as we try to use our complementary strengths and assets to imagine, fund, and execute sustainable community development projects. Construction-related projects in particular have become intensive experiments in how to meld diverse parties' distinctly different approaches to design and construction to develop facilities in the difficult informal settlement context where legal and regulatory regimes are inchoate and the building process is fraught with theft, vandalism, political meddling, compromised workmanship, contestation for job opportunities, inadequate supply of water and electricity, and the like.

NGO and city partners that sustain a year-round engagement with communities now count on the CTPC for an annual infusion of energy, insight and capacity. CTPC student projects in informal settlements in turn would be impossible without the knowledge, advance work and staying power of local partners. These organizations also accept the risks of embracing ambitious work with students and visiting faculty: they can be overtaxed during engagement and left afterward with unfinished construction projects, flawed programs, upset communities, angry politicians, frayed nerves and other miseries.

Despite such risks, CTPC partnerships usually endure over a number of years. Organizations appreciate close collaboration in project design; they get a team of students and faculty advisors rather than individuals requiring individual oversight; and the program embraces action as a research and learning strategy. The program can also sometimes bolster organizations' *finances* (helping with proposals and fundraising—over $500,000 in eight years); *knowledge resources* (data collection and analysis, documenting successes); *staff development* (informal mentoring); *capacity for participatory action* (student efforts as a force multiplier); and *reputation* (visible innovations in settlement upgrading and national and international awards). These benefits are all rooted in the significant time that students and faculty invest in each project, estimated at 2000 or so hours of total WPI effort over four months.

On the academic side, "community organizations" are the academic departments and other units that advance the university's educational and research missions. The CTPC and other GPP centers take on complex socio-technical challenges that involve students and faculty from diverse disciplines, inevitably leading to sharing of ideas not just about the project, but about the nature of social and technological change and the university's mission. Beyond seeding broader academic collaboration, the program also provides a compelling reason for other campus organizations such as the library, student counseling, risk management, health services, financial aid, and others to work together more closely, advancing their individual missions and the university community's sense of collective purpose and accomplishment.

6 Analysis of Community Scale Impacts

Community scale impacts leverage individual and organizational processes to deliver opportunities or benefits to larger social groups, such as children, the elderly or disabled, micro-entrepreneurs, neighborhood residents, or an entire community. While some development professionals, academics and citizens frame project assessment largely in terms of more-or-less directly measureable community impacts, co-researchers and others often also value how public participation can stimulate subtler, longer-term progress in knowledge, attitudes, networks, experience, and ultimately capacity to leverage "sustainable development processes" to benefit themselves, their associates and their communities.

A small programmatic example is the Green Light Project, a CBO formed in 2011 through a student project with community volunteers to support health, jobs, children, seniors, and culture. Like most tiny volunteer organizations, it relies heavily on the commitment of a few individuals and is thus institutionally vulnerable; but it has become a registered non-profit, recently celebrated its fourth anniversary, and has added a soup kitchen. While the soup kitchen clearly doesn't address the root cause of hunger in the community, it does express residents' desire to reduce suffering and reinforce social solidarity. A team in another part of Cape Town recently rehabilitated a shelter for abused women and children as an exercise in healing and facilities improvement through the strong participation of the women and staff.

On a larger scale, student teams in two informal settlements have contributed to "reblocking," an approach to upgrading in South Africa that partners community teams with local government and civic groups to tear down settlements in stages, making room for roads, sewerage, electricity, drainage and new shack homes reorganized to promote security. These are difficult and contentious undertakings; community members must decide to engage in an uncertain process, contribute financially, engage in spatial planning exercises to negotiate the size and location of new shacks, elect leaders and form construction crews, and face delays and uncertainties at every turn. A student team in 2013 helped advance pre-construction efforts in Flamingo Crescent settlement and a year later another team was instrumental in designing and building a crèche and playground and convening a crèche management board, principal, and teachers. The program also supports non-material project impacts. For example, many informal settlements are communities in name only; residents may know few neighbors and live in suspicion or fear. Reblocking is thus as much about promoting leadership, cohesion, hope, resourcefulness, and capacity to collectively improve living conditions and opportunities, as it is an exercise in effective engineering design and construction under duress.

These engagements also affect the university "community." The Global Projects Program is WPI's most distinctive element, a source of identity and shared pride across campus and an asset for recruiting students and faculty. Arguably, the deeper the aspiration for community engagement and sustainable development outside the university, the greater the need to reinvent the university toward these ends. Not only must the curriculum support project-based learning opportunities for students, faculty review processes must support knowledge creation and academic work that is participatory, applied, culturally informed, multidisciplinary, and in service of diverse social groups.

7 Analysis of System Scale Impacts

The CTPC mission to support learning and action to advance sustainable community development was driven by urgent needs and a corresponding dearth of practical guidance for development practitioners working in informal settlements. Students have built the center's understanding of issues and potential responses in such overlapping areas as roads and stormwater, housing and community centers, energy and entrepreneurship, with particular aspirations to *system scale change* in the areas of early childhood development (ECD) and water, sanitation, and hygiene (WaSH). While far from fulfilled, these aspirations nonetheless inform project choice and strategic risk-taking and have led to promising early success.

The reblocking efforts noted above illustrate an intention to pioneer system change in both the *process of collaboration* among community, civil society and government and in treating upgrading not as a housing problem but as a *community development opportunity*. In that light, a specific contribution that was made to address community concerns about unattended children playing in the street was to integrate plans for a crèche and playground into the 2013 reblocking plan. New ECD partners were also recruited to support a community-based process that in 2014 built the crèche and playground and formed a management team, all part of a pilot project recently endorsed by the Mayor of Cape Town, Patricia de Lille, as a model for future development.

The aspiration to create new models for WaSH provision is driven by a crisis affecting millions of South Africans. There is strong demand for new approaches that support health, dignity, and functional sustainability. WaSH-UP is the CTPC's upgrading initiative built through collaborative projects over eight years, including in 2012 a strategic risk taken to build a facility aimed at changing the imagination about how communal facilities are built and operated. In contrast to untended, frequently dysfunctional toilets and taps, the WaSH-UP facility is an aesthetically pleasing place with space for social amenities and public health promotion. Another new facility under development with community labor and leadership will enhance environmental sustainability through waterless, urine-divergent toilets. The facilities are regularly toured by local and international urban development practitioners, activists, academics, and politicians, including (twice) the Premier of the Western Cape Province. Translating such interest and expressions of support into tangible policy change and resource flows is far from certain, however. While demonstrably more promising than existing approaches, major hurdles remain to sustainably operating the existing facilities, to say nothing of scaling up to meet huge national demand and achieve "system-level" impact.

As increasing numbers of educational institutions embrace project-based, community-engaged learning strategies, the academic "system" is slowly changing as well. Such programs can serve as models for engaging students and faculty meaningfully with local partners in sustainable development efforts that balance community and academic impacts at a range of scales. Prospects for systemic influence depend in no small part on understanding, documenting, and assessing such impacts.

Stoecker et al. (2010) argue the institutional infrastructure needed to support transformative work with communities “does not yet exist in higher education” and that a stronger commitment to assessing community impacts is a necessary predicate to getting there. While meaningful assessment will remain difficult both for academic institutions and community partners, the model described in this paper can provide a starting point for more intentional program design and assessment. Use of the model in anticipatory ways can highlight for all participants potential impacts at different scales. Even when evidence of impact is elusive, clear intentions regarding both academic and community impacts, from the individual to the systemic level, may increase the likelihood of positive outcomes for all.

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Developing Role Models for Engineering and Sustainable Development: Engineers Without Borders' Global Engineering Certificate

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Abstract

The presence of role models within the engineering community has long been an integral component of the education and cultivation of successive generations of the profession. As the profession continues to grow and evolve, new types of role models are required to reflect the changing nature of the world within which the profession exists. One such evolution is the creation of Global Engineers, professionals who are competent in an increasingly complex and globalized society. In this paper, we explore the function of role models in creating shifts within the profession in past decades and discuss the Global Engineering Certificate being implemented by Engineers Without Borders Canada at several Canadian universities to help develop role models within the Global Engineering space.

Keywords

Global engineering · Sustainable development · Certificate · Engineers without Borders · Education

1 Introduction

Globalization has been a widely discussed and debated topic since the dawn of the millennium. The increasingly rapid movement of people, ideas, goods and capital has its advantages but has also led to an exacerbated disparity between the rich and

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the poor (Shangquan 2000). Engineers that consider economic, environmental and societal aspects at work must be aware of globalization and how it factors into their work.

Due to the trends of globalization, the changing role of engineers in society, and the broad-scale changes in secondary education, Engineers Without Borders Canada (EWB) believes that more Global Engineers are needed to tackle the complex problems of the 21st century. EWB defines Global Engineers as those who have the following knowledge, skills and attributes:

- Awareness of globalization and its impact on engineering practice,
- Capability of performing leadership roles in interdisciplinary work environments,
- Competency in exploring complex societal issues,
- Ability to apply technical skills in a global context.

EWB believes that increasing the number and visibility of Global Engineer role models is an important step to foster the development of future Global Engineers. Within the Canadian context, role models play a key role in the engineering community. This paper explores examples of how role modeling has been used within engineering to increase the number and visibility of women, aboriginal peoples and environmentally sustainable design engineers. We discuss (1) why EWB believes that role modeling is key to increasing the number of Global Engineers graduating from accredited Canadian engineering institutions, (2) EWB's strategy to increase the number and visibility of Global Engineer role models, and (3) how EWB's Global Engineering Certificate Program is structured to support the creation of more Global Engineer role models.

2 Case Studies: Role Models in Engineering

In this section, we explore the key functions that role models played in changing the Canadian engineering profession in response to emergent issues. In this work, the case studies we examine include women in engineering, Aboriginal students in engineering, and environmentally sustainable design engineers. We show that role modeling was key to increasing the representation of these sub-groups within engineering and that role modeling will therefore play a key role in increasing the visibility and number of engineers who demonstrate the characteristics of Global Engineers.

2.1 Women in Engineering

Engineering has traditionally been a male-dominated profession and community in Canada. The question of how to engage more women in the profession has being a perennial issue raised at all levels. From 1999 to 2013, female enrollment into Canadian engineering programs has decreased from 20.6 to 18.9 % (Engineers Canada 2013). Further, the proportion of engineering students who transfer programs and the proportion of engineers who change professions is higher for females than males (Fouad 2014). This attrition is often attributed to the engineering culture that perpetuates stereotypical male behaviour within student communities and a limited perception of prospects for women upon entry into the professional community (Fouad 2014). The percentage of women in high influence positions in the engineering education community remains low with an average of 9 % of tenured professors being women across Canada in 2013 (Engineers Canada 2013).

As an aspect of one's identity with a socially visible component, female engineers can very easily become role models to trigger more women joining and staying in engineering simply by their presence within the engineering community. In a study examining the performance of a cohort of chemical engineering students, a lack of women role models was identified by the investigators as a source of steadily declining performance among female students compared to their male counterparts (Felder et al. 1995). Within academia, mentorship relationships are more likely to be successful when the mentors reflect characteristics and traits that the mentee can empathize with (Chesler and Chesler 2002). Sonnert et al. (2007) further found that the more relatable role models are to the desired path of women engineering students, the greater influence this has on academic performance and graduation rates.

Efforts to address the challenge of insufficient role models for women in engineering have largely focused on addressing this role model deficit by shining a light on women within the engineering profession through awards and recognition in publications from professional associations and universities. In addition, numerous committees and organizations across the country advocate for ongoing efforts to find new and better ways to recruit women to study engineering. These organizations undertake interventions during adolescence, challenging the dominant engineering culture, and hosting spaces for these issues to be discussed and explored. Several examples include the National Conference on Women in Engineering, Engineers Canada's Women in Engineering Committee, and the Women in Scholarship, Engineering, Science and Technology organization based at the University of Alberta.

2.2 Aboriginal Students in Engineering

Another population that is disproportionately underrepresented within the engineering community is Aboriginal students and professionals. The Aboriginal community in Canada is growing faster than the non-Aboriginal population, yet enrollment within engineering schools remains low (Statistics Canada 2011). This underrepresentation within the engineering community is often attributed to disconnects between traditional ways of knowing and contemporary science, and socio-economic barriers to Aboriginal students accessing higher education (Canadian Council on Learning 2007). But the lack of visibility of successful Aboriginal role models within the engineering profession also plays a significant role in limiting the perceived opportunities that Aboriginal students see as available to them.

As noted above with respect to women in engineering, the closer that an individual is able to empathize with a mentor the greater of an impact that mentor will be able to have in increasing the perceived opportunities of their mentee (Lockwood 2006; Gibson 2004). In the case of Aboriginal representation within the profession, Aboriginality is not always a visibly identifiable component of one's identity. As such, efforts to connect prospective students with professionals requires established programs such as that initiated by the Association of Professional Engineers and Geoscientitst of Alberta (APEGA) in Alberta which connects professional mentors with students in five high schools in Edmonton and Calgary with high Aboriginal student populations (Littlechild 2012). The Canadian Council of Professional Engineers has made efforts to connect Aboriginal students to Aboriginal engineers through their outreach and education programs, including an online platform highlighting "A Day in the Life of an Engineer" (Pleasant-Jetté and Wiseman 2006).

2.3 Environmentally Sustainable Design

As the importance of environmental sustainability has grown in increasing importance within engineering, new ways to teach and engage engineering students about their role in practicing sustainable work has also become increasingly important (as evidenced by the existence of the conference at which this paper was presented, the International Conference on Engineering Education for Sustainable Development 2015). Integration of sustainability concepts into the engineering curriculum has become integral to the accreditation of undergraduate degrees in Canada.

Unlike women or Aboriginal representation in the engineering profession, role modeling excellence in environmental sustainability is a much less visibly identifiable characteristic of a role models identity. Within practicing engineering communities, the Leadership in Energy and Environmental Design (LEED) program is an example of a third party validation of sustainable design which can be used as an example for others to follow from. This is limited in that it focuses particularly on building construction and design, which makes it particular to one discipline. Similar programs such as Environmental Professional accreditation typically focus on those disciplines or practice areas that have a clear connection to environmental sustainability and do not always encompass areas which have less tangible relationships to environmental sustainability. In our increasingly interconnected and complex world systems, drawing attention to sustainability is important in all aspects of engineering practice and the skills of systems thinking and complexity analysis are integral to a comprehensive engineering education.

3 EWB's Theory of Change

EWB's organizational mission seeks to accelerate systemic innovations in Canada and Africa that have the potential to disrupt systems that allow poverty to persist. Engineers, as part of this global system have the ability to create positive change in all aspects of their work. In order to tackle the complex problems of the 21st century, engineers need to be equipped with the right skill set to interact in the globalized world, a skill set we define as those of the Global Engineer.

3.1 Why Role Models?

Engineering training is built on a foundation of role models from our professors at school, to professional mentors that teach us how to perform the act of engineering with integrity and effectiveness. Our professional institutions require that new engineers, those who are still "in-training", have their work overseen by a seasoned professional who is wise in the ways of their practice. This model has served our profession well in terms of training technically proficient engineers.

As discussed earlier in this paper, role models have been used within the engineering profession to increase the number of women, Aboriginal students and environmentally sustainable professionals. This leads to the conclusion that role models are a key component in encouraging development of a specialized type of engineer. In order for the engineering profession to evolve and tackle the complex problems of the 21st century, Global Engineer role models will be key in inspiring the development of more Global Engineers.

3.2 Why a Certificate Program?

EWB theorizes that the Global Engineering Certificate program will streamline the path that a student needs to take in order to gain skills as a Global Engineer. We believe its effects will include (1) highlighting current Global Engineers as role models, (2) inspiring more engineering students to gain the knowledge, skills and attitudes of a Global Engineer and (3) making clear the path that a student needs to follow in order to gain the knowledge, skills and attitudes of a Global Engineer.

4 Certificate Design

The Global Engineering certificate contains two main components, the first being theoretical (three half-course equivalents) and second, practical (120 h of co and/or extra-curricular activity). The aim of having both of these experiences is to ensure the students are able to not only learn Global Engineering theory but also have experience in applying Global Engineering concepts and apply them in a real-world situation. As the practice of Global Engineering is about dealing with complex problems of the 21st century, it will be vital for students to experience the challenges that are coupled with creating and implementing a solution to complex and ambiguous problems.

While the certificate program offers EWB a mechanism to validate a level of global education for the certificate recipients, an integral component of our theory of change relates to other students wanting to emulate these role models and pushing the limits of their own education.

4.1 Learning Outcomes

The learning outcomes of the Global Engineering Certificate build off of the 2014 Canadian Engineering Accreditation Board (CEAB) Graduate Attributes (Engineers Canada 2014): The key learning outcomes of the Global Engineering Certificate are as follows:

1. Aware of globalization and its impact on engineering practice,
2. Capable of practicing leadership roles and interdisciplinary work environments,
3. Competent in exploring complex societal issues,
4. Able to apply technical skills in a global context.

4.2 Theoretical Component

Three courses are required under the theoretical component of the Global Engineering Certificate: (1) Introduction to Global Engineering Course, (2) Discipline-Specific Global Engineering Course and (3) Interdisciplinary, Project-based Course. The courses have been selected in order to fit into a student's graduation requirements from their home university meaning that enrollment in the Global Engineering Certificate does not necessitate an increased course load. In order to fulfill the Global Engineering Certificate requirements, the student must successfully pass the courses in question. Approval of a course's ability to meet the stated learning objectives will be lead by EWB.

Introduction to Global Engineering Course: The Introduction to Global Engineering Course is meant to be the first formal interaction that students have with Global Engineering concepts when they enroll in the certificate. The Introduction to Global Engineering course content will be reviewed by EWB to ensure that the learning outcomes are achieved by said course.

EWB has outlined the following learning outcomes for students who complete the course:

1. Be able to perform critical analysis of engineering practice in a globalized world context,
2. Be able to form opinions on how technology contributes to changes in society and vice versa,
3. Demonstrate knowledge of the historic and present role of engineers in global systems,
4. Possess a functional understanding of globalization and development as complex systems,
5. Understand the role of engineering in systemic change,
6. Be aware of systemic failures in technical and societal systems,
7. Be able to evaluate and make decisions on technology, policy and processes as leverage points for systemic change.

When the Global Engineering Certificate was launched in fall 2014 at Memorial University of Newfoundland (MUN), the EWB's Online Introduction to Global Engineering course was not available. Students working toward the certificate in 2014/15 were required to fulfill the course component by taking MUN's ENGI 8151: Technology, Sustainable Society and International Development. The ENGI 8151 course offered by MUN was available both in-person and online, the course was also available to students who did not study at MUN. In the future, EWB plans to offer the Introduction to Global Engineering course online. The platform that will host the course will also provide a library of Global Engineering resources in the form of a library and online network of Global Engineering students and professionals.

It is recognized that some Universities might be keen to develop their own, in-person Introduction to Global Engineering Course, in this case, EWB would work with the universities to develop these courses. The development of Introduction to Global Engineering courses by individual universities will show a positive sign that Universities are eager to further purse the inclusion of Global Engineering concepts in their curriculum.

Discipline-Specific Global Engineering Course: The Discipline-Specific course will cover frameworks, techniques and knowledge that enable Global Engineers to approach discipline-specific system level design in a globalized world as well as in low and middle-income areas of the world. By the end of the class, the student will be in a better position to approach system level design to choose appropriate technology and resolve technical "discipline" engineering issues in a globalized context.

EWB has outlined the following learning outcomes for students who complete the course:

1. Be equipped with a foundation to apply their technical skills in a global context,
2. Develop knowledge of the role of their discipline of engineers in global systems,

3. Understand system level design to develop appropriate engineering projects in a globalized context,
4. Possess competency in exploring complex disciplinary technical problems
5. Have knowledge of appropriate discipline-specific tools for engineering design in different international contexts.

There may be cases where a course has been missed for pre-approval, in this case it will be up to the student to justify how the course they have taken does meet the required learning outcomes of the Discipline-Specific Global Engineering course. This information would be taken into account when EWB publishes the updated list of approved courses for the certificate.

At MUN and the University of Calgary, the first audits revealed that certain disciplines did not have a Discipline-Specific Global Engineering course that could apply to the certificate. In this case, if a University were interested, EWB would work with them to either develop or modify a course to meet the stated learning outcomes.

Interdisciplinary, Project-Based Course: The Interdisciplinary, Project-Based course will require the student to be involved on an interdisciplinary team project involving the application of engineering principles, design and project management concepts.

The following learning outcomes for that students who complete the course:

1. Practice their awareness of globalization and its impact on engineering projects,
2. Demonstrate leadership and interdisciplinary team skills,
3. Practice and apply disciplinary technical skills in a global engineering project,
4. Demonstrate effective communication skills,
5. Develop an understanding the dynamics present within a team, risk management and diagnosing common project problems,
6. Knowledge of Global Engineering Projects and common attributes of successful and unsuccessful projects.

This course will likely be the 4th Year Design Course that is required by the CEAB. All 4th Year Design Courses do not necessarily include an interdisciplinary or global component, in this case students would be required to modify the base requirements of their course in order to meet the learning objectives. Upon completion of the course, the students are required to submit a reflection paper to confirm that they have fulfilled the learning outcomes. Other project courses may be eligible for the certificate, EWB plans to work with each university to determine which courses fall under this category.

4.3 Practical Component

The practical component of the Global Engineering Certificate requires each student to complete 120 h of experiences that will aid the student in enhancing their leadership, teamwork and communication skills. Within the broader statement of leadership, the student will be asked to develop the core competencies of a leader: commitment, congruence, emotional intelligence, collaboration, common purpose, community and change. These competencies are based on "The Seven C's: The Critical Values of the Social Change Model" developed by Wagner (2006). These values have also been referenced in a national study performed by the U.S. based, Multi-Institutional Study for Leadership (Dugan and Komives 2007).

EWB has outlined the following learning outcomes for the practical component:

1. Develop leadership skills including: Communication, listening, global collaboration, ethics, willingness to seize new opportunities and the ability to participate in, foster and motivate teams,
2. Demonstrate ability to develop plans and iterate on plans based on identified goals and objectives to foster innovation,
3. Demonstrate ability to monitor and reflect on personal leadership and progress,
4. Deepen understanding and appreciation of the complexity and value found in connections with team members,
5. Participate in building a community for Global Engineering leaders to connect and learn together,
6. Develop the following core competencies of a leader (see above).

These Global Engineering experiences could take the form of leadership roles on and/or off campus, leadership training, engineering practice (via internship, co-op or summer work terms), intensive volunteer, study or research abroad experiences or mentorship of other students enrolled in the Global Engineering Certificate.

5 Conclusion

In this paper, we discussed why Global Engineers are needed to tackle the complex problems of the 21st century, how role models were instrumental in furthering other sub-groups within engineering (specifically women in engineering, Aboriginal students and environmentally sustainable design professionals), how the Global Engineering Certificate Program can help to fill the role model gap, and how the certificate is structured to develop and promote Global Engineers. By highlighting Global Engineers and filling the role model gap, more students can be inspired to gain the knowledge, skills and attitudes of Global Engineers.

Ongoing monitoring and evaluation is a key part of EWB's strategy to further develop the theory of change. Close conversation with partner universities and students is required to ensure that the certificate is modified based on lessons learned and well positioned to create high-quality and high-visibility Global Engineer role models.

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Systems Thinking for Dealing with Wicked Sustainability Problems: Beyond Functionalist Approaches

Johanna Lönngren and Magdalena Svanström

Abstract

Many of the most pressing sustainability issues are not purely technical problems. To work for sustainable development (SD) requires addressing wicked sustainability problems (WSPs), such as climate change, poverty, and resource scarcity. Previous research has shown that addressing WSPs is challenging for engineering students. In particular, students may feel overwhelmed by a WSP if they lack appropriate tools for dealing with the complexity, uncertainty, and value conflicts that are present in the situation. In this paper, we aim to investigate whether systems thinking competence (ST) can provide such a tool in engineering education for sustainable development (EESD). For this purpose, we elaborate on previous descriptions of WSPs, and draw on (E)ESD literature about ST to discuss different approaches to ST and their usefulness for addressing WSPs. We conclude that ST indeed can be valuable for addressing WSPs, but that it is necessary to be clear about how ST is defined. We suggest that mainstream approaches to ST in engineering education (EngE) are not sufficient for addressing WSPs.

Keywords

Systems thinking competence · Wicked sustainability problems · Sustainable development · Engineering education

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1 Introduction

Many of the most pressing sustainability issues are not purely technical problems. To work for sustainable development (SD) requires addressing highly complex and contested problems, such as climate change, poverty, resource scarcity, environmental degradation, and global health problems. Such problems have been called *wicked sustainability problems* (WSPs) (Lönngren 2014).

Research on engineering students' approaches towards WSPs indicates that fully integrative approaches to WSPs are most useful for addressing WSPs. Lönngren Ingerman, and Svanström (forthcoming) have shown that adopting such integrative approaches to WSPs can be challenging for engineering students. Students may feel overwhelmed by a WSP if they lack appropriate tools for dealing with the complexity, uncertainty, and value conflicts that are present in the situation. If students lack such tools, they may understand a problem as a complex system, but still expect to be able to solve it by dividing it into separate parts and solve each of these parts in isolation, i.e. they abandon the systems perspective as soon as they attempt to solve the problem. As students realize that their proposed non-systemic solutions are inappropriate, they may conclude that nothing can be done to improve the situation. Such a conclusion prevents them from further striving to address WSPs.

In this paper, we aim to investigate whether *systems thinking competence* (ST) can be a valuable tool for facilitating a fully integrative approach to WSPs that takes into account both systemic complexity and the presence of normative conflicts. We focus particularly on the context of engineering education for sustainable development (EESD). For this purpose, we first elaborate previous descriptions of WSPs by contrasting the concept of WSPs to other commonly used terms such as *ill-structured problems*, *wicked problems*, and *design problems*. Second, we draw on (E)ESD literature about ST to identify different approaches to ST and discuss their usefulness for addressing WSPs. We conclude that ST indeed can be valuable for addressing WSPs, but that it is necessary to be clear about how ST is defined. We suggest that mainstream approaches to ST that are widely used in engineering education (EngE) (and to some extent in EESD) are not sufficient for addressing WSPs.

2 Wicked Sustainability Problems

Jonassen (2000) collected descriptions of a large number of problems from diverse professional, personal, and political contexts. Based on a cognitive task analysis of these problems, Jonassen offers a tentative typology of eleven problem types that are organized along a continuum from well-structured to ill-structured problems. Jonassen further suggests that the more ill-structured a problem is, the more challenging it is to address the problem.

The term *ill-structured problems* has been used by other scholars to describe problems that involve a high degree of uncertainty (Jonassen 1997); lack definite right or wrong solutions (Voss et al. 1983; Simon 1981; Kitchener 1983; Cho and Jonassen 2002); are highly contextualized (Jonassen 1997); involve political considerations (Fernandes and Simon 1999); and are characterized by a high level of inherent ambiguity and normative conflict (King and Kitchener 1994; Jonassen 1997), as well as unclear goals, unstated constraints, and multiple criteria for evaluating solutions (Jonassen 1997; Voss 1987). Unfortunately, despite the widespread use of the term ill-structured problems, connotations associated to the term differ significantly between scholars. In particular, not all scholars (e.g. Simon 1973) highlight the normative dimension (i.e. the presence of normative conflict) of ill-structured problems.

Wicked problems is an alternative term that has been widely used in contexts such as design research (e.g. Buchanan 1992) and sustainability research (e.g. Seager et al. 2012). The term wicked problems was originally introduced by Rittel and Webber (1973) to describe design problems in the domain of social planning, and it explicitly addresses normative dimensions of such problems. Rittel and Webber provided a list of ten characteristics that distinguish wicked problems from what they thought to be the mainstream understanding of problems in domains such as science and engineering:

1. There is no definitive formulation of a wicked problem. [Definitely describing a wicked problem requires that one already knows what the solution will be.]
2. Wicked problems have no stopping rule. [It is always possible to further improve a solution to a wicked problem.]
3. Solutions to wicked problems are not true-or-false, but good-or-bad.
4. There is no immediate and no ultimate test of a solution to a wicked problem. [Because of complex systems interactions, a solution to a wicked problem will have consequences that will reach far into the future and into distant parts of the system. To evaluate a solution to a wicked problem, one would need to wait until all these consequences have occurred.]
5. Every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.
6. Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
7. Every wicked problem is essentially unique. (…) There are no classes of wicked problems in the sense that principles of solution can be developed to fit all members of a class.
8. Every wicked problem can be considered to be a symptom of another problem.
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. (…) The analyst's "world view" is the strongest determining factor in explaining a discrepancy and, therefore, in resolving a wicked problem.
10. The planner has no right to be wrong. (…) Planners are liable for the consequences of the actions they generate. (Rittel and Webber 1973, pp.161–167).

Farrell and Hooker argue that Rittel and Webber's description of wicked problems needs to be understood in the historical context in which it was developed:

> At the time of writing, Rittel and Webber were responding specifically to the disappointed expectations aroused by the new systems approaches to problem solving that would bring the social sciences within science and engineering, and more generally to still broader claims for computational approaches to mind and artificial intelligence, engineering and formal management approaches to problem solving, and the like that would permit subsumption of psychology generally (thence economics, etc.) and so also design under the prevailing logical conception of scientific rationality. (Farrell and Hooker 2013, p. 682).

Farrell and Hooker (2013, 2014) argue that since then, much has changed in the understanding of science, engineering and design. Most importantly, science is no longer understood as a purely logical, machine-like activity but a highly contextualized process that results in ever-changing theories with which humans attempt to understand the world. Farrell and Hooker lament that, despite this changing conception of science, design and engineering, the kind of "negative response" that Rittel and Webber offered "to such rationalising ambitions remains widely supported throughout the literature on design process" (Farrell and Hooker 2013, p. 682).

In an attempt to disrupt the common understanding of *design problems* as fundamentally different from science problems, Farrell and Hooker (2013) discuss each of Rittel and Webber's ten characteristics of wicked problems in relation to both design and science problems. They suggest that the ten characteristics can satisfactorily be explained by three general sources of wickedness that are common to design and science: *finitude*, *complexity*, and *normativity*. Finitude is related to the limits of cognitive ability and resources. However smart one is, or however powerful a computer is, there will always be a limit to what processes can be performed. Complexity is described as a result of interactions between parts of systems, such as nested hierarchies, feedback and feedforward loops, or cascading effects in seemingly distant parts of a system. Normativity is related to the importance of human norms and values for problem understanding and resolution. Conflicting norms and values are common between different agents, but even "within an agent's normative commitments" (Farrell and Hooker 2013, p. 686).

Farrell and Hooker (2013, p. 685) suggest that each of these three sources of wickedness (finitude, complexity, and normativity) represents a methodological challenge for problem resolution. They "content that it is the depth and extent of this methodological challenge that ultimately constitutes the wickedness of a problem". In other words, a problem exhibits a higher degree of wickedness the more finite cognitive resources are, the more complex the problem situation is, and the more important normative aspects are. Farrell and Hooker suggest that there is not a binary demarcation between wicked and non-wicked problems. Rather, there are many kinds of wicked problems, including various kinds of science, engineering and design problems.

In another paper, Farrell and Hooker (2014, p. 29) acknowledge that "[d]ifferences continue to exist between design and science in their use of values and norms". While scientists generally "recognise a common set of epistemic values" related to the search for knowledge, "designers face a multitude of client norms that need not be significantly related to one another" (ibid. p. 37). In other words, they argue that values and norms are more diverse in design than in science.

In the context of SD, values and norms are even more diverse than in many areas of design. While the SD concept introduces some basic constraints (i.e. the necessity to consider ecological, economic, and social aspects for present as well as future generations), we suggest that these constraints increase rather than decrease the potential for value conflicts. For example, the demand to consider future generations means that SD requires designing for resilience rather than measurable performance (Seager et al. 2012).

Addressing SD problems requires not only considering conflicting interests among a set of clients, it also requires recognizing extended networks of stakeholders that may or may not be able to actively make their interests and values known to those who attempt to address a problem (e.g. marginalized groups of humans, non-human animals, ecosystems, or future generations). Issues of justice, power, and agency are central and cannot be reduced to a well-defined set of conflicting values. To denote such problems, we here use the term WSPs (c.f. Lönngren 2014). WSPs should be understood as a subtype of wicked problems that are (a) guided by a very diverse set of values and norms associated with the concept SD, and (b) embedded in highly complex, global systems. In other words, WSPs are characterized by exceptionally high levels of complexity and normativity, and thus of wickedness.

We agree with Farrell and Hooker that real-world science and engineering problems often include aspects of finitude, complexity, and normativity, and should therefore be seen as wicked problems. Unfortunately, students in engineering are seldom trained to address wicked problems, let alone WSPs (Jonassen et al. 2006; Seager et al. 2012). Lönngren, Ingerman, and Svanström (forthcoming) suggest that the current prevalence of well-structured problems in EngE may lead to a lack of awareness of problem types and a false assumption that all kinds of problems can be addressed with the same methodological strategies.

3 Systems Thinking Competence

ST is widely recognized as an important competency to be developed in the context of education for sustainable development (ESD). Based on a review of the ESD literature on competencies for SD, Wiek et al. (2011) suggest that ST is one of five key competencies in ESD (the others being *anticipatory competence*, *normative competence*, *strategic competence*, and *interpersonal competence*). Wiek et al. offer a definition of ST that has been widely used in the ESD literature (e.g. Claesson and Svanström 2013; Sprain and Timpson 2012):

> Systems-thinking competence is the ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global), thereby considering cascading effects, inertia, feedback loops and other systemic features related to sustainability issues and sustainability problem-solving frameworks (Wiek et al. 2011, p. 207).

In this definition, the methodological challenges of dealing with complexity (the presence of a large number of variables, non-linear relationships, etc.) are central. To deal with the exceptionally high level of complexity that is present in sustainability problems, Wiek et al. (2011) suggest the use of systems analytical methodologies. While normative aspects of sustainability problems, such as "perceptions" and "motives" are mentioned in passing in the above description of ST, Wiek et al. have chosen to mainly describe the challenge of normativity separately as normative competence, which they define as "the ability to collectively map, specify, apply, reconcile, and negotiate sustainability values, principles, goals, and targets" (p. 209). We suggest that separating normative competence from ST in this way may lead to an incomplete understanding of ST, in which ST is reduced to a tool for identifying the "current state of the social-ecological system" (p. 210), i.e. a form of analytical and descriptive competence. Such an approach to ST could be used if one ensures that it is combined with an analysis of the normative aspects of a situation. However, since ST is more commonly used in EngE than normative competence, and often in a rather instrumental way, we suggest that it is more useful to use an understanding of ST that *explicitly includes* the challenges of normativity.

Porter and Córdoba draw on literature from systems theory, operations research, and organization theory to develop a framework of three different approaches to ST, particularly in relation to sustainability problems: *functionalist*, *interpretive* and *complex adaptive systems* (CAS) approaches.

Functionalist approaches to systems thinking employ a "scientific, systems analytic perspective" (Porter and Córdoba 2009, p. 328). Such a perspective assumes that systems can be divided into individual components that can be analyzed and optimized independently from each other. The goal of functionalist approaches is to "[calculate] the most efficient and effective solution" (p. 326).

Interpretive approaches employ a more holistic perspective, acknowledging that in complex situations, the whole is greater than the sum of its parts. Systems are seen as "the mental constructs of observers rather than entities with an objective existence" (Porter and Córdoba, p. 323). Thus, questions of system definition are a central focus in interpretive approaches. Normative assumptions behind the problem definition are explicitly explored through participative engagement of diverse stakeholders. Despite this focus on diversity, interpretivism assumes "that conflict [among stakeholders] can ultimately be addressed and managed through rational dialogue" (p. 337). Thus, "it does not reject the premise that rational, systematic inquiry and insight will eventually yield a workable understanding of any situation" (p. 334).

CAS approaches recognize natural systems as not only complex, but also "adaptive". According to Porter and Córdoba, such systems are characterized by self-organization, emergence, and bottom-up change. These characteristics render them "unpredictable and uncontrollable from above" (p. 338). CAS approaches recognize that conflicts may be ultimately unresolvable, and that there may not be definite solutions to sustainability problems—or even a "best way of getting things done" (p. 338).

4 Systems Thinking Competence and Wicked Sustainability Problems in Engineering Education

In the previous two sections, we have developed a description of WSPs and summarized different descriptions of ST, respectively. We now return to address the aim of this paper, which is to investigate whether ST can be a valuable tool for facilitating a fully integrative approach to WSPs.

Functionalist approaches to ST take problem definitions and goal formulations for granted. According to Porter and Córdoba, functionalist approaches (such as complex systems analysis) are therefore most useful when problems are easily defined and have clear boundaries, when concrete and predefined goals exist, and when disagreement among stakeholders is low. We suggest that functionalist approaches alone are not suitable for addressing WSPs, since WSPs are characterized by high levels of complexity and normativity. In fact, applying functionalist approaches to WSPs may exacerbate rather than reduce existing problems such as power imbalances and environmental degradation.

Interpretive approaches, which include critical approaches, are most useful for understanding the multidimensionality of sustainability problems and the centrality of values and worldviews for problem definition. Porter and Córdoba suggest that interpretive approaches make it possible to take multiple perspectives into account and they may thus help to address social, environmental and economic imbalances. However, interpretive approaches assume that conflicts are ultimately resolvable, which is not the case with regard to WSPs. Lönngren, Ingerman and Svanström (forthcoming) have shown empirically that understanding a WSP as complex and contested while still expecting a definite solution can be associated with a sense of hopelessness which may lead to inaction and thus hamper initiatives for SD. Thus, interpretive approaches, despite their popularity in (E)ESD, may not be sufficient for addressing the complexity and normativity of WSPs.

CAS approaches to ST are useful when the degrees of complexity and conflict in a system are both high, as is the case in WSPs. Porter and Córdoba suggest that such problems should be addressed through a combination of all three approaches: "What is possible, and highly valuable, is a toolkit containing all three approaches along with the knowledge of the best use of each" (p. 344). Students who know how to use such a toolkit would be able to address complex sustainability problems: "with careful attention to the assumptions and limitations of each approach, the three may be employed simultaneously to address the needs of a single situation" (p. 342).

It is important to note that Porter and Córdoba write from the perspective of management education rather than EngE. In EngE, functionalist approaches are often the default, "business-as-usual" mode of addressing problems (Seager et al. 2012). Engineering students are widely trained to solve "story problems", i.e. purely technical problems that are delivered in short, written stories. All necessary information about a problem is present in the story. To solve story problems, "[l] earners are required to identify key words in the story, select the appropriate algorithm and sequence for solving the problem, and apply the algorithm" (Jonassen 2000, p. 77). In other words, story problems do not exhibit any of the three sources of wickedness identified by Farrell and Hooker. They resemble neither WSPs (Lönngren, Ingerman and Svanström, forthcoming) nor workplace engineering problems (Jonassen et al. 2006).

We agree with Farrell and Hooker that addressing complex sustainability problems such as WSPs requires using all tools that are available, i.e. functionalist, interpretive, as well as CAS approaches. Functionalist approaches can be useful for solving limited aspects of a WSP, such as optimizing a specific process that is part of an integrative strategy for addressing a WSP. However, we suggest that the current predominance of functionalist approaches in EngE (which is coupled with the predominance of well-structured problems) is detrimental for the development of students' ability to address WSPs in integrative ways. Therefore, we further suggest that EESD practitioners should strive to increase the share of (1) WSPs rather than story problems, and (2) interpretive and CAS approaches rather than functionalist approaches to problem solving in their teaching practice. EESD research can support practitioners in this endeavour by further elaborating the descriptions of interpretive and CAS approaches (and possibly identify and describe additional approaches not described by Porter and Córdoba), and investigating the value of such approaches for supporting integrative approaches to WSPs. Research could also provide guidance in the form of intended learning outcomes, assessment approaches, and specific educational activities suitable for developing students' ability to address WSPs in integrative ways.

5 Conclusions

WSPs are problems that are exceptionally complex and characterized by particularly challenging value conflicts. In this paper, we have discussed whether ST can be a valuable tool for facilitating a fully integrative approach to WSPs, particularly in the context of EESD. We have suggested that ST indeed can be valuable for addressing WSPs, but that it is necessary to be clear about what approach to ST is used (e.g. functionalist, interpretive, CAS) since not all approaches to ST are equally suitable for addressing WSPs. In particular, we have argued that functionalist approaches alone are not sufficient for addressing WSPs. Since functionalist approaches are common in EngE, we have suggested that EESD practitioners should strive to increase the share of (1) WSPs rather than story problems, and (2) interpretive and CAS approaches rather than functionalist approaches to problem solving.

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A Strategy to Incorporate Social Factors into Engineering Education

Stelvia Matos and Olga Petrov

Abstract

As societal expectations have changed from narrowly focused environmental issues to broader sustainable development concerns, it is vital that future engineers graduate with an understanding of how social impacts may affect or may be affected by their decisions. Drawing on complexity theory and sustainability literature, this paper describes how engineering programs can incorporate a course that will enable graduating engineers to explore the interdependencies among technical, economic, environmental and social dimensions of sustainability. System's elements and interdependences are identified using modularity, a technique that applies deductive and inductive methods. Using the example of a sustainable lignin-based product we demonstrate how such methods can be demonstrated in class. We then discuss the implications for engineering teaching and propose an integrated sustainability analysis course that focuses on harnessing social factors within sustainability systems, by seeking them out and exploiting interdependencies. This will prepare future engineers to work on a more realistic scenario, and more broadly explore new ideas and possible solutions.

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Sustainable development · Social factors · Engineering education · Complexity theory · Curriculum

1 Introduction

While much has been discussed on incorporating environmental focused topics such as life cycle assessment, renewable energy, and waste minimization in engineering course materials, few changes have addressed the social component of sustainability (Tainter 2006; Davidson et al. 2010; Kohtala 2014). This implies that educators must revise courses and curricula so engineering graduates are prepared for the new challenges of sustainable engineering. A key barrier for such change is educator's difficulties to address the complex interdependence among the environmental, economic and societal dimensions of sustainability and to deal with qualitative data collection and analysis. Yet the need for change is urgent, as currently graduating engineers may not realize that isolated attempts to reduce environmental impacts may provide less than optimal solutions or even detrimental outcomes (Matos and Hall 2007).

This paper describes how an integrative analysis approach to sustainability can enable engineers to explore the interdependencies and to identify how social impacts may affect or may be affected by their decisions. We draw on complexity sciences and sustainability literature as a guide to understand the interactions and the different concepts involved in a sustainable system (Kauffman 1993; Innes and Booher 2000; Matos and Hall 2007).

We start by describing the similarities between complex systems and sustainability, as both involve a large number of elements or agents that connect and interact with each other in many different ways and are thus constantly changing and evolving (Kauffman 1993). As complexity theory also emphasizes the importance of searching for the interactions and sources of change among elements or agents that constitute a particular system (Mason 2009), we describe how modularization, a technique that has been applied to manage complexity, can be used as a framework for such searching process. Modularization consists of a process that identifies parameters, their role in the completion of a task and the degree of interdependences (Baldwin and Clark 2000). Parameters and interdependences are identified by deductive and inductive methods (Matos and Hall 2007). The former involves quantitative data, i.e. codified form of knowledge such environmental, costs and process design data. The latter involves qualitative information such as stakeholders' perception about the benefits of a technology and cultural values, which draw on social sciences methods for data collection, analysis and reliability. Using the example of a sustainable lignin-based product, we demonstrate how such methods are applied, providing educators with a practical example that can be used in class. Finally, we propose a sustainable analysis course that draws on this integrative approach and discuss the implications for engineering teaching.

In contrast to previous approaches to sustainability teaching that focused on exploring environmental and economic parameters disregarding cross integration with social factors, we propose harnessing social factors within a sustainability system, by seeking them out and exploiting interdependencies.

2 Sustainable Development and Complex Systems

Complexity theory has first been developed in the fields of physics, biology, chemistry and economics but it has been also applied in the field of social, organizational sciences and operations management (Thrift 1999). It deals with environments, organizations, or systems that have a very large number of elements or agents that interact to each other in many different ways (Kauffman 1993). These elements or agents may include atoms, molecules, human agents, institutions, corporations, etc. (Mason 2009). Complexity theory also suggests that it is the multiple interactions among the elements that are responsible for the phenomena, patterns, properties, and behaviors that characterize a particular field. Simon (1991) suggested that a complex system often takes the form of hierarchy by being composed of subsystems that, in turn, have their own subsystems, as molecules form cells, species form ecosystems and consumers and corporations form economies (Waldrop 1993).

Kauffman (1993) draws on the biological concept of fitness landscape to describe a complex system. In biology, fitness landscape is a distribution of possible genotypes (fitness values) mapped from an organism's structure to its fitness level. Kauffman (1993) argues that a landscape can be more or less rugged depending on the distribution of fitness values and interdependences among the elements. The lower the number of interactions, the smoother the landscape (Fig. 1a) and the more straightforward is to find a combination of choices of elements that work, i.e. the highest peak. However, the more complex the system, the more rugged the landscape (Fig. 1b), and the more difficult is to make the right choices that lead to the

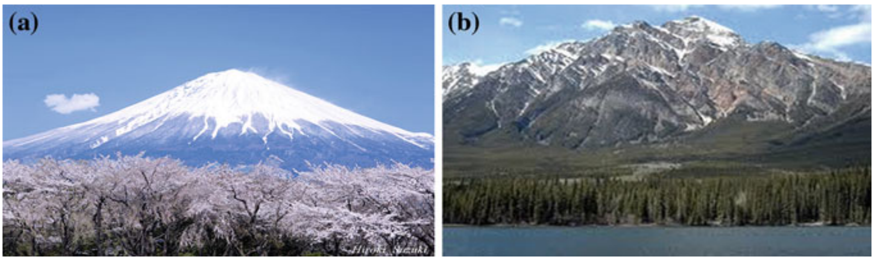

Fig. 1 **a** Smooth landscape or Fujiyama Mountain type—low number of interactions. *Source* http://sceneryseries.blogspot.co.uk/2008/12/fujiyama.html. **b** Rugged landscape or Rocky Mountains type—high number of interactions. *Source* https://www.flickr.com/photos/zinnie/305549202

highest peak because the number of possible solutions, or peaks, is large. In this case, the combination of choices of parameters that lead to the optimum solution may never be found. According to Kauffman (1993), in such situations it is better to satisfy rather than optimize avoiding complexity catastrophe, i.e. when considering too much interactive complexity hinders adaptation and stops the system's evolving process.

Similarly, sustainable systems are characterized by a large number of social, economic and environmental elements or agents that interact with each other (Matos and Hall 2007). A number of studies have examined the interactions of these elements. For example, in the case of transgenic technology, the interactions between environmental (potential impacts, risk), social factors (small farmers rights) and technology (research and development) had negative effects in the technology trajectory. Such effects included millions of dollars spent in legal actions and delays in technology diffusion (Chataway et al. 2004; Hall et al. 2014a). In the automobile industry, the 1950s Ford Edsel is a well known case of a technology launched as a stand-up product that led to millions of dollars lost in development, production and marketing (Dicke 2010). The very word Edsel became a symbol of commercial failure, which has been attributed to a number of factors including the lack of appropriate interactions between developers and consumers (Deutsch 1976). Another case is Iridium, a satellite-based mobile phone network launched in 1999 that promised to revolutionize communication systems by allowing calls to and from any point in the world. Yet the technology was a commercial failure, as developers did not consider consumers' end costs and willingness to carry a large and heavy phone around (McIntosh 1999).

Economic and environmental elements may include operating costs, pollutants, energy and water consumption, etc. Social elements include, NGO representatives, media, laws, regulations, etc. According to Matos and Hall (2007) sustainability is an inherently rugged landscape that requires coordination of social, environmental and economic systems. In addition, the inexistence of a single optimum requires agents to undertake a collaborative search approach, which can be accomplished by forming cross-functional teams, requiring tighter synchronization among their actions and establishing a common goal (Levinthal and Warglien 1999). This will encourage recombination of partial solutions, bringing together elements that were previously known but distant from one another. We speculate that had Ford Edsel and Iridium considered such cross-functional team approach during the technology development phases, they may have been able to adapt to consumers' expectations and needs at that time.

Levinthal and Warglien (1999) also suggest that communication among these agents is an important mechanism for igniting cooperation. Engineers' sound understanding of science and mathematics with the attention to economics, health and safety, and environmental impacts, give them the unique opportunity to play a crucial role in fostering collaboration among different teams.

3 Modularization Process Applied to Sustainability Analysis

Modular design structures are advocated as particularly useful when interdependencies between elements of the system is so large that integrated design efforts become almost impossible (Levinthal and Warglien 1999). The general idea of modularity is that a complex system can be managed by dividing it up into smaller pieces or modules where interdependence within elements of the same module is strengthened and independence across different modules is reduced. Strong interdependencies are easily identified (e.g. the links between raw material costs and product price within the economic module). Interdependencies across modules are harder to identify and to change (e.g. the links between food regulations and market prices across the social and economic modules). However, once the designers or technology developers acquire more knowledge about how the interdependency works, it becomes possible to choose a solution from a set of possibilities (Baldwin and Clark 2000). Drawing on Baldwin and Clark's Design Structure Matrix, Matos and Hall (2007) developed a framework to identify key elements and interdependencies in a sustainable system that includes the following steps:

1. List economic, technological, environmental and social elements. Ask "What elements would you consider?" Note that these elements do not have to be exclusively quantitative.
2. Seek for interdependences. Ask "If, there are any changes made in a element (e.g. change package material from plastic to cardboard), what other elements will also change?"
3. Identify task hierarchies. Ask "Whose decision do you need to know in order to make your decision?" For each element, identify all predecessor elements.
4. Identify uncertainties related to the technology or process under analysis. Ask:

   - Is it feasible from a scientific and engineering perspective?
   - Is it commercially viable?
   - Are there any potential environmental impacts that are unknown or require specific investigation?
   - Are there any potentially negative side effects on, or from, secondary stakeholders?

Note that interdependencies are found by identifying what elements change as a result of changes in other elements. The task hierarchy structure is also crucial to the understanding of interdependencies as it lists tasks and coordination links between agents. For example, if tasks A and B are interrelated but are performed by different agents, then these two agents must communicate with each other before making their final choices. In practice, the above framework calls for robust quantitative and qualitative data collection methods that ensure data accuracy and validity.

4 Deductive and Inductive Data Collection Approaches

As sustainability is inherently complex its design outcomes are never completely predictable. In order to manage these challenges, an integrated approach of search and adaptation needs to be considered. The first step is to list the system's design elements, and categorize the hierarchical relationships and interdependencies, i.e. applying deductive approach. This includes system information such as key inputs, yield, critical process conditions, e.g. temperature and pressure and design calculations such as process flow diagrams, mass and energy balances, equipment sizing, hazard and operability studies and economic analysis. These topics relate to the core body of engineering degree discipline and curricula. The second step involves inductive methods, which deals more with the tacit knowledge of designers about dependencies, and less with the codified, formal knowledge typically taught for engineers. We draw on social science methods to fill this gap and to develop a process of qualitative data collection and analysis (Fig. 2) (Glaser and Strauss 1967; Eisenhardt and Graebner 2007).

The process starts with secondary data sources from the academic literature, government and industry documents to identify the key issues related to the unit of analysis (e.g. a new process or technology) and both primary and secondary stakeholders involved in the value chain. Primary stakeholders are those with a direct interest in the technology, such as customers, shareholders, employees and suppliers and secondary stakeholders are those that can indirectly affect, or are affected by the technology, such as NGOs, social activists, media, etc. (Freeman 1984). Once preliminary issues and key stakeholders have been identified, a list of questions to be applied in interviews and/or focus groups is then developed and used to initiate the discussion, but not to constrain stakeholders' possibilities for raising relevant topics. The data collected allows for the identification of other relevant stakeholders and elements (Berg 1988). The interviews and/or focus group data is recorded and transcribed. Using computer-aided qualitative data analysis software, the transcriptions are coded into categories and subcategories of relevant elements. For example, the subcategories energy costs, raw material prices, profit margins, etc. form the category economic issues, much like the systems and related

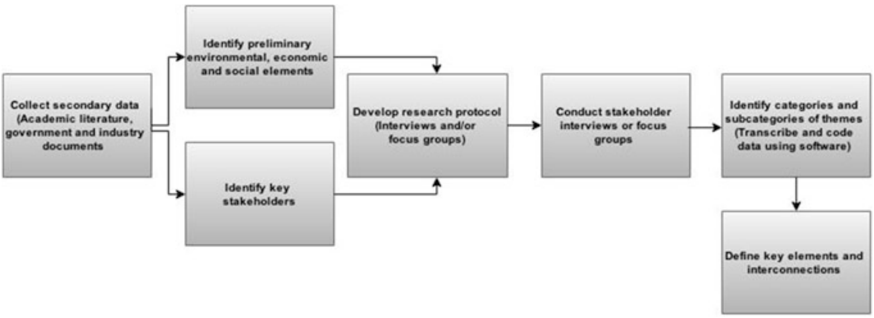

Fig. 2 Data collection and analysis process based on qualitative research methods

elements that describe a complex landscape. Note that interactions between categories are also identified during this process and can be coded under the theme "interconnections". For example, environmental performance may be affected by the choice of raw material of a certain product, which in turn may affect costs. Coding is usually performed in two rounds by different researchers for internal reliability, identification of gaps and interview follow-ups.

4.1 Identifying Key Variables and Interconnections: Sustainable Lignin-Based Product

An innovative bioprocess that produces vanillin from lignin has been developed by scientists at the University of British Columbia, Canada, as part of a broad research project aiming to explore new sustainable opportunities from lignocellulose-derived products. The new vanillin is produced via wheat straw fermentation using the lignin degrading bacteria *RHA045*, a mutant strain of the *Rhodococcus jostii* bacteria obtained through gene knockout technique (Sainsbury et al. 2013). Here we summarize a practical example of the application of the proposed integrated sustainability analysis, which can be used in class.

Deductive Data: Preliminary lab test results showed that vanillin can be produced from wheat straw with a maximum growth rate of 0.0139 min^{-1}, vanillin yield 96 mg/L, Monod constant $K_s = 0.0114$ g/L and optimal growth conditions of 30 °C and pH 7 (Sainsbury et al. 2013). Process design calculations based on these parameters included inoculation, fermentation, separation and extraction phases (Baldwin 2014). Key environmental issues identified during the design process included the need of an absorbent system to remove VOCs from the extraction column. In addition, it was recommended to keep the bacteria concentration in the reactors as low as possible to reduce carbon dioxide emissions from the fermentation process. Estimate inventory of key resources used and emissions generated in the production process are listed in Table 1.

Table 1 Inventory data for the production of vanillin via wheat straw fermentation

Material inputs	Amount	Unit/kg of vanillin
Molasses	17.77	kg
Ammonia	0.80	kg
Sulphuric acid	0.08	kg
Ethyl Acetate	0.08	kg
Water	9.45	m^3
Wheat straw	2.84	kg
Process electricity	404	kWh
Waste water	0.23	m^3
Carbon dioxide	13.72	kg

Inoculation, separation and extraction phases were included (Baldwin 2014)

Petroleum based vanillin prices range between $12–15/kg, lignin based ranges around $13.00–17.00, and natural vanillin between $1200–4000 (Wong 2012). In the US, some high-end synthetic vanillin products can cost up to $700/kg. Based on the inventory data collected during the process design calculations and the estimated costs of raw material, electricity and labour, the new vanillin has to be sold at a price of $960/kg in order to break even the operating costs (Baldwin 2014). This is at least 60 times the market price for lignin-derived vanillin.

Inductive Data: Drawing on the methodological process depicted in Fig. 2, both secondary and primary data were collected and analysed, leading to the identification of the key social elements related to the proposed new vanillin. First, the high variance in price between synthetic vanillin and natural vanillin noted above draws the attention to the natural foods market as a potential target for this product (Hall et al. 2014b). However, the definition of 'natural' and related regulatory labels varies between countries. For example, a Norwegian company produces a specific type of vanillin that meets the EU requirements for "nature-identical" and it is thus sold at a higher price than regular lignin-based vanillin (Wong 2012). For the new vanillin, the Canadian Food Inspection Agency (CFIA) indicated it does not qualify as natural, although additional technical information may lead to approval for a "natural flavour" label:

> The production of vanillin from wheat straw using bacteria fermentation would not be considered natural as it utilizes chemicals in the process. […] Under the "Nature, Natural" section of the Guide to Food Labelling and Advertising, there is a small section regarding "flavour descriptors". The information in that section could still apply to your product." (CFIA Chemistry Specialist)

The questions here are whether the process can be changed to exploit the lucrative 'natural market', whether it is possible to induce regulatory reform, or if it is more feasible to exploit the technology elsewhere, where the process meets 'natural' regulatory criteria (Hall et al. 2014b).

There are contrasting views about genetic engineering technology from different stakeholders. From one side, scientists expect consumer acceptance regarding the knockout technique used in vanillin preparation to be straightforward. One scientist stated that "… *there should be no issue because bacterial and other microbial strains have been used for many centuries in food preparation, and so this is something that is still done today in many different ways; for example, preparation of soy sauce, brewing of beer, things like that*." On the other side, an NGO protest against any kind of production process that does not come from the natural beans states that:

> ETC (Erosion, Technology and Concentration) Group and Friends of the Earth are launching a public design and branding competition to shine a spotlight on synthetic biology (extreme genetic engineering) in our food. Use your creativity to help us expose the very un-natural new ingredient coming to a confection near you, and what it means for vanilla farmers." (ECT 2014).

Key Interactions: Although the new vanillin production process has been shown to be technically feasible, the data indicated that there might be opportunities of developing vanillin for the more lucrative natural market. Such economical issue interacts with the technology aspect of the proposed process, as the developers need to consider making changes in the process so it falls within the definition of natural. Although changing the production process and maintaining costs below $700/kg remain challenging, the lucrative natural market niche provides a useful value proposition as justification to proceed with developing the technology (Hall et al. 2014a). Note that regulatory definitions for food additives and "natural" market trends are highly complicated and specialized business issues are beyond the radar of engineering curricula. Nevertheless, by acquiring knowledge about how interdependency works, it becomes possible to identify what set of skills need to be sought out in order to bring together the required elements of a possible solution and then adapt.

Regarding NGO's perception of the technology, it is difficult to predict whether there will be protests and if they will have any effect on the development and application of the vanillin technology. However, this shows the importance of the technology developers and engineers to adapt by being aware of the different views in case there are opportunities to address stakeholders' concerns about the technology. For example, it may be helpful to clarify that the technology involves knockout gene technique to avoid any confusion with the GMO technology, which has been notorious for generation negative reaction from the public.

5 Integrated Sustainability Analysis Course

We propose a course that integrates social elements into the environmental and economic analysis of sustainability for engineering (Table 2). This course will enable graduating engineers to identify and examine key social issues related to engineering operations, first by learning relevant methods to collect and analyse qualitative data and then by exploring the interconnections between sustainability dimensions.

The course starts with an overview of key concepts and the description of sustainable systems through the lenses of complexity theory and landscape theory. The point here is to show that, similar to complex systems, sustainability requires an integrated analysis of its core elements, in this case, environmental, economic and social factors. In the beginning of the course, the graduating engineers are encourage to connect with the university's science and engineering faculties and identify a potential innovation that they can use as case study throughout the course. Then modularity is described as a useful technique applied to manage complexity systems, helping to identify key environmental, economic and social elements and interconnections related to that particular potential innovation. Next, a review of deductive methods for environmental and economic data collection and analysis is

Table 2 Integrated sustainability analysis course contents

Part 1: Introduction
• Course description and objectives
• Course project description, selection of themes (case studies) and respective groups
Part 2: Introduction to complexity theory and fitness landscape
• Definition, key characteristics and related concepts
Part 3: Sustainable development as a complex adaptive system
• The links between complexity theory and sustainable systems
Part 4: Search and adaptation processes: identifying elements and interconnections
• Modularity approach, design and task structure matrices of interactions
Part 5: Deductive approaches: When to apply what quantitative analysis methods?
• Environmental (LCA, risk assessment, etc.)
• Economic (cost estimates, market prices)
Part 6: Integrate frameworks and content of course-to-date into the case studies
	Part 7: Inductive approaches: social sciences qualitative data collection and analysis methods
	• Design and site selection
	• Data gathering
	  • Secondary data and desk research
	  • Primary data collection methods: interviews, focus groups, surveys
	• Data analysis
	  • Mapping: identify and describe critical elements
	  • Identify linkages between elements
	  • Coding process
	  • Textual analysis software
	  • Overlapping data collection and analysis
	  • Measuring data validity and demonstrating reliability
	Part 8: Integrate inductive approaches into the case studies
	Part 9: Course project wrap up
	• Demonstration of integrative analysis using both deductive and inductive methods
	• Identification of key environmental, economic and social parameters and interdependencies

presented with a focus on key differences, advantages and disadvantages. Next, an in depth description of inductive methods is performed, including data design collection and analysis, issues with reliability and data validity. The course contents are then integrated into the case studies projects where the graduating engineers are expected to demonstrate their ability to perform a simplified integrated sustainability analysis using the approaches discussed in class.

6 Conclusions

Integrating social factors into sustainability analysis remains a gap in the engineering curricula as it usually focuses on environmental and economic aspects of a new product or process. However, as sustainability is essentially a complex system, its core elements, i.e. environmental, economic and social factors, interact with each other, and failing to consider this interaction may lead to counter-productive or unsustainable decisions. We suggest that implementing a course that draws on the key concepts of complexity theory can fulfill this gap.

Our contributions to the sustainability education discussion are two fold. First, we propose that the analysis of social impacts needs to be taught as an integrative component of the environmental and economic analysis of sustainability. Social factors, and their potential impact on and from engineering decisions, have not been fully explored in engineering courses. Second, we contribute by presenting a specific/practical analytical process of qualitative data that will allow graduating engineers to identify and analyze social factors.

Search process include both deductive and inductive approaches, the latter addressed by applying social sciences data collection and analysis methods. We suggest that by exploring search and adaptation processes (i.e. assuming a rugged landscape) engineers will have opportunities to identify effective solutions that would otherwise be missed under a 'smooth landscape' approach.

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From Caring About Sustainability to Developing Care-Ful Engineers

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Abstract

Engineering is commonly thought of as a problem-solving profession (e.g. Allenby in Union College Symposium on Engineering and Liberal Education: Educating the Stewards of a Sustainable Future. Schenectady, New York, 2009; Zhou in Eur J Eng Educ 37(4):343–353, 2012). Still, good problem-solving depends on good problem-framing, which typically means capturing both the technical and social aspects of the problem at hand. It can though be challenging for engineering students to capture both these aspects of a problem. Cech (Sci Tech Human Values 39(1):42–72, 2014) has pointed out that significant challenges still exist within engineering curricula with regard to "reading" technical problems with multiple layers of meaning. What can be done to better this state of affairs? Fortunately, sustainability issues have caught the attention of this generation of college students (Watson et al. in J Prof Issues Pract 235–243, 2013). Building on the student enthusiasm associated with sustainability may be one way to foster student development regarding how to include ethical dimensions as an integral part of engineering framing and problem solving. We suggest that one option to achieve this is by teaching sustainability using an ethics of care framework that offers elements that more easily engage individuals in problem framing. This approach assumes that because engineering students "care" about sustainability as it applies to their disciplines, faculty can use an ethics of care framework to help students operationalize ethics as an integral component of the engineering decision-making process. By building on these initial lessons, students are better prepared to consider the socio-technical

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dimensions of engineering problems. Our argument draws upon examples from the University of Portland that demonstrate how students have a difficult time translating ethical theories to engineering problems, and also show how the care ethics approach can manifest itself naturally in the engineering curricula. We hope this paper serves to facilitate efforts to intentionally use sustainability issues to improve the teaching and learning of engineering ethics and further cultivate the T-shaped engineer.

Keywords
Engineering ethics · Engineering ethics education · Sustainability · Ethics of care · Engineering problem framing

1 Introduction

When in 2008 the National Academy of Engineering (NAE) announced its fourteen Grand Challenges for engineering and divided them across the four dimensions of sustainability, health, security, and the joy of well-being, it simultaneously acknowledged the primacy of those challenges connected with sustainability. "Foremost among the challenges are those that must be met to insure the future itself" (NAE 2008). With regard to this emphasis, it bodes well that a significant percentage of engineering students are interested in sustainability, and those engineering students are particularly interested in sustainability topics that pertain to engineered systems (Watson et al. 2013; UBC 2009). More evidence of this interest can be found with the many student chapters of Engineers for a Sustainable World, Engineers without Borders, and Engineering World Health; three groups with a mission to allow students to apply their engineering knowledge to improve the sustainability of developing communities.

We suggest that if intentionally designed, the positive impacts from leveraging student interest in sustainability can go beyond helping to address sustainability-related challenges to reach into the heart of how the activity of engineering is conventionally perceived. In particular, we propose that education in sustainable engineering lends itself well in helping future practitioners see that engineering design is not simply equivalent to technical problem-solving, but inherently involves internalizing social and ethical values as part of the problem-framing processes that lead to good solutions. Before engineering education in sustainability can have such an impact, however, the challenge faced by many engineering students of capturing both a problem's ethical and technical dimensions in the design process needs to be addressed. Because of this challenge, focusing on sustainability, even though sustainability is a normative concept, might not by itself be sufficient for developing student awareness of this inter-connectivity.

How can awareness of this inter-connectivity best be generated? In this paper, we respond to this question by suggesting that one option for developing this awareness is by approaching ethical-decision making through the lens of an ethics of care. We start by looking at an example at the University of Portland that illustrates the problem that engineering students have when connecting ethical theories to technical decision making. We then describe how an ethics of care can be used to direct student interest in sustainability to include the ethical context as an inherent part of framing an engineering problem which we illustrate with another example from the University of Portland. We conclude with lessons learned and suggestions for the next steps.

2 (Not) Drawing Connections

All ABET-accredited undergraduate engineering programs are required to have a culminating major design experience which students complete to demonstrate the knowledge and skills that they acquired over their education, and that they can incorporate appropriate engineering standards and multiple realistic constraints (ABET 2013). At most schools, this culminating design experience is referred to as the senior capstone. At the University of Portland, all engineering major programs include a three-semester senior capstone experience with a one-credit introduction to the senior capstone in the spring semester of junior year known as EGR 300, along with the more traditional courses in fall (2 credits) and spring (3 credits) semesters of the senior year. The aim with EGR 300 is to help students not only select their project, but also to learn about the various professional issues that may affect successful completion of that project and, ultimately, projects in their future careers. One of these professional issues is engineering ethics.

The University of Portland is a Catholic university where all students complete the same core curriculum which includes a relatively heavy dose of theology and philosophy. Most undergraduate engineering students (as with each student on campus) will have completed Introduction to Philosophy, as well as Ethics (taught by faculty in the Philosophy department) prior to taking EGR 300. The sophomore-level ethics course provides an introduction to some of the major approaches in classical and contemporary moral philosophy emphasizing the ability to understand and concretely apply theories such as utilitarianism, deontological ethics, social contract theory, the ethics of care, natural law, and virtue theory while exploring the limits of relativism and absolutism.

In EGR 300, faculty use a small module in the course to briefly remind students of these lessons from their ethics course and how they apply to their discipline. This opportunity was also used to assess student understanding of professional and ethical responsibility as required by ABET. The assessment involved four performance criteria with a scoring scale of 4 (clear demonstration of superior attainment), 2 (adequate attainment), and 0 (poor attainment). The performance criteria are as follows:

- *Performance criteria 1:* Students recognize ethical issues, i.e., they can see the ethical implications of specific situations and choices.
- *Performance criteria 2:* Students can analyze and critically evaluate ethical dilemmas, have an understanding of competing values, and can scrutinize options for resolution.
- *Performance criteria 3:* Students can apply the engineering code of ethics for their discipline to a professional situation.
- *Performance criteria 4:* Students recognize that there may be no single ideal solution to ethically problematic situations.

In Spring 2014, the assessment directed each student to provide an analysis of the assigned case study Henry's Daughters© (NIEE 2010) which deals with various business ethics and technical ethics issues associated with the research and development of autonomous vehicles. Two and a half instructional sessions were used to remind students about ethics, draw the connection to engineering, and discuss the professional codes. In the first session, a philosophy professor presented a review of ethical theories to the entire cohort of students. In half of the second session, an engineering instructor led a discussion of the case study used for the ethics assessment. In the other half of the second session, a panel of practicing engineers discussed ethical situations in their own careers. In the final ½ session, various engineering instructors discussed the code relevant to each major. The students' analyses of the case study were then assessed in regards to the four performance criteria listed above. In the assignment, students were required to choose two ethical issues to analyze from the many presented in the case study. They were provided with a template for the solution and the solution was graded using a defined rubric. The possible grades were 4, 3, 2, 1, or 0, with 4, 2, and 0 equal to the scoring scale above. The student averages for the assignment are shown in Table 1.

While the results indicate that students attained the ABET outcome, they also disclosed several problems with how well students connected their sophomore ethics course with the engineering process. Note that while some students felt that the EGR 300 module was needed to supplement what they learned in the required ethics course, many others stated that they learned "all they needed" in the ethics course and EGR 300 was redundant. In the evaluation, students also noted that the case study was too simplistic and removed from what "real" engineers do. Despite the critique, the most difficult aspect of the written assessment for almost all students was developing an adequate range of alternative actions to address the two ethical situations that they identified in the case study. Even more relevant for this

Table 1 Average scores for ethics assignment

Majors	# Students	Average
Civil engineering	42	2.74
Computer science	24	2.88
Electrical engineering	34	3.24
Mechanical engineering	54	3.02
Overall average	154	2.93

paper is the fact that few students selected any of the technical ethics issues to analyze i.e., the issues of social experimentation and risk/safety associated with this particular case study. Instead, they chose to focus on the business ethics issues such as favoritism, conflict of interest, and sexual harassment. While in part this result may be due to the video's poor portrayal of gender issues (Riley 2013), it was clear that many students did not see the connection between what they learn in Ethics with the engineering process itself.

3 Drawing Connections Through Sustainability Education and the Ethics of Care

How then can students in an engineering ethics class more readily see this connection? In this section, we discuss a possible path to developing this capacity. The path involves leveraging student concern for sustainability and using the ethics of care as a vehicle for helping students to frame a problem in which sustainability is at stake. As the next example from the University of Portland shows, it is in the problem-framing stage that students can best learn to see the connection, so that the problem they would then go on to solve would already be regarded as technical-ethical in character.

The lives of many of today's engineering students reflect a devotion to the cause of sustainability that runs both intellectually and emotionally deep. This devotion bears the characteristics of what philosopher Bernard Williams called a "commitment": a form of caring about something or someone that provides meaning for an individual's life, which someone might point to in saying "this is what my life is about" (Williams 1973). Because this commitment is part of the self-identity of these students, it makes sense to say that they care about sustainability rather than simply have an interest in it, as interests can be abandoned with minimal impact on self-identity. In his theory of education, Alfred North Whitehead proposed that the cultivation of learning begins with a stage of "romance," in which pupils are exposed to experiences that would captivate their interest and their emotion. (cf. Heywood 2012). It could be said that with respect to sustainability, many students are already in the "romance" stage, prior to any deliberate intervention on a faculty member's part.

Given how many students already care about sustainability as part of their self-identity, we propose both to take it as a starting point for an engineering ethics course (or module), and to connect it to student learning about the particular theoretical approach to ethics known as the ethics of care. As the senior capstone project we will discuss in the next section will show, at least some students naturally gravitate toward an ethics of care approach, without naming it as such, when involved in a sustainable design project. Because of this natural gravitation, we believe leveraging students' interest in sustainability makes for a good entry point with respect to developing their mindset so that they naturally include ethical considerations as inherent to the engineering design process. Our work builds on prior attempts to draw connections between an ethics of care and engineering. In a pioneering paper from 1999, Pantazidou and Nair reflect on how the ethics of care could offer a general pedagogical framework for teaching engineering students the design process. In a more recent paper, Canney and Bielefeldt (2015) propose a framework that is in part based on an ethics of care in order to help understand how engineering students develop their own personal and professional responsibility. Jones et al. (2015) demonstrate how an ethics of care framework can be used to help engineering managers incorporate sustainability as part of the engineering process itself. We would be remiss if we did not mention Riley's paper (2013) that reminds us that there are instances where an ethics of care approach to engineering has unfortunately been distorted by others to be the more traditional "standard of care," or worse, to be a defensive reaction to the notion of care as minimizing the moral agency of men.

Before turning to our example, a description of some of the key elements of care ethics is in order. In general, care ethicists agree that the *context* in which a moral agent is located provides not only the starting point for ethical deliberation, but contains moral content that needs to be specifically taken into account as deliberation develops. This emphasis on context separates care ethics from other ethical theories, including deontological ethics and consequentialism. For deontological ethics, moral decision making involves the application of a principle of reason for which the context of decision-making acts simply as a trigger or starting-point. In consequentialism, the context of action holds more moral import in that it needs to be taken into account in making a moral decision, but primarily as "input" for a decision-making procedure also governed solely by reason. By contrast, within care ethics, context functions in a more concrete, determinative way. A caring moral agent would act in response to what he or she discovers are the needs of individuals within a particular context (see for example Noddings 1984). This implies that there is no "one-size-fits-all" solution to moral dilemmas that share similar characteristics; each must be approached and addressed on its own merits and not as an instantiation of a particular moral "problem."

The ethics of care also conceptualizes the *moral agent* differently from other ethical theories, including the theory of aspirational ethics developed by Bowen (2009) in recognition of the fact that today's engineers need to design responsibly for a future where the scale of the potential impacts of their work far exceeds that of the past (Bowen 2009, 11). Rather than thinking of the moral agent as a self-sufficient, independent individual, the approach care ethics takes is to see individuals as fundamentally social creatures whose existence is primarily structured by relationships with others. These relationships are characteristically ones involving reliance upon others, so that a caring person, as a moral agent, directs her care toward others who are in need. While a caring moral agent certainly uses reason in making judgments about how best to care for others, these judgments are also rooted in relational feelings and attitudes, including empathy and trust. In forging and cultivating relationships involving such feelings and attitudes—for example, professor-student relationships, a skilled caring moral agent would overall be interested in the flourishing and well-being of those for whom she cares. In many cases, this interest would mean that over time the caring relationship would dissolve, or be transformed into a different relationship in which caring could be given by both parties on a fairly equal basis, but with each party still recognizing their dependency upon some others, say for instance those within a larger professional community.

4 Considering This Framework in Terms of a Senior Capstone Project

As mentioned earlier, at the University of Portland, the engineering senior capstone is organized across three courses. In the Introduction to capstone course, students first hear about the project choices and then organize themselves into teams to select a project. Sometimes the projects that are initially selected have to be switched by the faculty due to a variety of factors. For the 2014/15 academic year, this happened to one of the civil engineering senior teams. The original project that the student team selected focused on using solar disinfection to treat water collected in a rooftop rainwater system in the Portland metropolitan region. Faculty associated this project with the general theme of sustainable design. During the summer of 2014, when it became clear that faculty could not support that project, the team's faculty advisor secured another project that also involved water treatment and sustainability, albeit within a very different context. When contacted about the project change, the student team expressed interest in the project since it involved "sustainability" in terms of civil infrastructure and they were excited at the prospect of a "free" trip over fall break. The team included ZH who was to pursue a masters' degree in environmental engineering the following year and was double majoring in Spanish; KH who completed an environmental REU that summer; and CH who was also planning to pursue a masters' degree in environmental engineering. The faculty advisor added another student member to the team, MS, a dual US-Mexico citizen who travels to Mexico frequently and is fluent in Spanish.

The new project site was located in the municipality of "Antigua" Santa Catarina Ixtahuacan in the Sololá department of Guatemala and within the Sololá Catholic Diocese, a 3-hour drive from Guatemala City. The community includes approximately 150 homes and the project was sponsored by a non-governmental organization (NGO) of the Diocese of Spokane known as Family to Family. Project members were initially told—and this is important to keep in mind–that there was no other NGO providing support and that government resources were unavailable. In addition to the faculty advisor and the client, the student team was advised by two Portland engineers on a voluntary basis. Both Portland engineers had prior experience with developing community infrastructure as did the faculty advisor. At present, the community which includes five barrios is served by three gravity water system fed by mountain springs without treatment. The NGO reported that families get sick from drinking the water, however the extent of the problem was unclear. Initially, the student team and faculty assumed that the 2014–2015 project included tasks to:

- Assess the extent of the current and future problem in terms of drinking water quality, water usage needs in terms of quantity vs quality, and community/municipality/NGO assets & capabilities, limitations, etc.
- Identify and evaluate the possible potable water treatment goals for this community using available local and global information.
- Identify several centralized (community) and decentralized (household) alternatives to solve the problem in terms of feasibility, desirability, and viability—the three pillars of sustainability.
- Design and complete the necessary experimentation (on site in Guatemala) to determine appropriate system parameters for treatment.
- Prepare complete designs (specifications, drawings, etc.) for each treatment alternative that can be given to the community leaders to implement (avoiding language barriers etc.).
- Prepare a complete cost analysis and present worth analysis for this project, as well as a thorough sustainability assessment using the Envision™ Sustainable Infrastructure Rating System.
- Evaluate the pros and cons (design, construction, and operation) of each alternative based on above, and provide a final recommendation for the community. Consider how to best present the recommendation to avoid language barriers etc.
- Provide an O&M manual and any training materials (Spanish and English) needed for the project.
- Throughout the project, consult organizations that have been effective with similar projects.

The student team planned to visit the community over Fall Break to facilitate the partnership and collect the necessary information. Although two of the students spoke excellent Spanish, arrangements were made for an American contractor with detailed knowledge of the community over years of experience and fluent in both Spanish and the native language to accompany them and serve as translator. Prior to the visit, the team worked diligently on the first few tasks. They conducted controlled experiments of the effectiveness of several treatment methods, researched the local socio-economics of the area, read best practices literature regarding rural infrastructure development in similar contexts, and consulted with their advisors. They also developed a detailed water quality sampling plan for the site visit along with household, clinic, and community surveys. The advisors alerted the students to the potential for project changes once they visited the site and discussed several possible scenarios that could affect their progress in the country. That said, the entire team, students and advisors, assumed that the problem as framed was to design a water treatment system(s) appropriate to the community context. The team displayed excellent work ethic, organizational skills, and interpersonal effectiveness, and showed genuine interest in serving the community.

So what happened during and after the visit? The student team was very successful in terms of data collection that included information about public health, water quality throughout the life cycle of the water infrastructure, visual assessment of the infrastructure, and interviews with clinicians, the local priest, members of the three water boards, and a cross section of households. The site visit and the collected data convinced the students that they needed to re-frame the problem so that they could solve what “really mattered” to the community itself and not the many other stakeholders who had influenced the initial project statement. The team concluded that the water sources and water storage were not significantly contaminated to justify investing in a community-scale treatment system. Further, the community itself did not want a treatment system, did not like the taste of chlorinated water, and already had several donated but unused filters lying around. Instead, the student team suspected that the biggest water quality problem for the community was the improper sanitation practices observed at the individual households, along with the absence of a financial system to pay for ongoing operation and maintenance of the infrastructure. As such, they convinced their advisors to re-frame the problem as one to develop/provide educational materials regarding water use, and to research/recommend a financial system to manage the infrastructure.

In general, this outcome is not unusual in terms of discovering that the technical field data changes the original assumption; after all, data collection is an important part of the engineering process. However, the students paid attention to the socioeconomic and cultural aspects of the community, which led them to frame the problem differently, which in turn led to a new project scope oriented towards finance and education rather than the “best” water treatment design that they could develop. In other words, these “T-professionals” considered the socio-technical context for the problem that was presented to them as part of the framing process. And, this led to a much more nuanced view of what sustainable infrastructure requires—namely that the community takes ownership. This case study presents an example of post-normal science (Funtowicz and Ravetz 2003) where complex problems necessitate frameworks and extended peer communities that address the interrelated natural, technical, and social contexts along with their inherent uncertainties and values.

But, there’s more. During the site visit, the student team contacted their advisors and noted that they were struggling with what they themselves described as an “ethical” situation. Based on many conversations with community members, the student team discovered the reason why the community could not get any financial support from other NGOs, or the local government. They were told that in 1998, Hurricane Mitch destroyed much of the community’s infrastructure such that most of the community relocated to avoid similar disasters. However, some of the community stayed in an area (the team’s project site) that is considered uninhabitable and at too high of a risk for external aid; in fact external aid could be seen as facilitating a high risk of disaster for these people. Although the students could not verify all of the information they heard, from their own observations they concluded that the topography and geology negatively affected the water system infrastructure due to steep grade, loose soil, and frequent small earthquakes.

The student team wrestled with the question of whether to provide technical help (and financial help as requested by the community) that may only alleviate the situation in the short term, and even worse, encourage the community to live in a high risk situation. This ethical reflection continued upon the students' return to campus and played a significant role in their project re-framing, with the students deciding that since the community was not going to relocate in the short term, they should focus the capstone project on the primary reason, education and finance, for the immediate public health issue rather than engaging in the elaborate, but irrelevant design of new and more permanent treatment alternatives. In other words, the student team concluded that the community needed them in the short term, and caring for a community in some situations means helping the community to become less dependent on the care that is being given. This ethical dilemma was integral to how the student team framed their engineering project. Note that the student team made this decision despite the uncertainty of how their grade in the course could be affected, given that the course emphasizes traditional "design" as part of the requirements.

5 Future Connections to Be Explored

Our analysis in this paper has primarily been directed toward addressing the difficulty of how best to get students to connect the dots between their learning in a normative ethical theory course and their learning in an engineering ethics class (or module). We have shown that an ethics of care approach has the advantage of offering elements that can more easily engage students in understanding that the activity of problem-framing in engineering has ethical dimensions. And, we have shown an example of how sustainable development, and in particular, meeting those to be "cared for," resulted in a senior capstone team using ethical and other societal aspects in problem framing.

This leads to the following question: How can this initial caring about the community and the socio-technical complexity of sustainable development be used to expand students' ability to apply post-normal science to the similarly complex problems that they will most definitely face in the 21st century? We suggest that this expansion of a student's internalization of ethics can occur through a process of analogical reasoning where, to borrow a phrase from the philosopher Ludwig Wittgenstein, other engineering problems are seen to bear "family resemblances" to problems in sustainability. In addition, helping engineering students to develop skills of analogical reasoning could encourage them to move from caring about particular others with whom they have worked face to face e.g., in rural communities in the developing world, to others of different kinds. With regard to just who it is that can be cared for, Held (1993, 59) observes that "particular others can be actual children in need in distant countries, or the anticipated children of generations not even close to being born." For our perspectives discussed in this paper, this wide compass discloses the flexibility of care ethics and the potential for its use in a variety of engineering contexts. An engineering ethics course that starts with a module on sustainability in terms of an ethics of care and then uses "scaffolding" to increase students' capacity for recognizing the ethical dimensions may be one step towards developing an engineering mindset that inherently includes the broader context within which technical problems rest. To take this step is not to say that engineering ethics courses should concentrate on developing this particular approach alone. But, reflecting on what approach might be best to take with regard to framing a design problem involves being attentive to its particular nuances and detail. Here too the ethics we have been discussing can play a role in the formation of more "care-ful" engineers.

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Sustainability in BioEnergy Academy for Teachers (BEAT): Changing Perspectives and Practices Toward "Greening" the Curricula

Madhumi Mitra, Abhijit Nagchaudhuri and M.S. Xavier Henry

Abstract

A holistic approach of sustainability grounded in environmental concerns, also incorporates the dimensions of culture, economy, and social justice. It can be an added attraction bringing together various disciplines to explore pathways through which sustainability can be addressed in a practical manner. A one-week summer institute on Bioenergy and Bioproducts for educators from middle and high schools, and university faculty across STEAM (Science, Technology, Engineering, Agriculture, and Mathematics) disciplines was hosted by the University of Maryland Eastern Shore (UMES). This program is geared towards helping reform educational infrastructure by promoting multidisciplinary activities and content in the areas of sustainability, bioenergy, and bioproducts. The objectives of the Bioenergy Academy are: (1) to provide a systems-perspective in sustainability, bioenergy, and bioproducts education to STEAM educators and researchers; and (2) to develop and provide curricular materials and a set of teaching tools to educators for enhancing instruction in the areas of sustainable bioenergy and bioproducts. The Academy focuses on lessons and activities pertaining to sustainability, systems thinking, renewable

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energy with particular emphasis on bioenergy, bioproducts, and environment and policies related to energy issues. The participants got the opportunity to acquire concrete experiences involving teamwork, time management, and project execution skills; reflected on their learning experiences through presentations at the end of the institute; developed concepts related to organic chemistry, physics, engineering design, instrumentation, mathematics, biological, and environmental sciences; and actively experimented with feedstocks to generate biodiesel and environmentally-friendly soaps using the glycerin produced from the biodiesel. The BITES (Buildings, Industry, Transportation, Electricity, Scenarios) simulation tool developed by National Renewable Laboratory (NREL) of the United States Department of Energy (DOE) and made freely available over the internet allowed participants to play out scenarios to reduce carbon foot print based on those situations that can be realized through policy decisions leading to building improvements, reduction of industrial pollution, use of alternative fuels, electric cars, and other design modifications in the transportation sector, and cleaner and more efficient conversion technologies for electricity generation and conservation. A total of forty one educators have been trained through this program over a period of four years. The evaluation surveys (pre- and post) revealed that the educators gained substantial knowledge in the fields of sustainability, bioenergy, and bioproducts, and felt comfortable in implementing the content in their courses and laboratories.

Keywords
Bioenergy · Bioproducts · Education · Environment · Sustainability

1 Introduction: Background Information and Objectives

The Planet Earth is facing several crises and with the unsustainable trends continuing, the world will witness increasing interconnected problems such as overpopulation, elevation of greenhouse gases leading to disruptive climate, poverty, resource depletion, loss of biodiversity, food and water scarcity, and political instability. These will eventually cause the life support systems enter a state of disequilibrium (Cortese 2012). Although being "green" or eco-conscious is a positive step towards a sustainable world, the term "sustainability" encompasses more than ecological integrity (Costanza et al. 1997). The three pillars or E's of sustainability (environment, economics, and equity) relate to fostering of communities that are healthy, safe, secure with economic opportunity for everyone while keeping the Earth's life support system viable (Elkington 2012). With the publication of Education for Sustainability: An Agenda for Action in 1996 by the United States President's Council on Sustainable Development, global sustainability has become prevalent in the curricula of K-16 classrooms. Sustainability does provide the context or foundation for education in many subject areas as it transcends disciplines. The concepts and activities on sustainability can also provide ample opportunities for educators to reinforce skills of critical thinking, systems thinking, collaboration, and communication.

The "green initiatives" of the University System of Maryland (USM) as a whole (http://www.usmd.edu/usm/sustainability/) have provided the foundation for the program, "BEAT (Bio-Energy Academy for Teachers) the Energy Crisis and Enhance BLT (Bio-Energy Literacy for Teachers)" outlined in this paper. By providing educators with a comprehensive overview of the complexity of the "green" industries, more of today's students (tomorrow's workforce) are getting training to develop a systems perspective of the STEM (Science, Technology, Engineering, and Mathematics) fields. They are also learning to appreciate the wide range of skills necessary to address the challenges related to sustainability and climate change. Through directed training and programs such as the BEAT, the students reached so far have been developing a systems approach in problem solving, and increasing the likelihood of long-range improvements in the multitude of aspects encompassed in the "sustainability" issue. The primary goal of the BEAT program aligns with the overarching vision to expand the familiarity and knowledge of university faculty, in-service (middle, and high schools) as well as pre-service STEAM (science, technology, engineering, agriculture, and mathematics) teachers participating in the program with the complex topics of sustainable bio-energy and bio-products through a systems perspective. By training educators, it is anticipated that the students will become more aware of the greenhouse gas emissions, climate change, and the deleterious effects arising due to dependence on foreign oil. Exposing the middle and high school students, the university students, and the faculty to these topics will not only foster greater awareness, but also generate increased interest in STEAM careers. It probably does not come as a surprise that the recommendations made by the National Academy of Engineering for transforming engineering curricula for the new millennium echo that of the National Academy of Sciences and encourages sweeping changes that promote the integration of life-skills and civic responsibility outcomes along with academic outcomes as part of the overall educational experience of STEAM (Mitra et al. 2013).

The two objectives of the BEAT program are: (a) *To provide a systems-perspective in bio-energy/biofuel and sustainability issues to middle and high school in-service and pre-service teachers as well as university faculty*. The overarching vision is to expand the familiarity and knowledge of middle school, and high school level STEAM teachers and undergraduate pre-service teachers as well as university faculty from agriculture, biology, chemistry, mathematics, engineering and technology participating in the program with the complex topics of sustainable bio-energy through a systems perspective. Bioenergy systems comprise biomass resources, supply systems, conversion technologies, and energy services (McCormick 2010). Through the systems approach, the educators are exposing their students to the various perspectives related to the utilization of natural resources for bio-energy, ways to mitigate the global climate change, and understand the complexities that are involved in modern scientific and technological challenges. The students are also exposed to career choices in the cutting-edge STEAM disciplines;

(b) *To develop and provide curricular materials and set of teaching tools for educators for enhancing instruction in the areas of sustainable bio-energy and sustainability in their classrooms*—In addition to training the STEAM educators on a systems perspective of renewable energy, the program includes developing and providing curricular materials and laboratory tool kits for implementing classroom activities in bio-energy/bio-fuels and sustainability. The curricular materials are aligned with the national and state standards of science, technology, and mathematics and do provide sample lessons in bioenergy for middle, and high school students.

2 Program Description: Participant Selection and Activities at the Institute

The team (primary author and the coauthor) developed the program process and selection criteria. The educators submitted their resumes and a description of how they would use the training materials and/or training experience in their classrooms or research. Ten participants were selected during the first, second, and third years and eleven in the fourth year. The educators were a mix of in-service teachers, pre-service teachers, university faculty, teaching technicians, and graduate students. The high school teachers are represented cumulatively in the greatest number at 32 %, followed by middle school teachers and university faculty at 22 %. The graduate assistants represented 17 % of the total participants across four years and the pre-service teachers made up 7 % of the overall program participants (Table 1).

An important aspect of the BEAT program is to leverage the existing successful efforts (training programs, engagement exercises, and training Tools such as lab kits) to build a multidisciplinary, more comprehensive systems-oriented training package. Some of the highlights of the program activities during the one-week summer institute over the period of four years are delineated below.

2.1 Biodiesel

In the biodiesel activity, participants are introduced to the environmentally-friendly alternative to petro-diesel that is capable of being used in many of today's vehicles

Table 1 Teaching partner professional distribution

Teaching partner occupation	Total number 2011–2014	Total number as percentage (%)
Faculty	9	22
Research assistants	7	17
High school teachers	13	32
Middle school teachers	9	22
Pre-service teachers	3	7

with diesel engines. The concepts of carbon neutrality are also expounded upon since it is an integral reason for the adoption of biodiesel as an alternative in today's carbon-heavy economies. Using products that are readily available from many "big-box" and automotive stores (HEET, a source of methanol and Drain opener, a source of sodium hydroxide), in addition to vegetable oils that were pressed from grains produced at the UMES research fields, small amounts of biodiesel were created in the lab to demonstrate the ease with which that fuel can be synthesized. The synthesis of the fuel also lead to discussions concerning the market penetration of the fuel in the US versus other global markets as well as the viability of the byproduct, glycerin, which was used in the glycerin soap making. This activity culminated in a brief tour of the university's biodiesel facilities where the fuel is regularly made from waste cooking oil for the use in farm equipment as well as for the diesel power generator powering the Integrated Multi-trophic Aquaculture (IMTA) facility where both shrimp and *Gracilaria* are produced in an attempt to address food, energy, and environment concerns in the future bioeconomy in a sustainable way (Fig. 1).

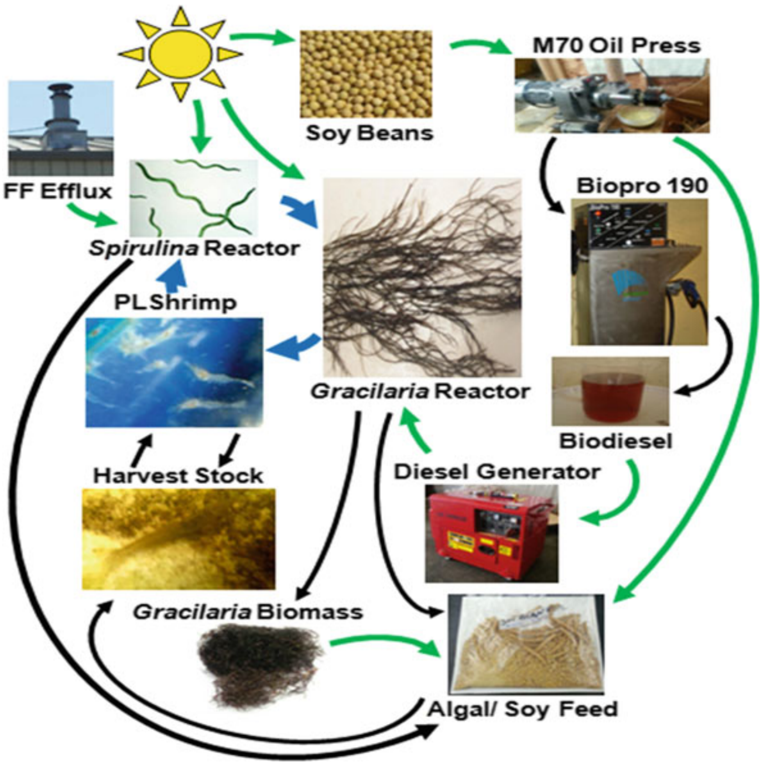

Fig. 1 Schematic of IMTA System depicting the production of oil from oil seeds for biodiesel synthesis, the use of the biodiesel to meet the IMTA's electrical needs, and the production of *Gracilaria* biomass for bioethanol production

2.2 *Gracilaria* to Bioethanol

Another biofuel to which participants were exposed was bioethanol. Here, macroalgae grown in the IMTA system is used to demonstrate the synthesis of ethanol which can be used as an additive to traditional gasoline or as its own alternative fuel in newer technology vehicles. The *Gracilaria* grown in the IMTA tank is commonly referred to as a nuisance alga since it readily forms pervasive blooms around the MidAtlantic region. Fortunately, from a biofuels perspective, the seaweed is comprised of quantities of easily fermented sugars, which is what the participants make use of in this lab, by simply macerating the alga and then treating it with basic baker's yeast and allowing the medium to culture over a 24-h period. Thereafter, the medium can be filtered of solids and distilled to reveal the small amount of crude ethanol liberated by the process. In a retrospective discussion, participants were given the opportunity to again surmise as to the viability of such techniques and products in the current market place and to how the process may be improved to increase future viability (Fig. 1).

2.3 Algal PBR

In this activity, participants were exposed to the concepts and of algal bioenergy and algal production systems. The scenario began with a brief lecture on algal ecology, to introduce micro and macro algae, eutrophication, algal storage compounds and other pertinent information. The activity then culminated in the participants constructing their own algal photobioreactors (PBR's) with *Arthospira platensis* inoculums and growth media using two 500 ml plastic water bottles, aquarium air hoses, and an aquarium air-pump (Fig. 2a). After constructing their PBR's, participants were also exposed to the implications of using PBR's in research. They also toured the facilities at the university where investigations using various scales of PBR's for the bioenergy and bioremediation efforts are undertaken.

2.4 Glycerin Soap Synthesis

In this activity, participants were introduced to a potentially valuable byproduct of biodiesel production using biodiesel glycerin (also known as glycerol). The glycerin that was previously obtained from the synthesis of biodiesel on campus was used to make environmentally-friendly soaps (Fig. 2b). Kits, produced at the university contained all the necessary materials to allow for the saponification reaction to be satisfied safely. The basic reaction, an acid plus base, utilizes the fatty acids present in the triglycerides within the biodiesel glycerin and react with sodium hydroxide (Lye), to produce the soap (a salt) and glycerin, which serves as a moisturizer. Essential oils from a variety of sources were also added based upon the individual's preference to add another dimension of originality to the soap making process.

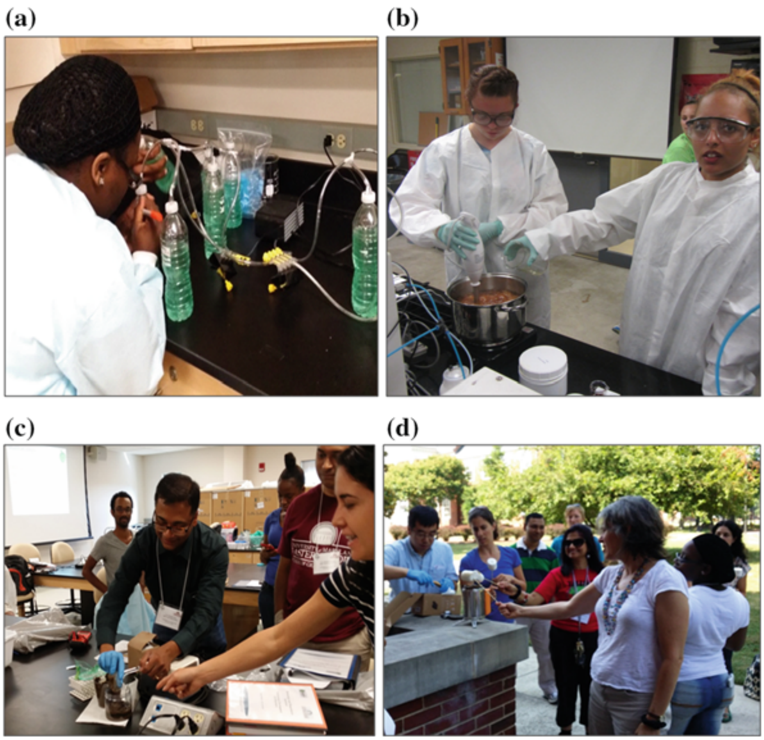

Fig. 2 **a** Participants receiving a brief lecture on algae ecology and putting the final touches on their *water bottle* PBR systems; **b** bioproduct soap making with biodiesel glycerin; **c** demonstration of the Mudwatt microbial fuel cell; **d** participants using the Biolite to prepare roasted marshmallows and charge their cell phones

After completing the reaction in the lab, the participants were exposed to several methods which they could employ to test the quality and safety of their soaps. Once the soaps were allowed to set and dry for 24 h, the participants created their decorative bars as gifts and mementos.

2.5 Sustainable Bioproducts

Given the common misconceptions surrounding “green” and organic products, the bioproducts activity was designed to expose participants to the many facets of these up-and-coming products. Firstly, a discussion of what it means to be “green” and organic was held to arrive at a consensus. Several product demonstrations and trials were convened to put these products through their paces. Some of the activities included a tasting of algal food products such as seasoning and chips and the synthesis of a biopolymer packaging peanut to protect an egg during the egg drop activity. There was also a comparative assessment of various traditional versus green cleaning products against the common day-to-day stain causing compounds. The participants concluded that many of the green alternatives met or in some cases, exceeded their expectations in comparison with the performance of the traditional products.

2.6 Mudwatt Microbial Fuel Cell

The Mudwatt Microbial fuel cell (MFC) activity was centered on the potential for harnessing energy from living microorganisms. The MFC's is a bioelectrical device that takes advantage of the natural metabolic activities of microbes to produce electrical power directly from organic material. In this activity, the participants collected mud from the banks of a river located on the university's campus, and prepared it for the use in the MFC. The MFC chamber was then filled with the mud and allowed to sit until a steady pulse of light was emitted from the diode indicating peak productivity. The participants were also able to check the voltage obtained from their cells and compared it with different mud preparations (Fig. 2c). The resistance of the MFC was also varied and its effect on the system was also recorded.

2.7 Biolite

Using the BioLite stove, the participants were exposed to the concept of thermodynamics, thermoelectric materials, the Seebeck effect, and the practical applications of their use in today's society. They also learned how the varied energy densities of feedstock may impact the energy production regime. The participants also collect various materials from outside and then tested their suitability for combustion within the stove. Thereafter, the stove was used to charge several mobile devices and also to roasting marshmallows and making green tea for the participants (Fig. 2d).

2.8 BITES

Buildings, Industry, Transportation, and Electricity Scenarios (BITES) tool can be accessed from the URL: https://bites.nrel.gov/education.php. It has been developed by National Renewable Energy Laboratories (NREL) and allows users to create 'what if' scenarios to explore and compare outcomes related to baseline reference cases of the carbon footprint by adjusting energy inputs to buildings, industry, transportation, and electricity generation sectors in the United States. An activity developed in consultation with developers of the tool at NREL was integrated in the institute during the third year. The educators expressed that the tool allowed them to better comprehend the broader dimensions of the overall picture that provides relevance for the emphases on bioenergy and bioproducts during the institute. In particular, they could readily see the carbon implications of using more biofuels in the transportation sector, as well as increased use of biomass for heat and power generation for buildings, industries, and electricity generation sectors.

3 Results: Program Impacts: Content Knowledge and Perception Surveys

The educators were administered 20 multiple-choice pre-and post-surveys to measure their content knowledge in the areas of sustainability, renewable energy with a particular emphasis on bioenergy, and bioproducts before and after the institute. The pre-institute scores were much lower than the post-institute scores. The data indicated that there was an improvement in the scores of the post-tests for all the four years of the institute. Figure 3a shows the average pre-test to post-test scores (in percentage) of the educators. The online perception survey was also a pre and post-assessment, in which the educators (participants teaching partners rated their comfort level of teaching the following topics within the following given areas: Agriculture, Sustainability, Forestry, Systems Thinking, Biomass, Biodiesel, Ethanol, BioHeat, BioPower, BioProducts, and Environmental Policy). The chart below shows the pre-test to post-test scores of 2011–2014 participants. The two different columns in the light blue and dark blue show the pre vs post-test percentages of educators who selected the criteria designations ‘somewhat comfortable’ or ‘very comfortable’ to describe their comfort-level with each of the listed topics. Comparing these two columns and the overall results of the PRE to POST perception surveys, there is an increase in perceived understanding of the participants with the outlined topics. This change is indicated by a shift toward increased levels of comfort through a self-assessed rating where each participant indicated his/her perceived comfort level with a given topic on a 5 point scale ranging from ‘very uncomfortable’, ‘somewhat uncomfortable’, ‘neutral’, to somewhat comfortable and very comfortable. Specifically, this change evidences a percentage shift

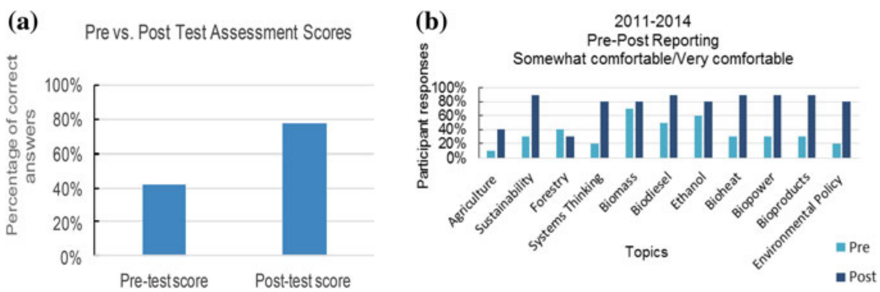

Fig. 3 **a** Pre versus post assessment scores. **b** Pre versus post perception survey

and increase with respect to the above-neutral scale designations ‘somewhat comfortable’ and ‘very comfortable’. Prior to the institute, an average of 25 % of the participants selected the rating designations ‘somewhat comfortable’ and or ‘very comfortable’ in describing their level of comfort in teaching the given workshop topics: Environmental Policy, Bioproducts, Biopower, Bioheat, Ethanol, Biodiesel, Biomass, Systems Thinking, Sustainability, Agriculture and Forestry. However, at the conclusion of the institute almost 76 % of the participants selected the higher comfort level ratings of ‘somewhat comfortable’ and or ‘very comfortable’ to describe their familiarity and competencies with these topics (Fig. 3b).

4 BEAT Interdisciplinary Impacts

Table 2 summarizes the activities which were implemented in various courses in middle and high schools as well as undergraduate education.

Table 2 Activities, disciplines, and level implemented and impacted

Activity	Disciplines impacted	Level
Algal PBR	Plant Science, Technology, Biology, Marine Botany, Materials Science, AP Chemistry, General Integrated Science	Middle School, High School, Post-Secondary
Soap Lab	Marine Botany, Biology and Earth Science, Biology and Environmental Sciences, Chemistry, Transdisciplinary Class, AP Chemistry, Materials Science	Middle School, High School, Post-Secondary
VO to Biodiesel	Biology, Chemistry, Technology, General and Analytical Chemistry, General Integrated Science, Biology and Environmental Sciences, AP Chemistry	Middle School, High School, Post-Secondary
Bioethanol lab from feedstock and algae	Ag. Science, Plant Science, Marine Botany, Chemistry, Biology, and Environmental Sciences	High School, Post-Secondary
Sustainability activity-design of homes, office	General Integrated Sciences and Human Ecology, Transdisciplinary Class	Middle School, Post-Secondary
Earth as an Apple	Earth Science and Biology	High School
Sustainable Bioproducts	Chemistry, General Integrated Science, Materials Science, Transdisciplinary Class	Middle School, High School, Post-Secondary
BITES	Pre-Algebra, Biology and Environmental Science, Environmental Science, AP Chemistry	Middle School, High School,
Biolite	Engineering, Transdisciplinary class	Post-Secondary
Microbial Fuel Cell	Physics, Transdisciplinary class	Post-Secondary

5 Conclusions and Discussion

The program has been successful in engaging educators from the "STEAM" disciplines. Through hands-on learning activities in classrooms, fields, and laboratory settings, participants are more aware of the critically important issues of the "carbon cycle" and its relevance to renewable energy with a special focus on biomass, sustainability, climate change, and the utilization of natural resources and wastes for the generation of bio-products. Survey instruments for students' perception and appreciation of topics related to renewable energy and sustainability are currently being developed to document and analyze feedback from the high school and university students. Teacher training materials such as workbooks focusing on topics related to sustainability, bioenergy, and bio-products from natural resources and wastes have been developed along with assembled biodiesel, algal photobioreactor, and soap kits. As a follow-up, educators have been utilizing these resources to develop unit and lesson plans and to share with their peers so that more educators and their students are positively impacted. Besides contributing to the workforce development needs in areas of critical importance, the BEAT program efforts are enhancing awareness of sustainable practices such as reducing waste, promoting recycling, and advancing the green initiative on campus as well as on the lower Eastern Shore. Sustainable approaches to deal with issues related to energy, the environment, and agriculture are prominent in the grand challenges of the 21st century as identified by the National Academy of Science and the National Academy of Engineering (http://www.engineeringchallenges.org). The activities in the program are consistent with the recommendations of the National Academies with regard to transformational changes to agriculture, science, and engineering education for the new century and provide a foundation for continued education endeavors. Some of the activities (algae photobioreactor, biodiesel from cooking oil, environmentally-friendly soap making, microbial fuel cell, Biolite, and BITES) from the institute are permanently incorporated in agriculture, food, and resource sciences; marine and environmental sciences; engineering curricula; and other STEAM courses at the University of Maryland Eastern Shore. There has been an increased interest in the students from sciences and engineering to participate in the experiential learning activities in the areas of renewable energy and sustainability. The BEAT program has facilitated in attracting students in pursuing STEAM degrees with a focus on sustainability issues. So far about 41 educators have been trained through the BEAT program and more than 20 undergraduate (about 60 % from engineering) and graduate students have been involved with research-related activities in sustainability. The classroom tools, lab kits, and workbooks are self-sustaining for the educators not just in their classrooms but to other teachers through sharing of resources. The knowledge in the training sessions is transferable to other regions of the country.

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Author Biographies

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Fostering Reflective Practice for Sustainable Professional Development: *Lead by Design*, a Pedagogical Initiative

Cecilia Moloney, Janna Rosales, Cecile Badenhorst and Jonas Roberts

Abstract

In the 21st century, practicing engineers are working under conditions of rapid change, both in the technologies of engineering as well as in the contexts in which engineering is practiced. The "grand challenges" of today and of the future require a broad range of knowledge and skills, and the capacity to connect engineering with other sectors. To respond, universities must educate engineers who understand engineering principles at fundamental levels, but who also have nimble design and process skills. This paper presents findings from a research project that developed, implemented and evaluated new diversity-attracting integrative pedagogies intended to tap into the motivations and values that engineering students bring to their work and study. Our initiative, named *Lead by Design*, responds both to the changing demands on engineers and to ongoing efforts to increase the retention of women in the profession. In this paper, research findings are presented from the *Lead by Design* project that show the importance of narratives in fostering the reflective practice that can underpin both a sense of identity as an engineer and professional sustainability.

Keywords

Engineering education · Integrative pedagogies · Transformative education · Diversity · Reflective practice · Narratives · Free-writing · Reflexivity · Professional self-awareness · Professional development · Identity

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1 Introduction

In the 21st century, practicing engineers are working under conditions of rapid change in technologies, as well as changing socio-political conditions at the local, national, and global levels. Change is anticipated to be a reality over the careers of current and future engineering students, whose engineering careers might extend well into the middle of the 21st century. Although it is difficult to predict exactly how ongoing change will contribute to future engineering knowledge and practice, we can expect that the "grand challenges" of today and of the future (NAE 2008) will require a broad range of new knowledge, new skills, and new connections of engineering with other sectors to solve the problems we may collectively face. To respond to these challenges, universities must educate engineers who understand engineering principles at fundamental levels, but who also have nimble design and process skills that will enable them to work on interdisciplinary teams, provide leadership to self and others, and integrate a wide range of relevant factors into innovative engineering solutions.

At the same time, the rates of women entering engineering studies remain low in Canada, and the long-term rates of participation in the profession are even lower (Engineers Canada 2014). While the low participation rates of women in engineering are influenced by many factors, they are symptomatic of the need for change within engineering education and practice; indeed Calnan and Valiquette (2010) refer to women as the proverbial canaries in the engineering coal mine. Increasing the participation rates of women and of other diverse groups in engineering requires both recruitment and longer-term retention strategies. Retention in engineering, in both the short and long term, can be fueled by positive experiences of university-level engineering education. We (and others) argue that university engineering education must be transformed to foster the sustainability of the individual engineer over her or his career (Moloney 2010; Goldberg et al. 2014).

A key aspect of such sustainable engineering education is that it expand from its current dominant focus on the content material of engineering, i.e. the "what" and "how" of engineering, to an appreciation and experience of the connected interdisciplinarity of engineering practice, layered upon the emerging self-understanding of the engineering student: the dynamic "who" and "why" of the person who aspires to be a scientist or engineer (Moloney and Rosales 2011). The absence of explicit advertence to the "who" and "why" can be linked to long historical structures within engineering education (Goldberg 2010).

Past research shows that identifying with engineering as a profession includes three necessary components: *thinking* like an engineer, *acting* like an engineer and *feeling* like an engineer (Herzig 2004; Moloney 2006). An explicit focus on the "who" and "why" within engineering education will enable the linking of the motivations and values that students bring to engineering with their innovative practice of engineering. This linkage will foster an important aspect of sustainable development in engineering, notably the career-long sustainability of engineering professionals in our changing world (and in particular for women and members of other diverse or under-represented groups). These engineers will produce better engineering solutions for the benefit of us all.

1.1 Purpose and Research Goals

The purpose of our *Lead by Design* research project was to propose, implement and evaluate new diversity-attracting integrative pedagogies that tap into the motivations and values that students bring to their work and study, including a sense of themselves as citizens engaged in understanding and meeting the complex challenges of our times, both locally and globally. While our efforts were aimed, in the first instance, at promoting women in engineering, we argued that the health of engineering requires broader change and engagement with diversity. Thus, inclusivity and a wide definition of diversity were important components for our research design.

The research questions we are interested to address are: (1) What motivates engineering (graduate) students in their career and life choices in engineering? (2) How can we develop innovative pedagogies to enhance the retention of women (and other diverse groups) in engineering and their long-term sustainability in the practice of engineering?

Towards answering these questions, and to study the relationships between diversity, identity, and professional success, we developed a five-day co-curricular course, called the "*Lead by Design* Institute on Leadership, Diversity and Dialogue for Graduate Students in Engineering." This pilot program was offered in April 2014 to engineering graduate students at Memorial University, with the intention that the results of our research inform the design of similar pedagogies and programs for undergraduate engineering students in later projects. Following a review of the relevant background literature, the structure and curriculum of the *Lead by Design* Institute are described below. Our research findings concerning reflective practice and identity are presented and discussed, along with discussion of their importance in fostering professional sustainability. The paper ends with conclusions and perspectives on future work.

2 Background

2.1 Integrative Pedagogies in Engineering

There is a growing literature on strategies to enhance the current-day relevance and longer-term sustainability of engineering education, based on a range of pedagogies. Our particular focus is on integrative pedagogies that aim to connect the person who is learning with the material being learned and its wider context, and thus make positive learning experiences and longer-term retention in engineering more likely. Engineering education researchers and practitioners have begun to argue that the established undergraduate engineering curricula do not respond adequately to the needs of the present, much less to those of the future (Grasso and Burkins 2010; NAE 2005; Reeve 2010; Sheppard et al. 2008). Established engineering programs tend to educate students to be specialized and technical problem-solvers within their disciplines. However, the 21st century context of engineering, as well as much of current engineering practice, points to benefits when engineers are problem-definers as well as problem-solvers (Sheppard et al. 2008), and more significantly, are able to engage in socially responsible and interdisciplinary collaboration (Goldberg 2010). Such a systemic transformation would include not only an integration across the disciplines but also greater emphasis on: building teams and teamwork; the development of more effective communications skills; cross-disciplinary dialogue, and dialogue between humans and their objects of study; increased awareness of the social, political, environmental, commercial and government contexts of engineering and science (Sheppard et al. 2008); and methods to heighten awareness of self (Moloney 2010).

Research into, and the practice of, integrated engineering education are demonstrated in several programs in Canada—such as University of Toronto's Leaders of Tomorrow (Reeve 2010) and the MetaKettle Project at Memorial University (Moloney and Rosales 2011)—and in the United States, such as at Smith College (Grasso and Burkins 2010) and Olin College (Sheppard et al. 2008). Programs in other disciplines, such as the Undergraduate Semester in Dialogue at Simon Fraser University in Vancouver, Canada (Gunnlaugson and Moore 2009) demonstrate successful program elements that can provide inspiration for engineering education.

The need for transformation in engineering education is most notable at the undergraduate level, but is also significant for graduate studies. The graduate student experience in engineering is marked by a deeper and more focused engagement with the "what" and "how" of an area of engineering, as well as the need for greater self-motivation. The latter points to a heightened need for a self-understanding of "who" and why," as well as a heightened need for leadership on the part of graduate students (Moloney 2006). Graduate students may not view themselves as leaders in their graduate studies, in part because the graduate student experience in engineering can be one of working substantially alone on one's own research, or of working as a member of a supervisor's lab team. Professional development for leadership is crucial, since without a strong sense of agency it is very hard to be a discoverer, or an intellectual leader of oneself or others. Moreover, graduate students do provide leadership for one another in their lab communities, and leadership will be expected of graduates entering the workplace with higher degrees (Cohen and Cohen 2012). For women graduate students, as well as for other under-represented groups, it is important to develop a strong sense of autonomy, self-direction, and leadership, not just from the perspective of having power *over,* but also of having power *to*, that is, the power to do something (Freeman et al. 2001; Williams and Emerson 2008).

2.2 Reflective Practice and Narrative

Since engineers regularly engage with design and problem solving, developing reflective skills is a key element in the ongoing professional development of engineers. Professionals often face conflicts in values, goals, purpose and interests, and there can be competing views about practice. Reflective thinking is one way that professionals can successfully navigate these conflicts, through a cycle of questioning that allows an individual to examine his or her experience in order to derive meaning from it (Gibbs 1988). Reflective practice attempts to explore the boundaries between one's professional work, the multifaceted demands of the outside world, and the dynamics of one's inner life. Ultimately, reflective practice should lead to constructive action and change. In many professional practices reflection can become routinized and uncritical (Galea 2012); uncritical reflection can then re-enforce bias, inequalities and discriminations rather than expose them. A way around this focusses on *reflexivity* as a core concept (Bolton 2010). While reflection is examining what we think, reflexivity is the ability to look back in on ourselves, to recognize our own influence, within a context, as an agent in the practice we are involved in (Thompson and Pascal 2012).

Reflective writing is meant to be a spontaneous form of writing (also called "free-writing"), used as a means of critical reflection. Because it is spontaneous, reflective writing starts with an experience, and is oriented towards understanding the experience. As such, this form of writing pays attention to thoughts, but also to emotions, and therefore often is an engagement with the unorganized and even confusing aspects of an experience (Boud 2001).

Free-writing is a method of writing that consists of non-stop stream-of-consciousness writing for a timed period, such as for 2–5 min. The idea is not to cross out or re-read what is being written but to keep going forward, writing everything down without criticizing or judging, thus keeping the inner critical voice quiet. The results are often quite surprising in terms of the insights at which one may arrive. Free-writing is a form of personal writing, even if oriented towards a professional topic, and the process is meant to enable a greater sense of self-awareness.

Reflective practice is thus a key process skill for engineers to advert to their sense of identity as engineers, and for students and young engineers to become more aware of the process of identification with the profession and to work through areas of dissonance in their identity.

Free-writing as a reflective practice often produces elements of one's personal narrative. From the perspective of research, narratives are a popular source of data in qualitative research (Merriam 2009). In the social sciences there is a long history of narrative inquiry and analysis. While it has roots in late 19th Century scholarship, the last three decades have seen a boom in this type of inquiry. Constructivist, postmodern and performance philosophies have fed the growth in narrative approaches (Specter-Mersel 2010). Data thus collected can include stories people tell about their identities, values, relationships and experiences. The purpose of collecting narrative data is to tap into the meanings respondents attach to issues and to actions taken. A narrative approach is a distinct inquiry into human nature. In other words, narratives hold answers to peoples' experiences and the meanings they attach to how they understand processes around experiences (Merriam 2009). Narrative methodologies are not new to engineering (Pawley 2009), and have proved valuable for tapping into the less technical, process-related aspects of the field. For research on women in particular, narratives have proved to be a well-matched methodology (Sahib and Vassileva 2009).

2.3 Lead by Design Institute

2.3.1 Description of Institute

The *Lead by Design* Institute was a co-curricular program that brought together 14 graduate students from the Faculty of Engineering and Applied Science at Memorial University in St. John's, Canada, for a five-day workshop in April 2014. Participants took part in a variety of leadership, communication, reflective-practice and skill-building workshops and explored questions such as: "What is engineering?", "What attracts you to engineering?", "What makes an empathic engineer?", "How will you contribute to redesigning engineering?", etc.

2.3.2 Curriculum Development

The objective of the *Lead by Design* Institute was to develop and implement a pedagogy to attract and retain more women and other diverse groups in the engineering profession by focusing on issues related to personal development and social justice. From the objective of developing an "ideal" pedagogy that would attract women and other diverse groups to engineering, the curriculum developed through an iterative process. The curriculum plan that unfolded into detailed plans and materials for Days 1-5 was developed around a thematic arc of "Understanding how we got where we are, designing (engineering) a new future," with a focal point on Day 4, "Re-engineering the foundations of my career." The curriculum consisted of three threads: (1) reflective practice; (2) dialogue to heighten personal, ethical and social awareness; (3) self-awareness, leadership and including yourself in the technical aspects of engineering. Specific activities included: skills building; dialogues and reflections; case studies in leadership and diversity; and a team-project on an engineering "challenge." The challenge culminated in a technical solution that students explained using a "non-standard form" (debate, skit, poetry, art, etc.) presented at a public Engineering Salon.

2.3.3 Research Methodology

As a research project, the *Lead by Design* Institute is based on theories and methods in: dialogue-based education (Gunnlaugson and Moore 2009); reflective practice (Bolton 2010); leadership of self and others (Cohen and Cohen 2012); feminist and other theories of liberation (Friere 1970); and the connection of affect with success (Csikszentmihalyi 1990), and in particular the cognitive and affective interactions involved in attraction to and identification with engineering (Turkle 2008). The project is also informed by other novel and emerging approaches to more integrative engineering education (e.g. Goldberg et al. 2014) including the integration of challenging technical materials in engineering with appreciation of one's thinking, acting and feeling like an engineer (Moloney 2006).

We conducted a basic qualitative study combined with descriptive survey results. A basic qualitative study is often found in applied fields of practice where data is collected through interviews, observations and document analysis. An assumption within this type of research is that individuals, e.g. the participants in the study, construct reality as they engage with their social world. Our purpose was to explore this engagement by examining a) how participants interpret their experiences; b) what these experiences mean to them, all in an effort to understand how people make sense of their experiences (Merriam 2009).

Several types of data were collected throughout the *Lead by Design* Institute, including (i) narratives and reflective writings; (ii) a pre- and post-institute survey; (iii) photographs of sessions, (iv) a video of the challenge presentation; and (v) the written observations of the researchers. Among the items in category (i), an important subset were the reflective narratives and free-writes, and, for this paper in particular, those that included comments on identity, values and choices in engineering. One idea behind the narratives and free-writes was to ascertain how the students identify themselves as engineers, and what form and shape that identity takes. Furthermore, we wished to obtain insights into the processes that inform identity-building.

Throughout the *Lead by Design* Institute, participants were asked to free-write on several topics each day. Topics of the free-writes included reflections on the previous day(s), or were constructed to be directly related to the research questions noted above in the section *Purpose and Research Goals*. While participants were engaged in free-writing, at least one researcher recorded observations of the participants (per Merriam 2009) and how they were reacting to the experience of free-writing.

3 Results and Discussion

Our research findings from the 2014 *Lead by Design* Institute indicate the importance of writing and narratives in fostering the reflective practice that can underpin both professional identity and professional sustainability. Indeed, analysis of our data shows that the narratives and reflective practice were key to eliciting statements about identity and professional sustainability.

3.1 Narratives and Reflective Practice

The free-writes in the *Lead by Design* Institute employed the same technique previously used by the researchers (Rosales et al. 2012), based on (Badenhorst 2007). Participants were invited to write in landscape mode, using coloured paper and fine-tipped markers, as these aesthetic differences separated the free-writing activity from the often anxiety-laden task of academic writing.

Initially participants were a bit reluctant to free-write with coloured markers and paper, but we observed an increasing ease with the free-writing over time, to the point where by the end of the Institute participants wrote with ease, and even eagerly engaged with each new free-write topic. Moreover, quantitatively, the average word count per free-write increased over the Institute, from 54 words per free write on Day 1 to 107 words per free-write on Day 5.

From the post-Institute survey, in response to "The free-writing exercises helped me to understand my identity as an aspiring engineering professional," all Agreed, 7.1 %, or Strongly agreed, 92.9 % (N = 14). In response to a post-Institute survey question on what activities were most helpful or insightful for their professional development, participants wrote (with participant names anonymized):

- Free-writing was the most helpful and insightful because I actually was putting my thoughts into words … I think it was the best thing from this institute. (Maxwell)
- Free-writing. It's a way to reflect my deep thought without any boundary and dig up some information I didn't realize. It's a way to think deeper and have a conversation with myself. (Stephen)

Looking more closely at the content of the free-writes, we can find insightful comments from participants. On Day 1, participants were introduced to free-writing and reflective practice, with five opportunities to free-write that day. Their writings on Day 1 tend to be less personal and more "academic" than those they produced on subsequent Days. At the start of Day 2, participants were asked to free-write on, "What did you learn (or was significant) about yesterday?" Several responses cited free-writing, e.g.:

- I was very amazed by the term "free writing". I know this word from many years. But yesterday I understand it completely. … I think through this kind of exercise you can relax your mind and it will also help someone to develop new ideas … (Colt Tropper)
- … the greatest part was to learn about free writing and surprisingly after I started free writing it gave me a relaxing time also. (Melisa)
- Free writing: First time I heard about free writing. It was fun!! … when I want to open up or when I want to start my thoughts to fall I will use this method in future. (Lilly)

while other responses cited reflective practice, e.g.:

- Reflective thinking. It makes things more specific. …The gap between the ideal and practical was visualized. (Charlotte)

By Day 4, in response to a free-write on "Reflect on writing the narratives—what do you want to know?", two participants wrote:

- My process of writing narratives became or gradually became good but slowly. … However this exercise helped me to think deep & look into my history when I really select[ed] engineering. (Aji)
- It was not easy to look into the mirror and explore the deep thought in my mind. After a few times of practice it became much easy for me to write. … reminding me that why I am here, doing what I am doing and being who I am. … The answer sometime is very simple, right there in your hand. (Kelly)

One participant did express concern, though, about the challenge of adopting a new process:

- Other thing I want to know is how to keep this habit and apply to my works everyday. (T. Smith)

While the free-writings elicited personal insights, participants also noticed the transferability to their engineering work, such as on Day 3, in response to "What is something significant that you've learned this week?":

- The free writing and narrative although daunting at first are liberating and I can see them as useful tools for writing my thesis. (Amy)

Overall, participants started narrative writing reluctantly, as they were not familiar with it or were not used to self-reflection. But over five days of facilitation, bolstered by the positive experience of participating in what became a friendly and supportive group, the participants engaged more readily in narrative writing, even to enjoying the process, and also appeared to find benefits in self-reflection.

3.2 Narratives and Professional Identity

Identity is more difficult to extract from the free-writes than the reaction to the free-writing process itself. Nonetheless, some quotes from the free-writes attest to the participants' growing insights into their professional identities. For example, on Day 4, in response to an activity to free-write on "Re-engineering the foundation of your career", one participant wrote:

- I still need to get to know more about my foundation, my value, motivation and vision. … In an engineering perspect[ive] we could make something with a model and data. What I need to do is to gather(…) data for my foundation and set up a model. Give a try or shot, by trial and error. Being there means something. (Stephen)

Also as noted above in the section *Narratives and Reflective Practice*, some participants looked forward to benefitting from using free-writing and reflective practice in their ongoing engineering careers.

In addition to the free-writing and self-reflection exercises that occurred frequently throughout the Institute (for a total of 24 over 5 days), the curriculum of the *Lead by Design* Institute included a companion exercise consisting of the writing and revision of a personal narrative on how each participant came to be in engineering. This narrative writing-revision exercise was coupled with another exercise to bring in and speak to a physical object, or an image of an object, that inspired them when they were young, as in the manner of (Turkle 2008). These exercises were developed to be explicitly oriented towards increasing the self-awareness and more precise articulation of the participants' sense of professional identity.

The purpose of the narrative writing-revision exercise was for participants to reflect more deeply on the process and/or turning points that developed their identity in engineering. The exercise consisted of writing a short story (200-1000 words were recommended) about something significant that influenced their choice to study engineering.

The first narrative was written prior to Day 1 of the Institute. To assist the participants to spontaneously write a story with specific details from their experience and history, we suggested that their story could be written to address one or more of the following questions: What material object influenced or stimulated your interest to study engineering? What role model, mentor or teacher helped stimulate your interest to study engineering? What aspect of the world do you wish to change through your work in engineering? What dreams do you have for your career?

Later, each participant revised their narrative mid-way through the Institute. Feedback was provided to each participant's Draft 2, with a particular focus on deepening the reflective process. Each participant subsequently produced a final version of their narrative by the end of the Institute.

The purpose of revision was to help participants to better understand their pre-Institute sense of identity, as expressed in the initial draft. Meanwhile, participants were working intensely on various other threads of activity throughout the Institute; some of these activities tended to keep the questions asked for the pre-Institute narrative alive and present in the consciousness of the participants, allowing ongoing reflection towards heightened self-understanding in response to the questions, and their individual refinement of their sense of identity.

For example, one participant, anonymously named Sheri, started Draft 1 by acknowledging an early interest and sense of talent in mathematics and physics (as did many of the engineering graduate student participants). But closer to starting university, Sheri had found it difficult to choose between mechanical and electrical engineering. Sheri noted in Draft 1:

> I was actually more tended to the Mechanics as the concepts seemed to be more tangible. On the other hand, Electrical Engineering was more intriguing … So, the best for me was to ask for some advice before making the final decision. So having received enough consultation from professional advisers, I eventually found my way into the fantastic area of Electrical Engineering! (Sheri)

In Draft 2, Sheri noted an early interest also in medicine, that was later refined into interests in biomechanics and biomaterial engineering, and specifically in medical prosthetics. By the final narrative, Sheri was able to write a more refined and specific self-understanding and sense of identity as an electrical engineer, by noting that early interests in the design of medical prosthetic limbs had been part of the eventual career decision to pursue electrical engineering. Sheri's final narrative included this statement:

> And I thought that electrical engineering is the best, as unlike mechanical engineering, it's not only limited to designing the shape of the prosthetic, but it also brings [tons] of opportunities for me to help the human being living a better life. (Sheri)

Thus, Sheri's narrative revisions lead to a refinement of self-understanding and a more precise and more specific articulation of professional identity as an electrical engineer.

3.3 Professional Sustainability

While we cannot claim that the *Lead by Design* Institute had a significant impact on the professional sustainability of the participants (that would need a longitudinal study), it is worthy of note that all 14 participants remained to the end of an intense 5-day Institute. Indeed they left with thanks and enthusiasm. In a final Day 5 reflection on whether their undergraduate programs prepared them for graduate work, and what might be missing from their present studies, several participants indicated the importance of the process skills introduced in the *Lead by Design* Institute, both for themselves and for other graduate students. For example, two responses were:

- The chance to practice my soft skills was also very rare and I didn't even know it is so important. Spring institute helps me once again to open my mind, to view myself as an engineer from different perspectives. This is fun. (Kelly)
- … I want programs and leadership courses like these to be made compulsory or part of degree programs at [Memorial University] so everyone benefits from it. Because it makes you a good engineer and you can excel more in the job market if you have such skills. (Maxwell)

4 Conclusions

By the feedback of its participants, the *Lead by Design* Institute provided an insightful co-curricular experience that opened to them the value of reflective exercises. As participant-observers, we witnessed the growing awareness/self reflection of the participants across the 24 free-writes and other activities of the Institute. The free-writes, personal narratives, session discussions, etc. were indicative of a growing realization of their identity as engineers. While difficult to claim with significance, we can also suggest that this growth was aligned with a greater awareness of agency, i.e. the power to be the kind of engineer they want to be. Participants' reflective practice enabled them to have insights into their previous personal experiences that had led each of them to choose engineering at an earlier stage in their studies, and enabled them to see a continuity from those earlier experiences with their unfolding careers. Future work is needed to investigate the extent to which the experience of participating in the *Lead by Design* Institute can have an influence in enhancing their individual identity and professional sustainability over the longer term. As well, future work is needed to explore the implementation and evaluation of this pedagogical approach for a wider spectrum of engineering undergraduate and graduate students.

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D-Lab and MIT IDEAS Global Challenge: Lessons in Mentoring, Transdisciplinarity and Real World Engineering for Sustainable Development

Susan Murcott

Abstract

This paper reflects on the Massachusetts Institute of Technology's D-Lab and IDEAS Global Challenge pedagogy over the past 14 years (2002–2015). The MIT IDEAS Global Challenge, a program of the MIT Public Service Center, is an annual invention and entrepreneurship competition that awards up to $10,000 per MIT team for innovations and service projects that positively impact underserved communities. IDEAS student teams work with a community partner on projects that are designed to improve the quality of life globally. Since its founding in 2002, IDEAS has awarded more than $600,000 to 132 teams. D-Lab Water, Sanitation, Hygiene and Environmental Innovations for the Common Good (D-Lab WASH + ENV) is a MIT course offered for the past 10 years within a curriculum of over 20 D-Lab classes in international development. This author has mentored several hundred student teams that have entered the IDEAS Global Challenge, mostly through this course D-Lab WASH + ENV, including 26 winning teams. Eighty-one percent of these IDEAS winning teams have been led by women students. This is a model of the kind of program that can bring gender parity to science, technology, engineering and math (STEM) disciplines while nurturing the "whole student." In common with the wider family of D-Lab courses, the D-Lab-WASH + ENV course is structured around experiential learning and real-world engineering. This paper links the Engineering Education for Sustainable Development (EESD) conference themes with the D-Lab/IDEAS pedagogy in terms of key concepts: **mentoring**, **transdisciplinarity** and **real world engineering**. It ends with challenges and recommendations.

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1 Introduction

Two Massachusetts Institute of Technology (MIT) programs, D-Lab and the IDEAS Global Challenge (referred to throughout this article as “IDEAS”), are examples of outstanding programs that re-imagine engineering education for sustainable development. Concurrently, they do an exemplary job at supporting women’s success in science, technology engineering and math (STEM) subjects, as well as nurturing the “whole student.” This paper addresses the Engineering Education for Sustainable Development (EESD) conference themes and the D-Lab/IDEAS pedagogy in terms of key concepts: **mentoring**, **transdisciplinarity** and **real world engineering**. It articulates a vision of re-imagined engineering education, identifies challenges faced by the D-Lab and IDEAS programs at MIT, and ends with recommendations.

2 What Is D-Lab?

Founded in 2002 by Amy Smith, Senior Lecturer in MIT’s Mechanical Engineering Department, D-Lab is an MIT program that challenges students to use their science, engineering, technology, math plus social science and business skills to tackle a broad range of global poverty issues. D-Lab seeks to build a global network of innovators to design and disseminate technologies that meaningfully improve the lives of people living in poverty. The program’s mission is pursued through interdisciplinary courses, technology development, and community initiatives, all of which emphasize experiential learning, real-world projects, co-creation with community partners, and scalability (the ability to scale up technological innovations to ensure health and well-being to millions of people).

D-Lab students have developed innovative technologies and processes such as community water testing, water and wastewater treatment systems, human-powered agricultural processing machines, medical and assistive devices for global health, clean-burning cooking fuels made from agricultural and other bio-waste, all carried out with community partners who co-conceive, co-design, co-build and co-implement these innovations within underserved areas.

In its first decade of existence, D-Lab developed 18 MIT courses with about a dozen offered during any given academic year, for example: D-Lab Development; D-Lab Design, D-Lab Dissemination, D-Lab Energy, D-Lab Schools, D-Lab Health and D-Lab Mobility. (A full listing of D-Lab courses is here: http://D-Lab.mit.edu/courses/). Many of these courses are cross-listed with academic departments: for example Mechanical Engineering, Architecture, Urban Studies and Planning and Sloan School of Management. In addition, they provide credit towards major and minor courses of study. All D-Lab classes are connected to communities around the world including partnerships in Brazil, Nicaragua, Guatemala, Ghana, Peru, Cambodia, Tanzania, Botswana, El Salvador, Uganda, India, Zambia and Nigeria. Most D-Lab classes offer an opportunity for field work. Students may pursue undergraduate research or other long-term research projects with D-Lab staff members.

Most D-Lab instructors are experienced development-practitioners and dedicated teacher-mentors. Few are tenured faculty. The emphasis is applied, experiential, inter-disciplinary (crossing two or more academic department boundaries) and trans-disciplinary (crossing many disciplinary boundaries and including all relevant stakeholders to co-create a holistic approach). The implicit sustainable development goal of these endeavors is to learn about and to improve the well-being of present and future generations and in so doing, to protect and preserve the earth. Some in-coming students say they elect to attend MIT because of D-Lab. Many students find their D-Lab class(es) and field experience to be life-changing and a high-point of their MIT careers.

D-Lab has grown into a powerful force for innovation on campus and a widely recognized program of creativity, innovation and entrepreneurship around the world. It has grown by leaps and bounds over its 14-year history and is comprised of many diverse initiatives, including—International Development Innovators Network (IDIN), Comprehensive Initiative for Technology Evaluation (CITE), D-Lab Scale-Ups, Youth Outreach, and a core group of instructors, staff and development-practitioners. This paper is not meant to speak for the entire D-Lab community, but rather to offer the author's reflections based on her own D-Lab teaching and learning experiences.

3 D-Lab Dissemination

3.1 Background

The author's association with D-Lab began in 2003 when she, together with Amy Smith, the founder of D-Lab, and Heather Cruickshank, Senior Lecturer in the Civil, Structural and Environmental Engineering Division of the Department of Engineering, Cambridge University, collectively taught a new course, Design for Developing Countries (SP753/SP722) at Cambridge University. In that same period, Amy Smith began teaching a new MIT course in the fall term, D-Lab Development, which was an introduction to international development, with the option for field work during January's Independent Activities Period. Subsequently, Design for Developing Countries, the Cambridge University graduate level course, was reworked into an MIT undergraduate class, D-Lab Design. Concurrently, the author was invited to teach D-Lab Dissemination, which was the third “D” of the original D-Lab trilogy of courses (i.e. Development, Design and Dissemination).

The MIT course catalogue description of D-Lab Dissemination (SP723, later re-catalogued as EC715/11.474) reads as follows:

> D-Lab III is the third in the D-Lab trilogy of courses on “Development,” “Design,” and “Dissemination” focusing on disseminating innovations among underserved communities, especially in developing countries. Students acquire skills related to building partnerships and piloting, financing, implementing, and scaling-up a selected innovation for the common good. The course is structured around MIT competitions: IDEAS Global Challenge, $100K, Deshpande IdeasStream Innovation Showcase, and outside competitions…

3.2 Early Years of D-Lab Dissemination

For five years, from spring 2006 to spring 2010, D-Lab Dissemination focused on all manner of innovations in any discipline. Always, the emphasis of the class was supporting students as they formulated their creative idea and mentoring them through the creative process of bringing that seed idea to fruition. Entering the MIT IDEAS Global Challenge or some other competition or grant application process was always the student deliverable for this class. D-Lab Dissemination’s term project requirement was that the student formed a team and entered IDEAS or some equivalent competition(s) of their choice. Team projects are common in all D-Lab classes. The requirement to enter IDEAS or some other appropriate competition was, to my knowledge, unique to the D-Lab Dissemination class (although of course, any MIT student is eligible to enter the IDEAS competition).

3.3 Refocus of D-Lab: Dissemination to D-Lab WASH and Environmental Innovations

Meanwhile, the D-Lab program’s course offerings were growing rapidly. After the first five years of teaching D-Lab Dissemination, the author decided to refocus the D-Lab Dissemination course from innovations in any domain to projects exclusively in her area of expertise—water, sanitation, hygiene and environmental innovations. Thus, the course was re-named D-Lab: Water, Sanitation, Hygiene and Environmental Innovations for the Common Good (EC.715/11.474), or D-Lab WASH + ENV for short.

3.4 Small but Beautiful—and Award-Winning

This narrow focus has kept D-Lab: WASH + ENV classes small, but always we have subscribed to the philosophy of “small is beautiful.” While we have been small, with class sizes of about 10 students per term forming about four to five teams, we have been "beautiful" insofar as these teams have won many IDEAS and other competitions. In fact, teams mentored though this class, plus a few other teams the author mentored before this first class existed, have won 26 prizes in IDEAS competitions from 2002 to 2015. Of 132 winning IDEAS teams total over this period, teams this author has mentored represent 20 percent of all IDEAS winners.

4 IDEAS Global Challenge

4.1 IDEAS

As has been mentioned, one of the unique features of the D-Lab Dissemination/D-Lab WASH + ENV course is that the core deliverable for the course is to enter the IDEAS Global Challenge or some other suitable competition. Most students in the class elect to enter IDEAS. IDEAS is an annual competition held each spring at MIT. IDEAS stands for key themes of the competition: **I**nnovation, **D**evelopment, **E**nterprise, **A**ction, and **S**ervice. Awards are given for innovations that address community development challenges at home and around the world in underserved communities, engaging community partners to co-create solutions for identified community needs. Winning teams receive a grant of up to $10,000 to help fund the implementation of their service project. Founded in 2001, IDEAS complemented the pre-existing MIT $100K Competition, which tended, historically, to emphasize for-profit business innovation, but which has since expanded into multiple thematic areas all centered on entrepreneurship. Since 2002, the MIT IDEAS Global Challenge has awarded more than $600,000 to 132 teams. Offered through the MIT Public Service Center and sponsors, IDEAS is in MIT's best tradition of creative problem-solving, hands-on and experiential learning and entrepreneurial spirit to further positive change through innovation.

4.2 IDEAS Winning Teams from D-Lab Dissemination/D-Lab WASH + ENV

The author mentored two winning teams in the first IDEAS competition in 2002 and four winning teams in the 2014 and 2015 IDEAS competitions. In these intervening years, the author has mentored a total 26 winning IDEAS teams—20 % of all winning teams (Appendix 1). Many of these teams have innovated in the domain of water, sanitation, hygiene and environmental projects. Eighty-one percent of the winning teams the author has mentored have been led by women students. Since we are operating in the elite, male-dominated domain of engineering innovation and entrepreneurship, this is a solid manifestation of gender-inclusive pedagogy that we should seek to nurture and advance. In addition, some teams enter multiple competitions and concurrently or sequentially enroll in other D-Lab classes, sometimes in order to further develop the same team concept. Through this they get exposure to other disciplines and D-Lab instructors. Even if they only take one D-Lab class, students are aware that there is an entire MIT system of innovation and international development practice. So it is important to acknowledge multiple mentors and supporters for any one class's success. (See Appendix 2 for brief descriptions of five selected teams).

5 Mentoring, Transdisciplinarity and Real World Engineering: Re-imagining Engineering Education—Emphasizing the "Whole 'Trans' Student" Learning in Real World Communities and Environments

Three core pedagogical concepts—**mentoring**, **transdisciplinarity** and **real-world engineering**—have informed and contributed to the success of the D-Lab WASH + ENV class.

Therefore, in each of the three thematic sections below—**mentoring**, **transdisciplinarity** and **real-world engineering**—I begin by defining my terms. Then, because this University of British Columbia conference, Engineering Education for Sustainable Development, is about re-conceptualizing engineering education for sustainable development, and because likewise, D-Lab and the IDEAS are MIT programs that re-conceptualize engineering education, I will next illustrate various aspects of these core pedagogical framing concepts as they pertain to D-Lab WASH + ENV and IDEAS by discussing key themes within each conceptual framework.

In defining my terms, it should also be mentioned that although the D-Lab and IDEAS programs do not always explicitly use the terminology of sustainable development, D-Lab and IDEAS very much align with sustainability values, for example, as expressed in the best-known definition of sustainable development: "meeting the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission on Environment and Development, 1987). Below, I discuss the D-Lab and IDEAS conceptualization of engineering education for sustainable development, that is to say, the "whole student" learning in real world communities and environments, based on the author's experience over the past two decades of researching, teaching and mentoring at MIT generally and through active engagement with D-Lab and IDEAS specifically.

5.1 Mentoring

Mentoring is often thought of as advising or training a younger individual to help them realize their potential. In my opinion, mentoring is about nurturing a student's own creative capacity. While it encompasses training and advising, its focus is on being a role model. As female role models are less numerous in the fields of science, technology, engineering and math, I believe it is particularly important for female students and other "minorities" to receive female and other "minorities" mentoring.

Some of the dimensions of mentoring within the D-Lab WASH + ENV class and IDEAS include the following.

- *Value: Listening, Supporting and Enabling Students*: Given the rigors of technical science and engineering education, there is limited opportunity in the traditional classroom and core curriculum, which focuses on mastering fundamentals, for students to gain the confidence to propose their own ideas and see them through to fruition. Listening and supporting the students in all that they do and giving them the opportunity in the classroom and in the wider world to express and innovate is key to this pedagogy.
- *Value: Nurturing Inclusivity and Cooperation*: the D-Lab WASH + ENV class and the IDEAS competition provides opportunities to nurture values of inclusivity, cooperation and service, engendering a sense that we are all involved in solving these global problems by working together.
- *Value: It Doesn't Matter if You Win or Lose*: Every team which completes the process of entering and presenting their idea to the class, then subjects it to the scrutiny of the judges and the public at the IDEAS annual showcase gets invaluable experience in conceptualizing and taking steps towards realizing their dream idea. So regardless of whether they win an award, students make huge gains by embracing this opportunity and moving their idea forward.
- *Value: Walking the Talk*: The instructor attempts to be a role model who is also engaging in innovation and entrepreneurship in international development.

5.1.1 Mentoring the "Whole Person"

The "whole person" is not merely rational, but has an identity, a cultural inheritance, a place of origin, a creative imagination, core relationships, an emotional life, a spiritual dimension and a system of inherited values. D-Lab WASH + ENV mentors the "whole person" through an approach that recognizes and tries to advance the entire sweep of human knowledge, wisdom, experience and expression in arts, humanities, science and engineering, not only discipline-specific science/engineering learning.

5.1.2 Challenging the Student to Research and Develop an Idea or Project That They Love

Students are mentored in creating an idea or project that they are passionate about, that they could imagine giving themselves to for at least one academic term, for a year, for their university years or even for their lifetimes. The students attracted to D-Lab WASH + ENV are those who are passionate about exploring global water and environment projects.

5.1.3 Focus on Students' Learning Outcomes as a Complement to Teacher-Prescribed Teaching

Learning that is individualized and personalized fosters self-realization, problem-solving, communication, critical thinking and creativity. The key is to help a student foster her/his own ideas and to invest her/his whole self in realizing that idea. This suggests that the role of the teacher involves a comparable creative process that mirrors the process of the student's own learning.

5.1.4 Engagement of University Students with Vastly Different People/Cultures Living in Poverty

This engagement fosters profound and life-altering experiences that enable the student to know and experience herself/himself and the world clearly. University students who encounter vastly different people and cultures living in poverty are exposed to potentially profound, life-altering, deep-learning experiences.

5.1.5 Experiential Learning

Dewey's pedagogical model described in *Experience and Education* centers on the principle of learning through personal experience, also referred to as "the new education"—which includes "free activity, learning through experience, acquisition of skills and techniques which make direct vital appeal, making the most of opportunities of present life, acquaintance with the present world" (Dewey 1938, pp. 19–21). This exemplifies Dewey's role as the father of experiential learning.

5.1.6 Teaching and Learning While Sitting Together in a Small Circle

There is a lot of fascination, rightly, with the power of the internet to revolutionize education. MITx, edX among other on-line course platforms, are pioneering in that space. Meanwhile, the teaching/learning style of D-Lab and IDEAS is also pioneering a new pedagogy, which is both entirely contemporary in its use of digital media and at the same time is age-old. As on-line courses dive into the future, providing education for thousands of students at a time, the D-Lab WASH + ENV model is diving into the person, to recall that teaching and learning begins with the person, then their family, and hopefully extends to a teacher and her/his students. This relationship is a face-to-face mutual exchange of teaching/learning, curiosity, challenge, support and love. As in family, so too the educational highlights of our lives hopefully involve knowing and learning from specific teachers. It may be that when we sit together in small circles of such teachers/learners, that in these relationships we find the most profound meaning.

5.2 Transdisciplinarity

The Oxford English Dictionary defines **transdisciplinary** (adjective) as: "pertaining to more than one discipline or branch of learning; interdisciplinary" (OED 2013).

For example, "A recent workshop jointly sponsored by the American Association for the Advancement of Science and the U.S. Department of Energy has been attempting to lay **transdisciplinary** foundations for a federally supported research programme on the impact of increasing atmospheric carbon dioxide content" (*Nature*, May Vol. 3, No 1/2, 1979).

Transdisciplinarity (noun) is a derivative that expands the notion of transdisciplinary to create a holistic approach or unity of knowledge beyond any single discipline (Jean Piaget may have coined the first use of this term in 1970). Transdisciplinarity not only assumes the necessity of collaboration across academic disciplines, but importantly, engages with all the relevant stakeholders, not least, those most affected by the research. As a consequence, transdisciplinarity engages different ways of knowing; generating new knowledge and helping collaborators understand and incorporate the results or lessons learned by the research (see: Wickson et al. 2006).

I like the "trans" in transdisciplinarity. "Trans" as a prefix means: "across, through, over, to or on the other side of, beyond, outside of, from one place, person, thing, or state to another" (OED 2013).

We need language and concepts that take us beyond divisions, across to the other side of borders. "Trans" helps take us there both in our imaginations and in our daily routines.

So, with "trans," transdisciplinary and transdisciplinarity, we have this suite of meanings:

1. Across to the other side, beyond, from one place, person, thing or state to another;
2. Interdisciplinary;
3. Seeking a holistic unity of knowledge;
4. Collaboration among relevant stakeholders, not only among academics;
5. Engaging with the people affected by the research;
6. Embracing different ways of apprehending the world.

These meanings of "trans," transdisciplinary and transdisciplinarity reveal different nuances of meaning. Transdisciplinarity provides a conceptual framework that helps us comprehend and practice sustainable development. But transdisciplinarity is a cumbersome and academic term. I like "trans" as a simplification for the entire set of meanings above.

In my earlier work, I put forward the concept "co-evolutionary design for development" suggesting a suite of characteristics that parallel the multiple meanings of trans/transdisciplinary/transdisciplinarity (Murcott 2007). The D-Lab community refers to "co-creation" and "creative capacity building"—the idea in all cases being that innovation and scale-up of new technologies and approaches to bring basic health and well-being to millions of people is a relational, creative and collaborative process with multiple stakeholders across and beyond disciplines and borders.

5.2.1 Mind, Hand, Heart and Spirit

Since its founding in 1861, MIT has had as its motto "*Mens et Manus*, "Mind and Hand." "Mind and Hand" captures competencies that MIT has been historically famous for—science and engineering, basic and applied research, theory and practice. IDEAS and the D-Lab family of classes are also exemplars of "Mind and Hand." They embody science. They embody engineering. In recent years, it has been proposed that MIT change its motto from "Mind and Hand" to "Mind, Hand and Heart." There is a parallel initiative on campus: Mind + Hand + Heart http://mindhandheart.mit.edu/ to enhance mental health and well-being of the MIT community. I would suggest that a new MIT motto: "Mind, Hand, Heart and Spirit" is expressive of a broader "trans person" and "whole person" that includes not only the mind/body part, but also includes emotional, spiritual and moral dimensions. Heart and spirit may be uncomfortable territory in a scientific/engineering environment. But if we seek to train the "whole person," then we cannot ignore these dimensions. MIT should seek to cultivate graduates who are emotionally, spiritually and morally literate, as well as technically literate.

5.2.2 Diversity, Inclusion and Gender Parity

Bringing heart and spirit into the MIT identity would mean that we include and welcome a greater awareness of service to address global poverty, especially the poverty of invisible women and children. How do you bring heart and spirit (and women and children) into the community? One answer could be "inclusion." In terms of gender, one aspect of inclusion must be parity of women and men on the MIT faculty and administration, ideally sooner than one or two generations from now. What about in the next decade? It could be done … if there were the political will. Iceland, Norway, Sweden and Finland have taken concrete steps to achieve gender parity in their academic and all other institutions. If they can do this, so can MIT and other top engineering universities in the USA and around the world (Zahidi 2013).

5.3 Real World Engineering

This leads directly to "real world engineering" which refers to applied engineering projects conducted by teams from universities or research institutes working with local communities around the world. It is a specific application of experiential learning. D-Lab challenges technically-trained students to use their math, science, engineering, social science, business and other skills to tackle specific global poverty issues. For the D-Lab teams that enter IDEAS, real world engineering is linked with real world competition. The requirement for the D-Lab WASH + ENV class is to either enter IDEAS or any other competition(s) of their choice or to write a proposal to a relevant agency, non-profit or foundation in order to fund their idea. Entering IDEAS is the most popular choice among students from D-Lab WASH + ENV.

5.3.1 Situating Learning Beyond the University in Complex, Real World Contexts

D-Lab pedagogy is especially interested in engaging students in complex real-world contexts of extreme poverty. By the very fact of their being in university, university students are largely privileged. Exposing them to poverty challenges them to explore their own values and ways of knowing more deeply.

Engineers are problem solvers. Yet engineers-in-training can often be given trivial assignments, or expected to contribute only small or insignificant parts to a much larger puzzle, the meaning of which is never explained. The D-Lab pedagogy expects students to grapple with real world questions of our time and to situate them in a holistic, cultural context. How can our talents as engineers-in-training be applied to contribute to a better life for impoverished people and communities? Can we address climate change via a tree-planting social enterprise or a biofuels innovation? Can we alter patterns of materials and energy use to enable a sustainable world for present and future generations?

5.3.2 New Modes of Engaged Teaching/Learning in Small Face-to-Face Groups of Non-hierarchically Organized Teachers/Learners Solving Real World Challenges

Traditional engineering education has a narrow conception of achievement. This involves being right, being smart, and smarter than others, moving up the career ladder. It's about the achievement of degrees, status, titles, grants, money and power.

The author has been immersed in MIT culture for 28 years, a culture largely but not exclusively comprised of engineers and scientists who are innovative, entrepreneurial, individualistic and technology-focused. I relate to that culture both as an insider and outsider. I understand MIT culture from the inside because I am innovative and entrepreneurial. I experience MIT culture as an outsider for several reasons—I am a woman who embraces her feminist and feminine identity, I am people and community-focused, rather than individualistic. I agree with psychologist and professor, Carol Gilligan, who writes that "the moral injunction that emerges repeatedly in interviews with women is an injunction to care, a responsibility to discern and alleviate the 'real and recognizable trouble' of this world" (Gilligan 1982). I believe the Western tradition is seriously flawed in its exclusion of women's and other outsiders' voices and that the way we "meet the needs of the present generation without compromising future generations from meeting their own needs" is through connection with peoples universal aspirations for basic well-being, security, education and opportunity for themselves and their families. I engage in engineering projects that help other people. Women and men are attracted to these real-world projects. My inclination is to embrace my outsider status. Maybe it helps me think outside of the box. What I love about the D-Lab and IDEAS pedagogical models is that they are "being the change we wish to see in the world" (Mahatma Gandhi). These programs walk the talk of engineering for sustainable development.

5.3.3 Complex Systems Thinking and Complex Problem-Solving in the Face of Poverty

Complex systems thinking and complex problem solving in the face of extreme poverty has been the hallmark of D-Lab/IDEAS. A key concept in the D-Lab/IDEAS universe of systems thinking in the face of extreme poverty is the importance of collaboration, variously referred to as co-creation (Prahalad and Ramaswamy 2002), co-evolutionary design (Murcott 2007), human-centered design (IDEO 2015), user research framework (Smith and Leith 2014) and "Design with the other 90 %" (Smithsonian Cooper Hewitt National Design Museum 2015). Human relationships are an often side-lined aspect of complex systems thinking. This new pedagogy seeks to engage all people in the competencies of systems thinking, design and dialogue.

To give an example—the IDEAS competition requires each team to have a clearly defined community partner. This often overlooked dimension of partnership and of equality in the problem engagement phase of design involves the human dimension into the complex system. We are no longer concerned exclusively with system optimization, which maybe relevant but inconsequential in holistic engineering that emphasizes our relationship to our fellow human beings.

5.3.4 Strategic Thinking

Strategic competency in international development involves leadership. The starting point is the inclusive notion that "we are all in this together." Students in the D-Lab/IDEAS circles are challenged to co-create and implement projects and facilitate change in collaboration with community partners. Here, the contribution and challenge of D-Lab/IDEAS is how to implement projects and facilitate change in cultures and environments that are vastly different from the ones we are used to. To give an example—MIT students are privileged and generally have not grown up in extreme poverty. Most of us who are in a tertiary educational environment have had the privilege of access to such conveniences as piped water and flush toilets within a system of centralized water and wastewater treatment systems. However, in communities without safe water and improved sanitation, women and children may spend a significant part of their day carrying water from its source to their homes. These women and children, especially girls, often don't go to school and have been largely invisible to engineering designers and infrastructure builders. So, this raises the question of what would engineering leadership look like if we sought to co-evolve water and sanitation solutions with these still largely invisible communities and people, such as underprivileged women and children? Would the engineering designs be piped water and flush toilets? Would the most practical and achievable engineering designs be centralized water supply and end-of-pipe wastewater discharge systems? Should we design community-based and decentralized systems? Should we design water and sanitation systems that return clean water to aquifers, rivers, fields and forests? What systems would be embraced by communities that fit within their cultures and geographies?

6 Challenges and Recommendations

Below are several significant challenges encountered in teaching at MIT and the author's recommendations for addressing these challenges:

- *Tenured Faculty vs "the Rest"—Hierarchal and "Caste" Divisions in the Ivory Tower:* D-Lab/IDEAS are not typically led or supported by tenured academic faculty from science, technology, engineering and math (STEM) disciplines, some of whom may think that the extra-curricular and possible international travel component of these projects is a distraction from more high-priority graduate and post-graduate research, publication and achievement. This divides some tenured faculty, especially at elite research institutions like MIT, from the lower caste non-tenured lecturers, instructors, international development practitioners and staff who run these experiential learning experiences.

Dewey describes traditional education:

> Call up in imagination the ordinary school-room, its time-schedules, schemes of classification, examination and promotion, of rules of order and I think you will grasp what is meant by [traditional education]… The main purpose or objective is to prepare the young for future responsibilities and for success in life, by means of acquisition of the organized bodies of information and prepared forms of skill which comprehend the material of instruction. Since the subject matter as well as standards of conduct are handed down from the past, the attitude of pupils must, upon the whole, be one of docility, receptivity and obedience… while teachers are the organs through which pupils are brought into effective connection with the material. Teachers are the agents through which knowledge and skills are communicated and rules of conduct are enforced (Dewey 1938, p. 18).

Applying Dewey's system to tertiary education, that traditional system includes the tenured faculty system. Speaking only from my own limited experience in the present day context at MIT, many tenured STEM faculties seem to have limited field experience or competency with poverty and international development. Some may find these activities superfluous, extra-curricular or simply outside of their professional research purview. My modest proposal is that "the system" needs to include other "trans" voices from outside the borders of academia. We need to bring the outsiders in.

- *Do Women Teachers Lead to Women's Success in Engineering Leadership*?: Top MIT leadership, including the MIT Institute Community and Equity Office, embrace equity and inclusion, as per the recent recommendation to create a MIT Compact on what we aspire to as a community and what we expect of one another as MIT community members. (Bertschinger 2015). One dimension of inclusion is gender equity. MIT has made some significant strides to increase the number of women faculty. Between 1995 and 2011, the percentage of women on the engineering faculty has increased from 7 to 16% and the science faculty from 8 to 19 % (MIT 2011). Yet classroom instruction is still an overwhelmingly male enterprise.

6.1 Gender Parity

Gender parity is still lacking in STEM faculties and administration at MIT and around the world. But if gender parity is yet to be realized in engineering education and the other STEM disciplines, if we consider gender parity as well as service to the poor as important strategic objectives, then it is necessary to consider those rare examples where gender parity and service to the poor are already being achieved in STEM institutions. We have examples at MIT, such as the D-Lab and IDEAS programs, where women and other "minorities" are present in "trans" teams, and where women and "minorities" are attracted in great numbers. These programs, classes and development projects and design innovations are "being the change we wish to see in the world." The D-Lab and IDEAS programs provide rare examples of gender parity, with equal or even greater numbers of women and other "minorities" in successful leadership roles within MIT's Schools of Science and Engineering.

Gender parity is not only the ratio of the number of female students enrolled at primary, secondary and tertiary levels of education to the number of male students in each level. It must also be the ratio of the number of female faculty and staff teaching/learning with students to the number of male faculty and staff teaching/learning with students. When a discipline lacks women teachers, it lacks role models for women to enter and shape that field.[1] I would relish an engineering program that supports women and men in an inclusive environment of gender parity.

Without intending it, the percentage of IDEAS winning student teams led by women mentored by this author is an astonishing 81 %. In a N.Y. Times editorial,

[1]The **Gender Parity Index (GPI)** is a socioeconomic index usually designed to measure the relative access to education of males and females. In its simplest form, it is calculated as the quotient of the number of females by the number of males enrolled in a given stage of education (primary, secondary, etc.). It is used by international organizations, particularly in measuring the progress of developing countries. The Institute for Statistics of UNESCO also uses a more general definition of GPI: for any development indicator one can define the GPI *relative* to this indicator by dividing its value for females by its value for males. For example, some UNESCO documents consider gender parity in literacy. http://unstats.un.org/unsd/mdg/Metadata.aspx?IndicatorId=9.

Lina Nilsson, of the Blum Center for Developing Economies at UC-Berkeley asks: “How do we attract female engineers?” and “Why are there so few female engineers?” She says many reasons have been offered—workplace sexism, lack of female role models, stereotypes of women’s innate technical competency, the difficulties of combining tech careers and motherhood. Fixes have been suggested—mentor programs, student support groups, targeted recruitment, diversity commitments. But one solution stands out for its elegant simplicity. At UC-Berkeley, “**if the content of the work itself is made more societally meaningful, women will enroll in droves. That applies not only to computer engineering but also to core traditional, equally male-dominated fields like mechanical and chemical engineering**.” (Nilsson 2015). My experience teaching D-Lab WASH + ENV, and the success of women in engineering leadership in innovating with “ideas that help other people,” is the hallmark both of D-Lab and IDEAS. The D-Lab and IDEAS experience at MIT is identical to that of Nilsson’s at UC-Berkeley’s Blum Center for Developing Economies.

One additional question is whether having a woman teacher supports success of women in engineering leadership? In “Do Faculty Serve as Role Models? The Impact of Instructor Gender on Female Student,” (Bettinger and Long 2005) use a comprehensive, longitudinal dataset of nearly 54,000 students to complete one of the first large-scale studies aimed at estimating the impact of faculty on the outcome of students. They report that female instructors do positively influence course selection and major choice in some disciplines, thus supporting a possible role model effect. The findings provide insight into the possible impacts of policies designed to increase female representation on college faculties. If women teachers lead to women students’ interest in a particular academic discipline, then a corollary could be that lack of women teachers helps explain the gender gap between women and men in STEM disciplines. This suggests that one remedy is gender parity in the faculty of STEM departments. One would think that there should be tremendous interest on the part of the MIT faculty and administrators in understanding the reasons for women’s significant representation in the D-Lab and IDEAS contexts, both at the leadership and student prize-winning levels. The purpose of Appendix 1 is to document one instance of this success using the example of D-Lab WASH + ENV/IDEAS, where one woman mentor provides a role model to women students particularly and to all students generally.

This paper constitutes the author’s reflections on the paradigm of the D-Lab and MIT IDEAS Global Challenge and pedagogy as it relates to engineering education for sustainable development. This is a work in progress. Comments, critiques and ideas are welcome.

Acknowledgements The author would like to acknowledge the D-Lab and IDEAS Global Challenge instructors, staff and students who have contributed to making these programs such a dynamic, joyful, egalitarian and supportive learning environment, and without whom the successes described here would not have been possible.

Appendix 1

MIT Award-Winning Student Teams Advised by Susan Murcott. More info on specific IDEAS teams is available on the MIT IDEAS Global Challenge Website: http://globalchallenge.mit.edu/teams/past.

The table below lists the 31 winning teams (26 IDEAS teams plus 5 other team awards), along with the project location, the type and amount of the award, the team leader, D-Lab-WASH class participants and/or other students on that team.

Year	Team name	Project location	Competition[a] award	Team leaders, D-Lab-WASH class participants and/or team members
2015	Change: WATER	Jordon	$10,000 IDEAS Award	Grace Connors, Jessie Press-Williams, Diana Yousef
2014	Clean water clean data	Ghana, Guatemala	$7500 IDEAS Award	David Taylor, Natasha Wright, Marcelo Giovanni
2014	My H_2O Team	PR China	$1500 IDEAS Community Choice Award. $39,000 National Geographic Air and Water Quality Fund Award (2014)	Xiaoyuan "Charlene" Ren
2014	Ways2Clean	Bangladesh	$3000 IDEAS Award	Tamanna Islam Urmi
2013	Spouts of water	Uganda	>$50,000 from competitions, grants and fund-raisers	Seul (Kathy) Ku, Suvai Gunasekaran, Hannarae Nam
2013	Hope in flight	Ghana	$7500 IDEAS Award	Coyin Oh and Yiping Xing
2012	OpenIR	Indonesia	$7500 IDEAS Award	Arlene Ducao, Juhee Bae, Ilias Koen, Abdulaziz Alghunaim
2012	wecyclers	Nigeria	$7500 IDEAS Award	Bilikiss Olatoyosi, Alex Fallon, M. Hickman, Emily Boggs
2011	AQUA	Tanzania	$5000 IDEAS Community Choice Award	Peter Kang and Junyun Song
2011	Kosim water keg	Ghana, Guatemala	$10,000 Global Challenge Award	Joanna Cummings, Chris Schulz
2011	SafeWaterWorld	Chile	$7500 IDEAS Award	Samantha O'Keefe
2010	The grease project	Brazil	$3000 IDEAS Award	Ana Bonomi
2010	My city, my future (ArteRio)	Brazil	$3000 IDEAS Award	Kate Balug & Alix Beranger

(continued)

(continued)

Year	Team name	Project location	Competition[a] award	Team leaders, D-Lab-WASH class participants and/or team members
2010	PieceMeal vendors	Thailand	$1000 Community Choice Award	Kim Liao
2009	Global cycle solutions	Tanzania	$30,000 $100K Award Emerging Markets Track	Jodie Wu
2009	Global citizen water initiative	Tibet	$5000 IDEAS Award	Scott Frank
2007	New DOTS	Nicaragua, India	$5000 IDEAS Award	Angela Kirby, Jeff Blander, Elizabeth Gillenwater, Jose Gomez-Marquez, Minyoun Jang, Aron Walker
2007	Vac-cast prosthetics	Cambodia	$7500 IDEAS Competition	Tess Veuthey
2006	CentroMigrante	Philippines	1st Prize. MIT $100K Sloan Entrepreneurship Competition—Dev. Entrepreneurship Track	Illac Dias
2006	FirstStepCoral	Philippines	$7500 IDEAS Award	Illac Dias
2006	Peanut revolution	Philippines	$5000 IDEAS Award	Illac Dias
2006	Kounkuey design initiative	Kenya	$150,000 International Resource Award for Sustainable Watershed Management (2012)	Chelina Odbert and Jennifer Toy
2006	Synergetic power systems	Lesotho	$225,000 (Only winning student team in this competition in 2006)	Elizabeth Wayman, Amy Mueller, Matthew Orosz, Sorin Grama, Ignacio Aquirre, Perry Hung, Mark Wolf
2006	Synergetic power systems	Lesotho	$125K Ignite Clean Energy Business Competition Winner	Elizabeth Wayman, Amy Mueller, Matthew Orosz, Sorin Grama, Ignacio Aquirre, Perry Hung, Mark Wolf
2005	Parabolic power II (former team name of synergetic power systems)	Lesotho	$2000 IDEAS International Technology Award	Elizabeth Wayman, Amy Mueller, Matthew Orosz, Sorin Grama, Ignacio Aquirre, Perry Hung, Mark Wolf
2005	Solar water disinfection device	Nepal	$2000 IDEAS Award	Deborah Xanat Flores.
2005	Mozambique environmental sanitation initiative	Mozambique	$3000 IDEAS Award	Brian Robinson, Pragnya Alekai + 7 other teammates from DUSP

(continued)

(continued)

Year	Team name	Project location	Competition[a] award	Team leaders, D-Lab-WASH class participants and/or team members
2004	TestWaterCheap	Peru	$5000 IDEAS Award	Brittany Coulbert
2003	Lumbini water solutions	Nepal	$3000 IDEAS Award	Melanie Pincus
2003	MIT UV tube project	Nepal	$2000 IDEAS International Technology Innovation Award	Deborah Xanat Flores
2002	Dlo Prop—Water treatment project	Haiti	$1K Warm-up to the Sloan $50K business competition. Sustainable development category	Luca Morganti
2002	Pure water for nicaragua	Nicaragua	$5000 IDEAS Award	Rebecca Huang
2002	Innovative drinking water technology for bangladesh (Kanchan™ arsenic filter)	Nepal	$5000 International Technology Innovation Award sponsored by the Lemelson-MIT Program	Tommy Ngai, Sophie Walewijk, Roshan Shrestha, Susan Murcott

[a]Competitions Entered:
- IDEAS Global Challenge Competition (2002, 2003, 2004, 2005, 2006, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015)
- MIT $100K Competition (2006, 2009, 2013)
- Lemelson International Technology Award (2002, 2003)
- World Bank Development Marketplace Competition (2006)
- Commonwealth of Mass—$125K Ignite Clean Energy Business Competition (2006)
- International Resource for Sustainable Watershed Mgt Swiss Reinsurance Co. Ltd (2012)
- National Geographic Air and Water Quality Fund Award (2014)

Appendix 2

Descriptions of Selected Award-Winning Student Teams Advised by Susan Murcott. More info on specific IDEAS teams is available on the MIT IDEAS Global Challenge Website: http://globalchallenge.mit.edu/teams/past.

Kanchan™ Arsenic Filter ($5000 in 2002): The *Kanchan*™ Arsenic Filter (KAF) was designed to address arsenic contamination of drinking water at the household scale in rural Nepal. About 350,000 people (35,000 households) in the Terai region of Nepal, where there is high arsenic contamination of groundwater, are exposed to an arsenic concentration above 50 ppb, the national drinking water standard for Nepal. KAFs have been implemented for about two-thirds of that population—about 250,000 people which translates to about 25,000 households In addition to winning one of the original IDEAS awards in 2002, the KAF team has been recognized for a number of other awards including: World Bank Development Marketplace Competition (2003); Wall Street Journal Technology Innovation Award—Environment Category (2005); St. Andrews Prize for the Environment—2nd Prize (2006); Kyoto Water Prize—Top Ten Finalists (2006). A $50K award from Dubai Expo Live in 2014 is enabling the KAF team to reach 20,000 new users in 20 schools in the Bardiya and Kailali districts of the Mid- and Far-Western Terai region in 2015.

Vac-Cast Prosthetics ($7500 in 2007): There are over 25,000 new amputees annually in India as a result of accidents and disease. Despite the availability of free prosthetics and fitting services through several NGOs, only half of these victims receive a prosthetic device that is specifically tailored to their residual limb. One factor for a patient to opt for treatment is whether they can devote the time necessary for the prosthetic fitting and fabrication process in an urban clinic. Conversely, patient throughput by these organizations is limited by the finite resources that they can allocate per patient for the lengthy treatment. Fortunately, there is a novel sand-casting (SC) fitting technique that could increase patient throughput by a factor of five. However, SC cannot be deployed everywhere because it requires a vacuum device that is costly and electricity-intensive. VacCast Prosthetics has developed a simple alternative to this machine that overcomes these limitations. Our technology is unique, easy-to-use, human-powered, costs under $200, is built using materials commonly found in a mechanics shop, uses no electricity, and can be integrated seamlessly with the other sand-casting treatment devices. The Vac-Cast team has developed this device in collaboration with the Jaipur Foot Organization, the world leader in supplying prosthetic limbs and its affiliates to guarantee that our technology will meet the same needs as the electric vacuum machine. The follow-up to this invention and prize was that the team leader, Tess Veuthey, went on to win a Fulbright fellowship to bring this innovation to Cambodia, where there is a high number of amputees.

Hope In Flight ($7500 in 2013): According to a 2010 UN report, 80 % of thewaste generated in northern Ghanaian villages and towns consists of organic waste—most of which are not properly collected or disposed in a safe and healthy manner. One of these villages is Taha, our target community of about 600 people. Such accumulation of waste promotes infectious diseases and the contamination of precious water supplies. Hope in Flight utilizes a low-tech optimizing system that exploits the natural capabilities of the Black Soldier Fly (BSF), a species native to Ghana and other areas in Sub-Saharan Africa, to efficiently process organic waste. BSF larva turns every kilogram of organic waste into 29 US cents worth of protein meal! The collected BSF pre-pupae can be processed into profitable, safe, and nutritious animal feed. *Business Model* Using a technology transfer, Hope in Flight has brought the specialized waste bioconversion systems to entrepreneurs at the University of Development Studies in northern Ghana. The entrepreneurs use the systems to produce protein-rich BSF meal from organic waste, and earn a steady income by selling their farmed product for further processing. Hope in Flight sells the BSF meal as high-quality animal feed to egg, poultry, and fish farmers.

My H_2O ($1500 in 2014): My$H_2O$ is one of the first online crowd-sourcing platforms on water contamination and water quality issues in China <http://www.myh2o.org/>. Although the media in China has become increasingly open about China's environmental problems, the public is still only presented with limited information on water quality. Inspired by the air quality (PM 2.5) campaigns on social media that stirred public reaction and led to greatly increased transparency for air quality information, MyH_2O is one of the first online crowd-sourcing platforms on China's water quality. Created in partnership with China Youth Climate Action Network (CYCAN), MyH_2O aims to promote water risk awareness, increase information transparency and motivate citizen solutions through independent reports of water quality. In addition to their 2014 IDEAS Competition Community Choice award, this team also won a National Geographic Air and Water Quality Fund Award of $39,000 in 2014.

Clean Water Clean Data ($10,000 in 2014): Clean Water-Clean Data's product innovation is the "Smart Spout" that won a $10,000 IDEAS Competition award in 2014. The Smart Spout is a new spigot that can be placed on household water filters to record the frequency and duration of use. The data is read by a smart phone placed on the device. This product allows public health advocates to monitor how text message reminders reflect filter usage patterns. This innovation enables monitoring of consistent and continuous use and provides an objective measure of use, independent of reporting bias. The team intends to pilot their invention in 2015.

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What Do Programme Chairs Think About the Integration of SD in Their Programmes?

Iacovos Nicolaou and Eddie Conlon

Abstract

This paper presents the findings of interviews with six engineering programme chairs regarding their views about the level of integration of SD in their programmes. They are part of a wider study which is examining the integration of SD in engineering programmes across three Irish Higher Education Institutions. Previous stages of the study have determined that students' knowledge and understanding about SD is inadequate due to the lack of a holistic integration of SD competencies and the focus on skills development in their programmes. The paper will explore the apparent contradiction in that most programme chairs believe that SD is integrated into their programmes despite the evidence from the previous stages of this project which suggest it is not. This contradiction can only be resolved by an exploration of their understanding of SD and their philosophy of engineering education. We conclude that they believe SD is fully integrated because they have a narrow understanding of SD and a "traditional" approach to engineering focused on the development of core engineering competencies.

Keywords

Engineering education · Sustainable development · Integration · Programme chairs

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1 Introduction: EESD and the Role of Staff

Engineering Education is a complex system involving the collaboration of various stakeholders. Crawley et al. (2007) argue that students, universities, industry and society are the main stakeholders in Engineering Education for SD (EESD). Despite the aforementioned importance of universities in preparing students to become change agents there are increasing concerns that universities act more as barriers for EESD rather than as enablers (Peet et al. 2004; Donelly and Boyle 2006; Jones et al. 2010).

Some components of the current regime in universities can act as barriers. Curriculum design supports strictly disciplinary oriented programmes with little focus on SD competencies (Lehmann et al. 2008; Lozano 2010; Nicolaou and Conlon 2013) and staff are reluctant to acknowledge the importance of SD due to their misconceptions of the concept (Boyle 2004; Dawe et al. 2005; Lozano 2006). In one study characterising staffs' understanding of SD, the authors used metaphors as fundamental units of cognition for interpreting staffs' mental models of sustainability (Carew and Mitchell 2006). According to this analysis, staff has a variety of mental models for understanding sustainability. Some academics perceive sustainability as a continuous process focused on the needs of society. They have a broad view of the concept which is mediated by feedback from society. They are committed to holistic technology. This mental model is interpreted as seeing SD as a weaving concept. On the other hand some academics perceive SD as a guarding concept consisting of prescriptive technologies which focuses on the conservation of resources, waste management and the commodification of nature. They are committed to the notion of 'techno-optimism' and to traditional views that "objective experts equipped with technical knowledge are the appropriate people to initiate, control and monitor use of resources" (Carew and Mitchell 2006, p. 225). The latter metaphor leads academics to see SD as an added-on tool (Sterling 2001).

The misconception of the concept that some staff have leads them to have a narrow understanding of SD which is related to the environmental aspect of the concept (Summers et al. 2004; Reid and Petocz 2006; Cotton et al. 2007) and neglects the social dimension (Edvardsson Bjornberg and Skogh 2013). EESD "experts" argue that the social dimension is more relevant to SD than the environmental and the technological ones (Segalas et al. 2012). This in association with staff's neglect of the social dimension illustrates that action is needed to improve staff's awareness of the complexity of SD. According to Mulder et al. (2012) improving staff's awareness of the concept will help them acknowledge the importance of SD. Staff will then be able to see that the integration of SD in their programmes is imperative and integral to a lasting paradigm shift. If this fails then staff will see SD as a separate entity (Boks and Diehl 2006; Jones et al. 2010) and will continue to treat it as an added on tool.

It is acknowledged that staff's role is critical in EESD as the senders of the message of SD (Djordjevic and Cotton 2011). Thus if their knowledge and understanding of SD is limited then the message sent is distorted and creates significant knowledge gaps and limited understanding of SD among engineering students (Carew and Mitchell 2001; Azapagic et al. 2005; Nicolaou and Conlon 2012).

2 Scope and Rationale

The work reported here is part of a wider project that is designed to examine the level of provision of EESD in seven engineering programmes in three Irish Higher Education Institutions. The programmes' disciplines are civil, mechanical, structural, building services and chemical engineering. The project has already determined that final year engineering students' knowledge and understanding of SD is inadequate with significant knowledge gaps (Nicolaou and Conlon 2012). This is a result of an insufficient provision of SD competencies which is not based on a holistic approach to EESD (Nicolaou and Conlon 2013). The social dimension of SD was inadequately addressed. The programmes do not provide the broad and general education for SD that engineers need in order to become agents of change for SD (Ashford 2010).

Given the deficiencies in the provision for EESD that have emerged from our surveys of students (Nicolaou and Conlon 2012) and our analysis of programme content (Nicolaou and Conlon 2013) and the importance of staff to EESD, as indicated above, it was decided to explore staff's knowledge of SD and their views about its integration in engineering education. In the first instance we considered a staff survey but for reasons to do with concerns relating to possible low response rates and the limitations of survey data for exploring the underlying mechanisms shaping EESD it was decided to conduct a series of in depth interviews with programme chairs (directors) who are central figures in providing academic leadership on programmes and play a central role in programme validation and accreditation events. Thus we wanted to use qualitative methods to build on, and help us understand the quantitative data that had been collected in earlier stages.

In making this decision we were influenced by Critical Realism (Scott 2007) and its emphasis on the stratified nature of reality (consisting of the real, the actual and the empirical) and the need to look "below" empirical data to the realm of the real and identify the underlying casual mechanisms which can explain events. For Critical Realism the key ontological framing device is the relationship between human action and the social context: "the relationship between structure and agency or enablement and constraint" (Scott 2000, p. 3). Thus there is a need to consider individual and collective action and how they are shaped by social relations and institutional structures and culture. Critical realism also provides a social ontology which can be used to justify the combination of qualitative and quantitative methods in social research (McEvoy and Richards 2006; Scott 2007).

3 Methodology

The data reported here is entirely based on the collection and analysis of qualitative data through a series of interviews with programme chairs that were designed to explore the factors that impact programme design and programme chairs' views of SD. For the purposes of this paper we are focusing on their views about the integration of SD in their programmes and their personal understandings and beliefs about SD.

3.1 Interview Design

The interviews followed a structured design with a sequence of thematic areas and questions. Space and time was also left for probing and clarification of issues that the participants could raise during the discussion.

Our approach to designing the interview questions was driven by two considerations. We wanted to raise with the chairs a number of issues which had arisen from the previous stages of the project. In particular we wanted to explore the missing social dimension of SD including the ethics of SD, the focus on environmental and energy issues and the absence of any forms of interdisciplinary activity in the programmes. But we also wanted to explore these issues in light of key factors that arose in the literature which were deemed to have an effect on programme design. We wanted to encourage reflection on what the key factors shaping programme design were and how they might be constraining the implementation of EESD in the programmes under investigation. These factors included institutional policies on EESD; professional accreditation processes; commitment to EESD in programme design and staff knowledge and understanding of SD. Given the limitations of time in relation to the length of the interviews, we were concerned to address the process of programme design while at the same time seeking to understand the outcomes from earlier phases of the project. In essence it became essential to identify a number of key themes that could be addressed in an interview that would last for approximately 1 h.

In light of the above considerable time was spent mapping out the key issues that had arisen to concepts and factors that had been identified in the literature. We ended up with maps similar to conceptual maps in which we were trying to link the problems we had identified with possible causal factors. As a result of this work a number of key themes were identified for the interviews. These were:

- *Personal history of engagement with EESD.*
- *Institutional policy in relation to EESD.*
- *The role of professional accreditation in shaping programme design.*
- *Commitment to EESD in programme design and other factors which shaped programme design.*
- *Programme content and EESD.*
- *The integration of the social dimension and the ethics of SD.*

- *The role of multidisciplinarity in their programmes.*
- *In addition the chairs were asked to identify the key features of an engineer who wanted to contribute to SD and the key attributes that a modern engineer would need.*

In order to test the design and the effectiveness of the questions a pilot study was carried out that in general did not show any significant design flaws in the questions. Small adjustments in relation to question wording and placement were made.

3.2 Data Collection and Analysis

One hour interviews were scheduled with the selected programme chairs. The interviews were audio recorded for the purposes of transcription and analysis. One programme chair did not participate despite the several attempts to get in contact and schedule an interview.

The data analysis was carried out according to Braun's and Clarke (2006) six steps framework of thematic analysis of latent themes. Initially the audio recordings were transcribed which assisted with familiarisation with the data corpus. The interview transcripts were then imported into QSR's NVivo 10 where a participant-driven coding was carried out. Then the nodes generated were merged into wider categories under parent nodes which underwent further coding to support the categorisation. The underlying themes of the categories generated were reviewed; further coding was carried out to support the identification of the themes. The themes were then reviewed and further coding was conducted to further support the latent themes. Finally a report was produced that provided a detailed account of the themes supported with inferences drawn from the raw data. Thematic analysis is an iterative process of continuous coding until a satisfactory level of the review of themes is reached.

The sections below present the findings about the programme chairs' views of SD and their views about the level of integration of SD in their programmes. Full anonymity of the participants was assured; hence quotes extracted from the interviews will be referenced as Participant 1, 2 etc.

4 Findings

All programme chairs have an engineering focused education both at an undergraduate and postgraduate level. The majority of them have industrial experience prior to their academic career which has helped them to establish good links with industry that most of them still maintain.

According to them SD was not part of their education or professional development:

> No, it wouldn't have been in the context of actual lecturers on sustainability no, but I did qualify a long time ago and it wouldn't be as much as an issue back then. (Participant 5)

The following sections present data in relation to their understanding of SD and their views about its integration in their programmes.

4.1 Programme Chairs' Opinions Regarding the Integration of SD in Their Programmes

Prior to this study, a curriculum content investigation on the respective programmes was carried out to assess the level of integration of SD competencies. That study determined that the integration does not follow a holistic approach but isolated module attempts where the focus is on transferable skills and disciplinary elements related to the environmental dimension of the concept (Nicolaou and Conlon 2013). Although there are differences in the range of modules provided, the breadth of competencies covered remains the same among all programmes regardless of the discipline. In contrast to this finding the interviews reveal some variance between the programme chairs views about the integration of SD in their programmes.

There is a general agreement that engineering programmes follow a design that is influenced by a strict disciplinary focus on core engineering competencies and does not show an active commitment to SD.

> Had the team as a whole had a series of conclaves where we decided that module would have this content based specifically on sustainability, no we didn't. (Participant 1)
>
> The top down approach from the science foundation, the mathematics, the technology and the design theory and I suppose the design practice but then everything else is added on to the core competencies. (Participant 3)
>
> We focus on engineering applied subjects, systems design and transferable skills (Participant 4)

According to the participants, the programmes are designed with a disciplinary focus due to the fact that vital accreditation processes by Engineers Ireland focus on assessing the provision of core engineering competencies (even when efforts are being made to expand SD content).

> The last accreditation included a proposed introduction of a new stream to the mechanical engineering programme and it was a stream that was titled Sustainable Energy Systems. Of course that was talked about a little bit but the emphasis wasn't on sustainability, the emphasis was more meeting the requirements of the mechanical degree that we were saying to be the final award. So EI seemed to look at the criteria irrespective of the SD title of the stream and just focus whether or not the graduates coming from that stream would equally be applicable to a mechanical engineering award. (Participant 3)

Despite the general agreement of the lack of consideration of SD in programme design, programme chairs have different views about the way SD is integrated in their programmes. One participant argues that SD is embedded in his programme

> The fact is that we include in everything we do, its build in there, again it's how you define SD (Participant 5)

Another, whose programme was designed with an active learning rationale, has showed evidence of how SD is actually embedded but the example focuses on a single module with an environmental focus.

> For example in soil mechanics the problem that students work on in second year is creating a detention pond so that the university can have a sustainable supply of non-potable water. So they learn how to design dams to retain water, they have to determine what are the needs of the university so they decide the size of the pond needed and of course the overwriting theme is a sustainable supply of grey water. So it is there; it might not be in the center of discussion but is embedded and I think that is the answer to it (Participant 1)

Participant 2 argues that SD is "*nicely addressed*" across the programme.

> I think that it is important that we brought the subject in first year, third year and then in the design project because it then gives that sort of umbrella system instead of saying "we have 50 modules and there is a 51st which is about sustainability. (Participant 2)

This notion of having separate modules for SD is also supported by Participant 6.

When the participants were asked to discuss any particular focus on content for SD, the majority of them identified sustainability elements that are directly related with the discipline of each programme.

> The programme was driven around the subject areas and we had three themes energy as it applies to the civil engineer, environment and structure and infrastructure (Participant 1)
>
> Energy I suppose. Energy and water would be the main two for us. (Participant 4)

It is worth noting that none of the participants mentioned, without prompting, the level to which the social dimension is addressed by their programmes. When they were asked, the participants' responses suggest that the social dimension is not well integrated in their programmes.

> There is a little bit about engineers and society, what is their role but just the basic understanding. (Participant 2)
>
> The closest to it I don't think it is delivered. I don't think that the students have an explicit exposure to the social dimension of SD. (Participant 3)

Interestingly, when they were asked, the majority of the participants did not identify any specific weaknesses in relation to how SD is addressed in programme design and integrated in content.

> To be honest no, I think there is a nice balance. (Participant 6)

Nonetheless one programme chair was critical about the extent to which areas of SD are addressed in his programme. He claims that SD solutions are always seen as technical solutions:

> Touchdown, it's very much a case of why will we do this? Because of CO_2 emissions we need to reduce that we have limited resources and then there is your justification and then its straight into the technology. (Participant 3)

What is interesting about this response is that it comes from the chair with perhaps the most advanced understanding of SD. The evaluations of the other Chairs are also related to their views of SD which will be explored in the next section.

4.2 Programme Chairs' Views of SD

Programme chairs views about the integration of SD vary and differ as does their understanding of SD. Interestingly some of the programme chairs acknowledge that SD is a wide concept that incorporates various different aspects which however is difficult to define.

> So it's a difficult equation and I wouldn't put sustainability so much in terms of CO_2 and GHG production, I think it's a much wider issue than that (Participant 2)

So while they may believe there is more to it than environmental and resource issues they were not always able to identify what the additional elements were. Participant 3, who had the broadest understanding of what SD is, argued that:

> One of the biggest difficulties that I see is perceptions of what SD is. (Participant 3)

This is well illustrated in the majority of the programme chairs responses which describe SD as a concept that relates economic development with environmental considerations that are mainly focused on energy, materials and resource issues.

> By saving money you are saving materials which is linked to sustainability (Participant 1)
>
> I suppose its development that makes reasonable demands on the resources that we have so that the resources are not depleted, particularly finite resources (Participant 7)

There is also evidence indicating that some programme chairs also see SD as an ongoing process as expressed in the Brundtland Report.

> People describe sustainability as this generation not leaving a bill to the next one (Participant 4)
>
> Just trying to make sure that we use the resources of the planet and that we don't overuse them and that they will still be there for the generations to come. (Participant 6)

While this is an acknowledgment of the role of intergenerational equity the focus is on resource use. There was no evidence that the Chairs saw intra-generational equity as a key feature of SD.

One programme chair's definition deviates from the rest as he saw SD as a three pillar concept.

> I would see SD as being where change and creation occur due to human endeavour that can continue indefinitely without complete depletion of any resources that are non-renewable under three pillars of environment, society and culture and economics or commerce. (Participant 3)

Although Participant 3 had an engineering education like the rest of the participants, his personal interest about SD and his involvement in the design of a postgraduate programme predominately focused on SD has given him the opportunity to improve his awareness of it.

> Since I have been working in the educational sphere I have been heavily involved in a master's programme, a collaborative programme with two other institutes that's focused predominately in SD, it's actually a masters in sustainability technology and innovation. So I have been bit more of an awareness based on that compared to my previous background. (Participant 3)

Programme chairs were also asked their opinion about the characteristics that engineers should have in order to contribute to SD. Their views show a variance which is influenced by their own understanding of the concept.

All the participants argue that engineers for SD should have an awareness of the concept without though being specific.

> First and foremost awareness (Participant 3)
>
> They have to know about it in the first instance (Participant 6)

Although ethics and values were identified as an important characteristic, those where limited to engineers' professional conduct in relation to materials, safety and the environment while the social context of their practice was identified to a lesser extent.

> I think they would need to have a strong ethical set of moral values of what they create has an impact on everyone's lives. I think those include a global perspective on things, they consider the materials they use, are they aware exact how much energy is required to manufacture a cubic meter of concrete or a universal beam section (Participant 1)
>
> There is a much more organised and systematic way now approaching problems like the hazards to the environment and safety. (Participant 2)
>
> They will deal with things in a professional manner (Participant 4)

The discussion of ethical issues had a focus on micro ethical issues focused on design issues related with material use and safety while an awareness or knowledge of macro issues, such as social equity, were not mentioned as important attributes for engineers.

Most of the participants' views of the characteristics of engineers for SD are related with the necessity for engineers to be able to apply specific tools and have skills such as systemic thinking.

> They would need to be rigorous thinkers (Participant 1)
>
> The concept of LCA is important (Participant 2)
>
> For us the issue is energy, not much energy as carbon production more strictly speaking is low carbon design rather than low energy design. (Participant 4)

The majority of them argue that engineers are problem solvers without any reference to the role of engineers as problem framers (Donelly and Boyle 2006).

It is worth noting that the majority of the programme chairs argue strongly that the role of their programmes is to educate employable graduates that will have the competencies needed to work in industrial environments which include some elements related to SD.

> It is an issue for SD but for us is also an issue of job opportunities for graduates and so this is an area that we need to integrate more content. (Participant 2)

The programme chairs views about the characteristics of modern engineers are limited to the applied tools and skills that are directly related with their employability. The programme chairs neglect the importance of engineers understanding the social context of their practice and the complexity of the socio-economic systems in which engineering is applied (Gobling-Reisemann and Von Gleich 2007).

5 Discussion

The findings suggest that there are two latent themes informing responses across a number of topics explored in the interviews. The first one is programme chairs views of SD and the second their views of engineering education. It is evident that the former is impacting the latter. The participants have particular views about SD that leads them to believe that SD is mainly an environmental concept (Cotton et al. 2007). This misconception is influencing their evaluation of the extent to which SD is integrated into their programmes; their lack of engagement with the social dimension; and their identification of attributes that engineers who want to contribute to SD should have.

Their descriptions of the concept suggest that the majority of them see SD as a guarding concept which is focused on energy issues and environmental protection and supports a disciplinary emphasis. Only one participant was able to describe SD as a weaving concept that encourages awareness and puts the needs of society at the center of engineering (Carew and Mitchell 2006). In relation to the latter it is clear that personal interest and professional development opportunities related to SD are a vital component in improving staff's awareness about the concept since none of them have any formal education for SD and most of them were industry practitioners before their academic career.

Although the majority of them claim that SD is embedded, the data suggest that they see the concept as a separate entity and thus treat it as a complementary consideration in their teaching (Reid and Petocz 2006; Jones et al. 2010). This leads to a variance between the programme chairs claims and the findings of the curriculum content investigation (Nicolaou and Conlon 2013) which preceded this study. It is clear that SD is not a priority despite the explicit call for integrating SD at every level of education by the Irish National Strategy for SD (DOE 2007).

The focus on core engineering competencies is prevalent in the programmes. This is reinforced by EI's accreditation criteria which support the design of discipline specific programmes that focus on engineering competencies and transferable skills. All respondents identified EI as the most significant influence on the design of their programmes. Having the accreditation body supporting the design of engineering programmes that do not holistically consider SD suggest that the current regime of engineering education is unlikely to quickly undergo radical change (Winberg 2008). Kember (1997) argue that staffs' allegiance is primarily with their disciplinary communities and its traditional practices.

This study shows that these practices support professional standards and employability which, according to Jamison (2013), are key components of a market driven model of engineering education which supports a weak approach to sustainability (Lucena et al. 2010). On the contrary EESD requires a multidisciplinary holistic integration of SD competencies (Svanstrom et al. 2008). This may need to be underwritten by a socially driven model of education that would value public service, form engineers as change agents and encourage "in context" forms of learning giving attention to the social and cultural context of engineering (Jamison 2013).

Thus we can conclude that a key causal mechanism explaining the current regime of EESD in the programmes under study is the commitment to a particular ideology of engineering education which excludes its social dimension and situates SD at the nexus between the environmental and economic dimension of the concept.

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Injecting Sustainability into Engineering Design Projects

Libby Osgood, Wayne Peters and Stephen Champion

Abstract

Ideal engineering graduates are able to think critically, produce solutions that satisfy multiple stakeholders, protect the interest of the public, and assess their ethical, social, economic, and environmental obligations, based upon their knowledge of engineering principles. Project-based learning is an appropriate forum for students to develop these skills while focused on authentic design problems. In structuring an effective learning environment, intentional effort must be made by educators in all program areas—ranging from the choice of client to the information requested in the final report—to highlight students' greater responsibility within society. The decisions that an educator makes to the framework, deliverables, and exercises for a design project impact the degree to which students will engage in higher level decision making. This paper will discuss the strategies that have been employed in the first and second year projects that encourage students to use higher-level thinking and will introduce how sustainability will be an integral focus of the new Sustainable Design Engineering degree.

Keywords

Engineering design · Design project · Sustainable · Professional skills

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1 Introduction

The fundamental objective for engineering educators is the transfer of knowledge of engineering principles. Built upon this traditional foundation, ideal graduates are able to think critically, produce solutions that satisfy multiple stakeholders, protect the interest of the public, and assess their ethical, social, economic, and environmental obligations. Accreditation boards have also charged educators to ensure that students consider the sustainability of their solutions (ABET 2015) and understand sustainable development and environmental stewardship (CEAB 2014).

The challenge, then, for engineering educators is to develop learning methodologies that produce engineers who can recognize the many complexities inherent in a design problem, with a specific focus on the sustainability of the design. Project-based learning is an ideal vessel for students to develop critical thinking skills while focusing on authentic design problems. However, these skills don't develop automatically simply because students are designing for a real client or learning within a certain pedagogical framework. In structuring an effective learning environment, intentional effort must be made by educators in all project areas to highlight students' greater responsibility within society. The decisions that an educator makes to the framework, deliverables, and exercises for a design project impact the degree to which students will engage in higher level decision making. The design projects can incorporate sustainability through the framing of the problem, constraints, evaluation of ideas, and impact analyses. Activities can also be performed within the design course but outside of the project to deliver sustainability concepts for projects where the link to sustainability is not immediately obvious.

First and second year students at the University of Prince Edward Island have engaged in design projects with a focus on sustainability for more than 10 years through the 2-year diploma program. As the third year of the new Sustainable Design Engineering degree begins in Fall 2015, sustainability considerations will be woven into the curriculum. Students in the multidisciplinary four-year degree will learn engineering in a project-based professional practice environment, employing and enhancing their design skills each semester. This paper will discuss the program, project, and course activities that ensure sustainability concepts are prevalent throughout the degree, as well as a commentary on the efficacy of these techniques.

2 Continuum of Education

Engineering education is an ongoing, lifetime activity marked by an accumulation of both knowledge and work experience. In the early stages of this progression, knowledge and work experience are acquired through two distinct but sequential processes (Engineers Canada 2013). First, study in an accredited undergraduate

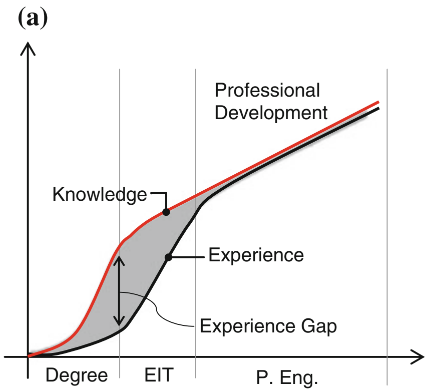

Fig. 1 The acquisition of knowledge and experience in engineering education in **a** a more traditional model and **b** a more integrated model

engineering degree program delivers the knowledge while, second, a subsequent four-year period as an Engineer-in-Training (EIT) provides the work experience. Finally, qualification as a Professional Engineer (P.Eng.) leads to a professional practice career enhanced by continual personal professional development.

In this long-standing model, knowledge increases quickly during studies while work experience tends to lag behind this, only ramping up once employment as an EIT is secured, as illustrated in Fig. 1a. The early "experience gap" which results from this model has two detrimental effects. First, it compromises employment success for new graduates entering the workforce as employers generally look for employees with work experience. Second, and perhaps more importantly, it represents a missed opportunity during early studies to reinforce the knowledge learned with practical engineering experience. It has been shown that co-op programs diminish the first of these effects (Noyes and Gordon 2011). However, limited research exists to demonstrate the academic benefits of the somewhat separated experience provided by co-op programs.

More comprehensive than coop, a continuum of education which integrates knowledge and experience in a more cohesive way, as illustrated in Fig. 1b, can be achieved through the use of real-world design projects throughout the engineering curriculum (Chandrasekaran et al. 2012). In this way, knowledge and experience are interconnected at all stages of study which eliminates the "experience gap" typical of a more traditional engineering education model. This allows students to learn professional skills and to weigh complex environmental and ethical issues in an authentic professional practice context. Additionally, it challenges professors to connect all classroom content to real-world professional settings and encourages students to retain what they learn in class so that university is seen as professional training from the first day the students enter their studies.

3 Integration at the Program Level

3.1 Sustainability Within the Degree

In this multidisciplinary degree, students graduate with the ability to design projects with consideration for sustainability at all steps in the design process. Rather than teaching sustainability with an ‘end of pipe’ mindset (Porter and Linde 1995), students are presented with different definitions of sustainability (WCED 1987; Engineers Canada 2006; Robèrt 1997; Hawken 1993). They utilize different models for considering sustainability, such as: life-cycle analysis (Young and Vanderburg 1994), clean technologies strategies (Beder 2000) the Natural Step (Robèrt 1997), and the Hannover principles (McDonough 1992), developing holistic solutions through the design projects.

Design textbooks for engineering students now highlight sustainability (Dym et al. 2014) whereas before they commented primarily on the environment (Dym et al. 2009). The textbooks purport that creative solutions will be discovered if students are open to working in multidisciplinary settings (Stephan et al. 2015; Kibert et al. 2012). This degree is tailored to allow students to self-discover multidisciplinary concepts to solve real problems.

3.2 Professional Skill Development Coordinated Across the Program

With a continuum of education mindset, students take a design course every semester during their degree, to put their increasing engineering knowledge to practice and learn professional skills. Rather than having an individual course on ethics, sustainability, social justice, or professional practice, modules are peppered throughout the design courses to regularly address this content. These modules, called professional skill developments (PSDs), are 1 h long, rely primarily on active learning with a short 15-min lecture, and conclude with an assessment activity. PSDs utilize handouts and PowerPoint slides to reinforce points in lieu of textbooks, and are structured throughout the curriculum as shown in Fig. 2, with additional detail for sustainability. Specific examples of Sustainability PSDs and their efficacy are discussed in Sect. 4.

The benefit of using PSDs as opposed to an entire course in that particular subject is that PSDs enforce the importance and connectedness of these often segregated concepts. In small doses, students are more receptive to accept the more abstract nature of these topics, as opposed to an entire course. Additionally, the repetition and review from previous sessions over time provides a better likelihood that students will retain the information and incorporate it in daily use. Additionally, these PSDs can be delivered regardless of the degree of sustainability of the particular project.

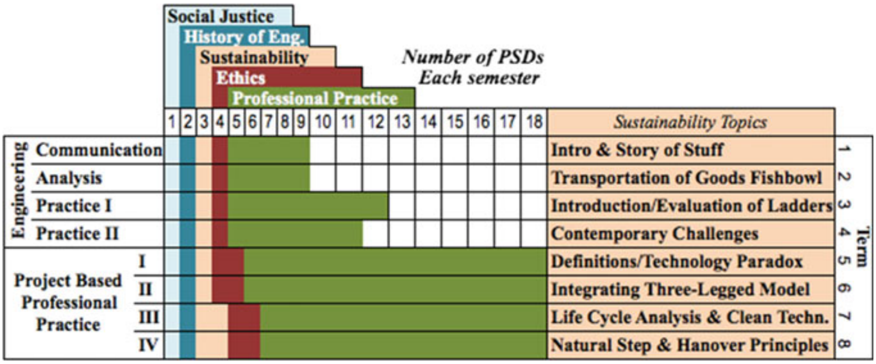

Fig. 2 Professional skill development modules across the curriculum

4 Injection Within Projects

The most obvious injection of sustainability is within design projects, where problems can be selected that require sustainable solutions and the supporting documentation provides the flexibility to add sustainability sections and evaluations. However, regardless of the client or project, sustainability should be included as a constraint and an assessment to reinforce this as a regular part of an engineer's job. The amount of integration of sustainability within a project can be categorized into three levels:

- None, where sustainability is not mentioned or assessed
- Assignments, where project documentation includes sustainability in the evaluation of ideas, impact analyses, and recommendations
- Problem driven, where the client constrains the problem to focus on sustainability and thus it is addressed in all steps in the design process.

Figure 3 shows how sustainability is injected into the projects over the degree, specifying level of integration and duration of projects.

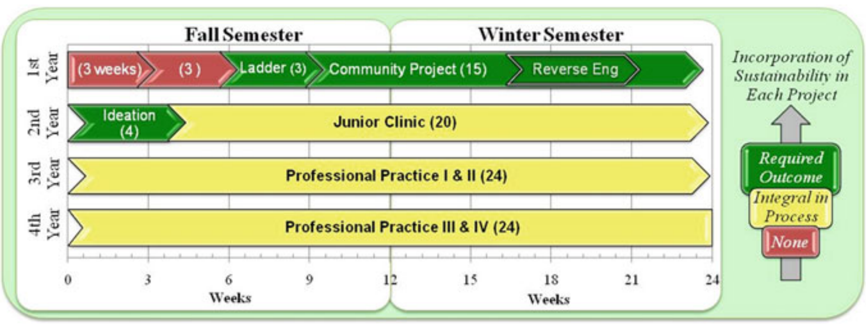

Fig. 3 Project duration and how sustainability is incorporated in each project

The first two projects shown in Fig. 3 do not incorporate sustainability. While these should be minimized, there is a necessity, especially in the first design course, to avoid overwhelming the student with too many objectives in the project. These two projects are focused on ideation and learning how to write technical reports, and do not proceed past the ideation/report phase. The third project introduces sustainability as a major focus, asking the students to redesign and build a ladder that is multipurpose and sustainable. This gives students the opportunity to explore the definition of sustainability and employ the minimization, reuse, and repurposing of materials. To reinforce the importance of reuse and repurposing, there is no budget provided. This very tight constraint forces the students to reimagine a ladder and explore the definition of sustainability. Either they plan to build only one, focusing on repurposed materials, or they find more organic materials in order for the design to be mass-produced. Students also produce requirements from the client's vague description of sustainability. This is an extremely enriching conversation as the students begin to see that they may not initially recognize what 'sustainability' implies. It also helps clarify the intent and specificity of requirements.

The final project of the fall semester continues through the entire winter semester and gives students their first interaction with an external client. For the community project, a client from a local or global organization proposes a general problem for all of the students to solve. For example, in 2013–2014, students worked with a new, large community garden organization to design irrigation, transportation, fertilization and cooking devices as well as educational demonstrations. The broad problem statement provides students an opportunity to identify specific problems, a step that is often performed by the professor due to time constraints. In this first step of problem identification and development, students can explore the sustainability of the current state of the problem using techniques learned in the ladder project to determine whether a change is even needed, before proceeding to research or ideation. Within this project, a 3-week reverse engineering exercise asks students to understand and evaluate an existing solution before finalizing one of their own. This allows the introduction of a number of sustainable concepts including life-cycle analysis and reliability. Students respond very well to this part of the community project, as many have never considered what fixtures are used on objects or what happens after an item is thrown out. The students eventually build, test, and present their devices at a public exposition.

The second year begins with a short duration project that requires a lot of creativity for a very focused problem. Past projects have included Rube Goldberg contraptions where students took 30 steps to water a plant, devices to walk on water, and gliders for a scaled-down Flugtag. The students are given a budget of $20, which constrains material selection to favour repurposing. In this project, students perform a specific evaluation of the sustainability of their ideas from a life-cycle perspective and well as determine the energy requirements to produce the materials. Students eagerly show their creativity in ideation and often produce amusing, albeit sometimes far-fetched descriptions of the sustainability of their device. While the project requirements vary each year, the intent is for students to develop critical thinking skills, experience the design process, and practice project documentation. The documentation is assessed for completeness and professionalism.

The junior clinic project pairs each group of four students with an individual client. Some of the clients demand highly sustainable solutions, but most projects are industry based where sustainability is not the focus. Over the two semesters, students methodically follow the design process to eventually build, test, and present their devices at the public exposition. The 'assignments' approach used here is the most comparable to industry, so it's especially important for students to learn how to incorporate sustainability into a design project. However, it is more effective to inject sustainability through frequent discussions at many points in the design process, questioning students' ideas and focusing questions on sustainability, rather than requiring specific assignments. Suggested discussion points are shown in Fig. 4.

Often through these discussions, students don't realize they are performing sustainability assessments, which can have a negative 'green' connotation for some students. The efficacy of this frequent questioning ingrains the necessity to constantly improve their ideas. Students vocalize that it is more difficult to produce sustainable designs rather than their constraint-free solution, however being forced to consider sustainability often produces a better product as students have put more thought into each step.

The professional practice projects in the third and fourth years, enable students to work more closely with industry, with the possibility of a two-year project. There are twice as many sustainable professional skill development modules in the final two years and the focus shifts from ideologies to analyses, as was shown in Fig. 2.

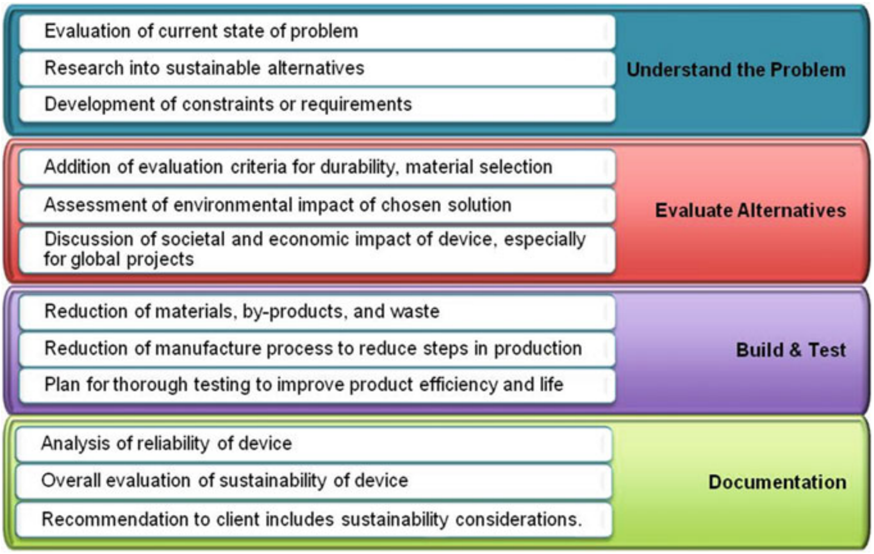

Fig. 4 Assignments to inject design into design projects

The same techniques are used from the junior clinic, with the addition of specific analyses for reliability, life-cycle, and material reduction.

A balanced plan at the program level is necessary to incorporate multiple levels of sustainability in the different projects, as students tire of too many 'green' projects and it's necessary for them to see how sustainability exists in industry. Additionally, there are some projects that do not include sustainability in any way, due to time constraints, knowledge level of students, and narrow objectives of the project.

5 Instruction Within Courses

The professional skill development (PSD) modules allow for short bursts of activity and instruction, keeping the topics engaging, for classes of 50 students. A cross-section of formats are selected to highlight the variability in learning and assessment techniques. As listed in Fig. 2, the first introduction to sustainability is using the controversial Story of Stuff (2013) video. Students are asked to watch the video and a critique of the video. When the students come to class, they work first in small groups then as a class to discuss the content of the video and if there were any aspects of it that they found surprising. Next the counter argument is discussed. Students provide a summary and two points of critical thinking for assessment, as this course is focused on communication. This PSD is delivered during the ladder project, so the students have begun to think about sustainability topics, and the objective is to make them think critically about what they read and hear, not just blindly accept information as facts. Students enjoy the video and it helps solidify sustainability as a concrete contemporary topic for them to discuss, as opposed to the current project for one specific client.

In the winter semester, students engage in a fishbowl debate about the most sustainable form of transportation of goods. Initially small groups are formed to discuss the benefits and drawbacks of the three proposed ways to transport items: trains, planes, or trucks. Then students are randomly assigned to a larger group representing:

- Truck industry
- Airline industry
- Train industry
- Environmental activists
- Government agencies
- Consumers.

Each larger group formulates arguments supporting their position, against other groups' positions, and anticipates counter-points against their position. A fishbowl is then held where one person from each group sits in a circle and debates to determine which mode of transportation is the most sustainable for transporting goods. In a fishbowl, students can 'tap in' to replace the person who represents them so eventually many students become involved in the debate. This is a very interactive PSD that helps develop students' critical thinking, especially when anticipating counter-points. Students are assessed on a reflection submitted after class based on their understanding of the topic, arguments presented, and rebuttal of counter-points. The formats of the PSDs change each time, to avoid monotony. This particular format allows for many students to be involved and have a large class discussion (without a lecture), and integrates some of the quieter students in the small groups before the fishbowl begins. The resolution is always different, generally dependent on the persuasive ability of the representative, but the students leave having considered six different viewpoints and are now aware that goods do not appear on shelves without effort.

In the second year, the sustainability, social justice, and elevator pitch PSDs are combined into one module. The flexibility of the PSDs allows conceptual topics (sustainability or social justice) to be combined with skills (elevator pitch). The goals of this PSD are to:

- Learn an official definition for sustainability (WCED 1987)
- Learn an official definition for social justice
- Develop critical thinking skills by comparing the two concepts through small group discussion
- Evaluate the sustainability of the first year students' ladder projects
- Practice delivering elevator pitches representing one of the ladders.

There are many parts to this PSD, but each is short. Students first debate the difference between social justice and sustainability, both seen as globally important issues but two different concepts. Students then evaluate designs of other students, on a project that they completed the previous year, so there is familiarity and novelty. Finally, students have the opportunity to practice delivering elevator pitches (sixty second presentations of ideas) by persuading a partner that their newly adopted ladder is the most sustainable. This requires students to consider the sustainability, develop persuasive arguments, tailor the arguments to the most important, and practice speaking. Students are assessed on their engagement during the elevator pitches, as all of the students are actively involved and excited (in order to better persuade). There are no spectators though some students are more reserved in their delivery. It is a lot to fit into a short period, but compares two important topics and again changes the format of delivery.

As students mature in their abilities, the PSDs increase in complexity, from primarily focusing on critical thinking and awareness, to gaining knowledge, to using knowledge to perform analyses. Assessment techniques vary based on the PSD, from written reflections to oral reports, and measure only the skill for that PSD. While the previously stated advantages to the PSDs are numerous, there are two challenges that must be addressed:

1. A cross-curriculum platform is required to best deliver a comprehensive, modular selection of PSDs, though individual PSDs can be used in any course.
2. While students are assessed in each PSD, there is no exam for students to 'cram'. This active learning approach follows the continuum of education in

which tests should not be required, but traditionalists are uncomfortable without a formal final assessment.

The first challenge is overcome by careful program-level planning, and the second challenge is outweighed by the benefit of regular acquisition of knowledge and immediate practice in design projects.

6 Conclusion

In place of a course in sustainability, a program, project, and course level integration has been successfully adopted to incorporate professional skills required of an engineer, such as ethics, professional practice, social justice, and sustainability. At the program level, students come into a professional environment in a continuum of education through multi-disciplinary design projects. Projects vary by duration and topic and have different clients based on the specific project objectives. At the project level, sustainability can be incorporated as defined in the problem or through assignments and regular discussion. At the course level, professional skill developments (PSDs) provide repetitive, gradual preparation for professional practice. Feedback from former students is positive, though gathered anecdotally. Students contend that the content from design courses and PSDs were immediately recognizable in industry, and they felt better prepared for their jobs. In order to produce the well-rounded engineers that industry demands, education methods must develop to meet the challenge.

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Embedding Sustainability Principles into Engineering Education

Danielle Salvatore, Naoko Ellis, Susan Nesbit and Peter Ostafichuk

Abstract

Because sustainability learning is necessarily situated in local culture and "place," engaging key communities-of-interest in planning and deployment is foundational to sustainability effort. Recently, the University Sustainability Initiative (USI), at the University of British Columbia (UBC), employed engagement techniques that reached out across the university campus to develop generic descriptions of sustainability attributes of graduating students, which propose that UBC students within all disciplines strive to develop four attributes in preparation for facing today's challenges (i.e., holism, sustainability knowledge, awareness & integration, and acting for positive change) (USI 2015a). The USI recognizes, "that in order to find creative solutions to the ecological, economic and social challenges of our time, we must explore, advance and apply our understanding of sustainability" (USI 2015b). This paper reports on a second set of engagement processes focused on developing the first stage of Engineering Education for Sustainable Development (EESD) degree-level learning outcomes that, in turn, aim to guide course redevelopment within the engineering programs. We start by presenting examples of sustainability learning opportunities offered in undergraduate programs elsewhere in North America. Most of these opportunities involve adding several

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courses to an already course-heavy degree. At several schools there is an option to complete a "certificate program" encompassing a few extra courses, but these certificate programs are not necessarily directed at engineering students. We then describe UBC Applied Science Faculty engagement activities, aimed at measuring the interest of administrators, faculty members, staff, and students regarding incorporating sustainability learning opportunities within the common first year curriculum. We next relate informal first year student survey responses to the literature and we outline recommendations for advancing the development of sustainability learning within the first year curriculum.

Keywords
Education · Sustainable development · Curriculum · Engineering

1 Introduction

1.1 Sustainability Learning Support at the University of British Columbia

UBC's University Sustainability Initiative (USI), established in 2010, strives to support student development of the UBC Sustainability Attributes and, where possible, integrate sustainability teaching and learning, research, and operations. The USI Teaching, Learning, and Research Office coordinates a number of different programs to support sustainability, including the:

- maintenance of an inventory with over 500 courses where students learn about aspects of sustainability;
- SEEDS (Social, Ecological, Economic Development Studies) Program that provides students with on-campus, for-credit, learning experiences during which students work with university staff on projects in support of transforming UBC's campus into a sustainability hub (USI 2015c);
- Greenest City Scholars Program where graduate students work for 250 h with the City of Vancouver on a project aimed at helping the city achieve its Greenest City 2020 Action Plan (USI 2015d);
- Spotlight Program where selected instructors are awarded funds to improve the teaching and learning of sustainability within their course (USI 2015e); and
- Sustainability Teaching Fellows program where selected faculty members work together on sustainability teaching projects that vary from year to year (USI 2015f).

An outcome of the teaching fellows program is the UBC sustainability attributes (USI 2015a) which propose that students graduate with four sustainability attributes, namely "holism," "sustainability knowledge," "awareness & integration," and "acting for positive change" related to sustainability background.

The 2014–2015 cohort of Sustainability Teaching Fellows are charged with creating sustainability learning pathways in their respective faculties. A sustainability learning pathway is a collection of sustainability-oriented courses that students pursue alongside their disciplinary focus. The Fellows meet periodically to share strategies, compare progress, and provide feedback.

1.2 Sustainability Learning Pathway Initiative in the Faculty of Applied Science

The Faculty of Applied Science (APSC) at UBC includes the School of Architecture and Landscape Architecture (SALA), the School of Community and Regional Planning (SCARP), the School of Nursing, six departments of engineering located at the Vancouver campus, and the School of Engineering located at the Kelowna, B.C. campus. As members of the 2014–2015 USI Teaching Fellows cohort, two of the authors of this paper are supported by the USI for two years to initiate and develop sustainability learning pathways within the faculty.

The objectives of the APSC Sustainability Pathway Engagement Initiative are to:

- assess the interest of, and support by, students and faculty members for sustainability learning pathways in APSC;
- develop sustainability pathway learning outcomes;
- build strategies for implementing undergraduate (UG) curriculum changes; and
- build strategies for creating pathways at the graduate (G) levels.

This paper focuses on the assessment of interest and support for sustainability learning within the APSC community at UBC, particularly within the engineering communities related to the undergraduate curriculum. It then presents and analyzes informal survey and roundtable discussion data indicating gaps and misconceptions of engineering-for-sustainability knowledge, skills, and attitudes.

2 Precedent Programs and Literature Reviews

This section includes a review of the engineering for sustainability programs available in North America and a literature review of program-level learning outcomes relevant to engineering for sustainability.

2.1 Engineering for Sustainability Programs in North America

Engineering undergraduate programs from eleven prominent North American engineering schools were examined with respect to their sustainability curricula. A summary of the schools is presented in Table 1. From the programs that were sampled, there were few formal sustainability pathways in engineering education, and half of the schools did not offer any type of pathway in sustainability. Those offering pathways, did so as add-ons, with additional courses required to achieve the pathway. At two schools there is an option to complete a “certificate program”

Table 1 Summary of sustainability pathways in engineering programs across North America[b]

	School of engineering	Pathway	Additional courses?	Certificate offered
Canada	University of Toronto	Minor	Yes	Renewable resources
	Dalhousie University	–	–	Sustainability leadership[a]
	McGill University	Minor	Yes	
	Queen's University	–	–	
	University of Calgary	Specialization	Yes	
	University of Manitoba	Specialization	–	
	McMaster University	–	–	
United States	Massachusetts Institute of Technology	–	–	
	Stanford University	Specialization	–	
	University of California at Berkeley	–	–	
	Georgia Institute of Technology	Minor	Yes	

[a]Offered to all students, not just engineering students
[b]Survey was conducted in September 2014

encompassing a small number of extra courses, but these certificate programs were not necessarily directed at engineering students.

The University of Toronto "Sustainability Energy" minor, offered to all undergraduate engineering students, illustrates one possible pathway. Students are required to take six 1-semester courses, in addition to the standard engineering program requirements. The University of Toronto also offers an undergraduate engineering certificate program in Renewable Resources. The requirements for the certificate program include a minimum of 3 1-semester courses from a select list. Both the minor and the certificate appear on student transcripts upon completion.

This review indicates that very few engineering schools offer pathways in sustainability, possibly owing to the heavy course load for meeting the Canadian Engineering Accreditation Board (CEAB) or American Board for Engineering and Technology (ABET) criteria (Engineers Canada 2008).

2.2 Literature Review of Sustainable Education in Undergraduate Engineering

The literature relevant to incorporating sustainability education in engineering can be divided into three main research questions:

- What is the level of knowledge and understanding of undergraduate engineering students in sustainability?

- Where are the gaps in sustainability education at an undergraduate level?
- What is the best method of implementing sustainability education into undergraduate engineering curricula?

Researchers in Australia (Carew and Mitchell 2002), Europe (Azapagic et al. 2005), and Ireland (Nicolaou et al. 2012) have collected survey data from senior undergraduate engineering students in order to assess the level and gap in knowledge through sustainability education in undergraduate engineering students. Although these studies were done in various parts of the world, all three reveal similar phenomena. They report that the students' understanding of sustainable development was very broad, with meagre or no understanding of the complexity of the concepts. The majority of the student responses to survey questions demonstrate a lack of understanding regarding what sustainability is, or vagueness in understanding the concept. Further, the studies suggest that engineering students tend to connect sustainable development with environmental issues and neglect the other two pillars, i.e., the economic and social imperatives. Results underline significant knowledge gaps regarding key social issues, as well as legislation, policy and standards. These studies also identified significant gaps in sustainable development in the engineering curriculum.

A study by Hanning et al. (2012) indicates there is a range in sustainability knowledge across engineering disciplines, where certain disciplines such as engineering physics and computer science engineering do not view the relevance of sustainability to engineering to the same degree as chemical engineering. This study suggests there is a lack of knowledge of how some types of engineering work is related to sustainable development, meaning there may be a potential lack of integration of sustainability in engineering within some engineering courses. The study by Azapagic et al. (2005) indicates that many engineering students regard sustainability more of professional, rather than of personal, importance. Students also view sustainability as more important for future generations. The researchers conclude that sustainable development needs to become an integral part of engineering education programmes. They propose a three-tiered approach (Azapagic et al. 2005):

1. Dedicated lectures and tutorials on sustainable development;
2. Specific case studies; and
3. Integration of sustainability into the overall curriculum.

This idea of a tiered approach is also suggested by Burian (2010), where sustainability is integrated into a civil engineering curriculum. Freshman and sophomore courses provide an introduction/description to sustainability and sustainable design; whereas, junior and senior technical courses and the capstone design project really incorporate sustainability with clear modules and examples. Their survey results show a clear increase in sustainability knowledge as the students progressed through the curriculum, that activities and assignments allowed them to achieve a deeper understanding and, finally, that the incorporation of multi-disciplinary interaction really enabled sustainable design practices.

3 Questions and Methodology

The questions driving the Sustainability Learning Pathway (SLP) Initiative in APSC at UBC are aimed at gauging community interest in, and ideas about, sustainability curriculum development, and learning something about first year student understanding and misconceptions of engineering-for-sustainability.

Two questions guide the SLP Initiative:

1. Is there an interest in, and at what level do students, faculty members, and the Dean of the Faculty support the development of a sustainability learning pathway in the undergraduate engineering programs at UBC?
2. What are the knowledge gaps and misconceptions relating to sustainability of current first year students and how can this information aid in the design of appropriate sustainability learning outcomes for a common first year design course offered at UBC?

4 Methodological Approach

The questions described above are answered by the following actions: Meet with the Dean to discuss his support of the development of a sustainability learning pathway for engineering students and identify indicators of faculty member interest in sustainability learning within engineering programs. Develop and deploy an informal survey to first year engineering students aimed at measuring comprehension, experiences and attitudes towards sustainability. Convene a roundtable discussion with interested faculty members from across engineering departments to discuss possible sustainability learning outcomes at both the first and fourth year levels.

4.1 Identifying Indicators of Faculty Interest in Sustainability Learning

Two of the authors conducted an informal meeting with the Dean on the subject of the APSC Sustainability Learning Pathway Initiative. No questions or agenda were set. The discussion was free ranging and candid.

One indicator was informally identified by the authors:

(a) The Teaching, Learning, and Research Office of the University Sustainability Office take an annual inventory of UBC courses offering sustainability-related learning. The inventory is voluntary, that is, a general call to register courses is distributed to instructors across the university. Instructors must respond to this call in order for their courses to be listed in the inventory. The number of engineering courses in the inventory was identified as an indicator of faculty member interest in sustainability learning in engineering.

4.2 Development and Deployment of an Informal Student Survey

An informal (i.e., not-validated) survey was developed and deployed to all undergraduate engineering students in December, 2014. The aim of the survey was to gather information from the students about their:

- comprehension of sustainability concepts acquired during their pre-university experiences;
- current comprehension of sustainability; and
- general attitudes towards sustainability—i.e. “what is one word you would use to describe sustainability”.

Since half the first year cohort engages in a two-hour module on sustainability in September each year, first year students were asked whether or not they had taken the module. The deployment of the survey in December served to collect data that might indicate the influence of the two-hour module on student learning. This two-hour module is composed of approximately one and a half lectures of the first year engineering course (i.e., APSC 150: Case Studies in Engineering) that focused on sustainable development and engineering. While taking the course, their knowledge was assessed with a question on life cycle assessment in the final exam and an assignment on the Seven Questions to Sustainability (MMSD Task 2 Working Group 2002).

4.3 An Engineering for Sustainability Roundtable Discussion

A two-hour roundtable discussion was convened in the fall of 2014 to gather ideas from interested faculty members from across the engineering disciplines about the sustainability knowledge, skills, and/or attitudes that a first year course could help students develop. The purpose of the roundtable was to develop a preliminary list of sustainability learning outcomes for the first year level to help students to develop their knowledge of sustainability.

5 Results and Discussion

5.1 Interest and Support for the Development of a Sustainability Learning Pathway

The Dean and Associate Dean envision sustainability learning to be deeply integrated into all undergraduate engineering curricula. This format may be emerging as best practice (see the discussion). There were 39 undergraduate engineering courses that instructors self-identified as having sustainability content, addressing topics including environment, society, economy and technology, and sustainability focused (USI 2015g). On closer inspection, many of these courses focused on analysis techniques rather than broad sustainability decision-making skills (for example, leadership skills, ethical reasoning skills, understanding of context, and other knowledge relating to the UBC sustainability attributes).

5.2 Development and Deployment of an Informal Student Survey

107 first year students, approximately 13 % of the first year cohort, responded to the survey. Of these, 49 had not yet taken APSC 150 and 58 had taken the sustainability module in APSC 150. In addition 105 respondents were from 4th year engineering students. The survey allowed for an overview of the current level of understanding of undergraduate engineering students on sustainability. One of the questions was "Please indicate how important you feel each of the following topics is to your interpretation of "sustainability". Some of the topics included: ecological resiliency, systems thinking, recycling, global and social justice, Life Cycle Analysis (LCA), distribution of wealth, Climate Change, etc. The students were asked to pick between critically important, very important, somewhat important, not at all important and unsure. LCA is one of the easier gateway concepts for engineering students to grasp. In APSC 150, the concept is introduced, but the process is not reviewed nor do students actively engage in an LCA learning activity. However as shown in Fig. 1, the importance of LCA, when considering sustainability, shifts to being more significant after taking the first year course.

On the other hand, 1st year students prior to taking APSC 150 are more likely to associate sustainability with *recycling,* as in Fig. 2, and/or *climate change*, compared to other student groups. This is comparable to many results indicated in the literature where concepts such as recycling get high scores in surveys due to having

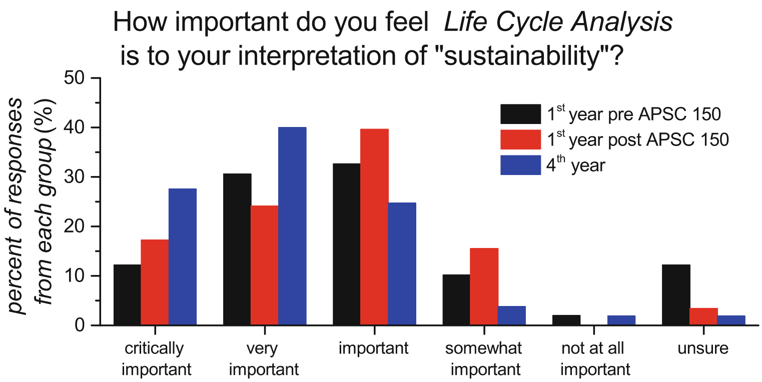

Fig. 1 Survey results for the question: "how important you feel *life cycle analysis* is to your interpretation of sustainability". 1st year pre APSC 150 in *black*, 1st year post APSC 150 course are in *red*

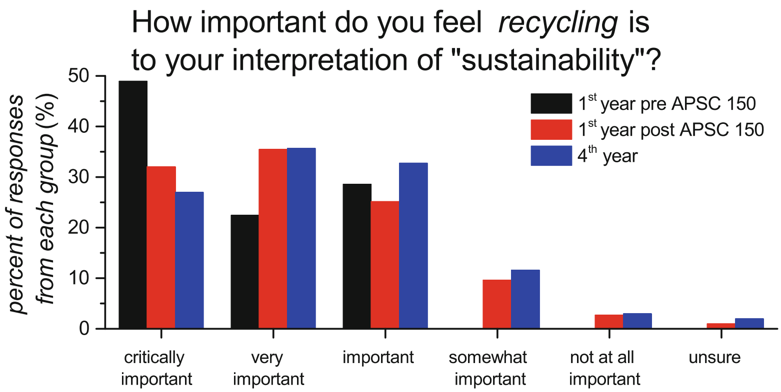

Fig. 2 Survey results for the question: "how important you feel *recycling* is to your interpretation of sustainability". 1st year pre APSC 150 in *black*, 1st year post APSC 150 course are in *red* and 4th year results are in *blue*

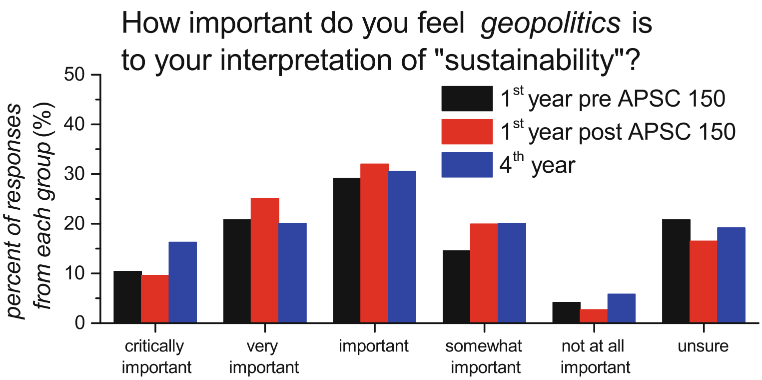

Fig. 3 Survey results for the question: "how important you feel *geopolitics* is to your interpretation of sustainability". 1st year pre APSC 150 in *black*, 1st year post APSC 150 course are in *red* and 4th year results are in *blue*

a high public profile and prominence in the media (Nicolaou et al. 2012). In contrast, the economic and social aspects of sustainability are not covered as extensively in media, and if they are not presented in the engineering curriclum there are high uncertainties in answers. For example, the survey results in Fig. 3 indicate that there was great uncertainty in students from all groups with the association of sustainability with *geopolitics*.

One concept that needs coverage and requires curriculum adjustment is *systems thinking*. Students responses vary, including great student uncertainty for *systems thinking* (Fig. 4). Given the similar trend of distribution for 1st and 4th year student respondents, it is conceivable that *systems thinking* is not sufficiently addressed in

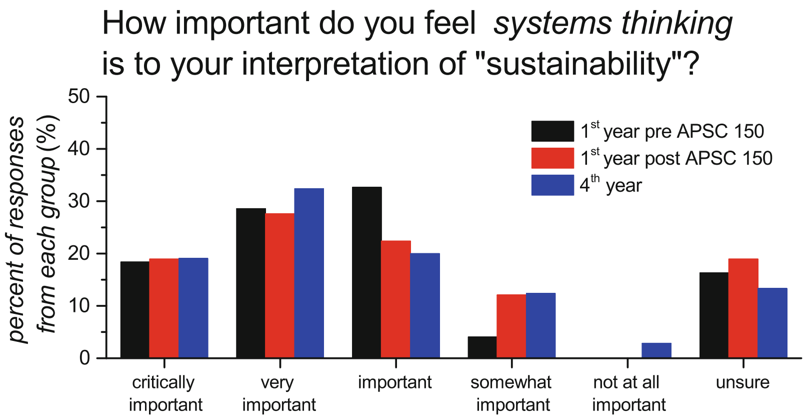

Fig. 4 Survey results for the question: "how important you feel *systems thinking* is to your interpretation of sustainability". 1st year pre APSC 150 in *black*, 1st year post APSC 150 course

the engineering curricula, despite it being one of the key competencies in sustainability development learning (Weik et al. 2011).

Generally, The survey results presented here closely mirror results found in the literature, where there is a great predominance in student responses that related sustainability with the environmental imperative, but a deficiency in responses that relate sustainability to the social and economic imperatives. (Hanning et al. 2012).

The survey results suggest that some concepts of sustainability are present at an undergraduate level but that the curriculum should be redesigned to include more concepts in the social and economic pillars.

5.3 An Engineering for Sustainability Roundtable Discussion

There were 15 attendees at the two-hour roundtable discussion during which the participants were able to begin developing a framework of intended learning outcomes and key themes related to sustainability for UBC engineering. There were several suggestions on how to introduce sustainability, all of which involved integrating sustainability throughout the curriculum. Examples included using case studies, in-class and out-of-class examples, and raising student awareness. Some possible first year learning outcomes that were presented are:

- Articulate the context of an engineering problem in terms of sustainability and identify areas of impact (including identifying all stakeholders);
- Describe the foundational concepts in sustainability (e.g. systems thinking) and demonstrate a working understanding of a sustainability lexicon; and
- Think critically to apply concepts from sustainability to real world problems; ask the right questions. One of the major themes that arose from the discussion was the need to prepare students for complexity.

6 Conclusions and Next Steps

Attitudinal barriers to embedding sustainability into engineering curricula at UBC appear largely absent. Indeed, the work presented in this paper suggests that there is significant interest on the part of administrators, faculty members and students to "get on with it." The need for understanding the theory and practice of engineering-for-sustainability seems obvious.

In addition to establishing the "student will" to engage in learning engineering for sustainability, the survey data described here provide an informal indication of first year student understanding of sustainability and provide the authors with gaps and misconceptions regarding sustainability. They also provide benchmarking data that may be used informally to signal the effects of subsequent changes to the first year program. Gaps suggested by both the survey data and the results of the faculty roundtable discussion include understanding the notion of complexity as manifested by systems thinking as well as thinking at different scales (from societal to detailed analysis). Misconceptions include the notion that sustainability relates only or primarily to environmental issues. Further, survey data suggest that pedagogies deployed at the first year level should support each student personalizing the issues of engineering-for-sustainability, such that sustainability is viewed as having links to behaviour as well as engineering projects, thus sowing the seeds for future understanding of the connections between the built environment and issues of "behavioural lock-in."

The next steps for the UBC APSC SLP initiative involve creating a framework of learning outcomes, activities, and assessments aimed at filling sustainability knowledge gaps, and addressing first year student misconceptions about engineering and sustainability. In these tasks, the literature offers significant guidance [e.g., Jowitt (2004), Blizzard (2012), Mulder et al. (2012)]. Once created, the authors intend to pilot the framework, with subsequent adjustments made that are based on pre- and post-course student data and possibly focus group data collected during the piloting stage.

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What Do Sustaining Life and Sustainable Engineering Have in Common?

Thomas J. Siller, Gearold R. Johnson and Wade O. Troxell

Abstract

Medical Education professionals in the U.S. have realized that medical education now consists of three main features: diagnosis, cure and in the case of chronic illness, health management (sustaining life). In a similar way, engineering education may be characterized by problem definition (diagnosis), problem solving and in the case of chronic engineering problems, problem management. Medical education has taken steps to modify its curriculum and pedagogy to reflect this new awareness whereas engineering education has not. What can engineering education learn from the medical education community? And, in particular, how do further challenges of sustainable engineering impact how engineering education should change?

Keywords

Problem solving · Engineering education · Sustainable engineering · Medical education

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1 Introduction

Since at least the end of WWII, engineering has been characterized as "problem solving," and engineers as "problem solvers." When asked, first-year engineering students often provide this answer when they respond to the question: What is engineering? But, it is not just engineering students who answer this way, even engineering faculty characterize themselves as problem solvers and several of the leading books on the reform of engineering education by Sheppard et al. (2009) and Jonassen (2013) also describe engineering as problem solving. Most of the current engineering curriculum reflects this emphasis on problem solving and the information mastery necessary for problem solving.

In a recent article on the whole professional (Denning 2014) based on the book by Goldberg and Somerville (2014), states that one of the principles of being a whole new engineer is to "Demonstrate competent performance in solving engineering problems," and further that one of the skill sets of the whole new engineer is "Analytical ability to rigorously analyze problems and apply scientific and mathematical principles to their solutions." This emphasis on problem solving isn't a criticism of the whole new engineer, in fact, many of these principles and skills are extremely important for engineers. But, we believe that this emphasis on problem solving leads to serious issues in both engineering education and the engineering profession.

Even the web site of Olin College of Engineering (2015) that states its commitment to changing engineering education states: "Olin was founded to radically change engineering education with the goal of fuelling the technical innovation needed *to solve* the world's complex future challenges," (italics added for emphasis).

But is engineering as problem solving sufficient? In an excellent paper from an earlier EESD conference, El-Zein and Hedemann (2013), argued that this emphasis on problem solving "determines the mode of engagement with the world and limits our ability to tackle root causes of social and environmental issues in technologically advanced societies." They discuss the idea that engineering demands more than problem solving by adding problem definition to the role of engineering and that engineers must "enunciate the *public good* that they are mandated to build or protect." The authors even propose that the titles of the various engineering disciplines be changed to reflect the public good that the discipline supports, for example, water or habitat engineering.

Downey (2005) and Siller and Johnson (2010) have argued quite effectively for getting engineers involved in the "problem definition" phase as a way to return engineers to professional status and to lessen the idea of engineering as a commodity by adding engineers to the list of stakeholders. However, it might be more complicated than just getting engineers involved in the problem definition.

When examining the National Academy of Engineering's list of Engineering Grand Challenges for the 21st Century (2010), one is struck by the notion that many of these challenges do not have solutions in the traditional sense, rather they represent situations where the "solution" is the management of the challenge. This seems true for our energy needs, access to clean water and improved sanitation, the nitrogen cycle, the carbon cycle, medicine and many others.

Trevelyan (2014) in his recent book, The making of an expert engineer, has studied practicing engineers in the field and reports that one of the main misconceptions of engineering students is that engineers are problem solvers. It turns out that this is not just a misconception of engineering students. As stated above, engineering faculty as well as others also hold this misconception and this significantly limits the role that engineers play in our society.

Put another way, if engineers solved problems the problems would go away. But, in fact, many of our technologically based problems seem to be exasperated by our so-called solutions. Because we are only solving small problems and the big problems call for management rather than solution, where should engineering educators turn for help?

2 Analogy with Medicine

For many, many years, the medical profession has also thought of themselves as curing (solving) medical problems. In some cases, this is true. Surgeons are often able to remove tumors or other growths that form the basis of what is referred to as an illness. The older problem solving approach is also still evident in such medical research fund raising activities as "Race for a Cure." Yet, over the years many illnesses have proven impossible to cure (chronic illness) so a new approach has developed, that of so-called managed care. Example chronic illnesses include hypertension, diabetes, Alzheimer's, MS, Parkinson's, HIV/AIDS, ALS, MDS, and many other forms of cancer, etc.

Like engineering problem solving, when medical professionals think they can cure (solve) a problem, the interactions basically come down to the patient-doctor relationship. Obviously, in the case of surgery, there is a professional team approach to the surgery, but the patient (client) only directly interacts with the surgeon and it is the surgeon who has solved the problem. This is directly analogous to an engineering team solving a problem for a single client without considering the needs of other stakeholders who may be involved with the problem.

The move to managed care changes these relationships. Often a team of physicians and other medical professionals are directly involved with the patient as well as others on the patient's side such as other family members, other medical organizations, insurance company boards, etc. This shift to a managed focus rather than a problem solving focus enables an easy expansion of the role of other groups of individuals. The same would be true of engineering problems; if they are managed rather than solved, the role of other stakeholders is much easier to include in the team approach to management.

Because early diagnostics in medicine becomes so important with respect to treatable but not curable illnesses, medical education has put an increased emphasis on diagnostics and team-based approaches to diagnostics noting that it has become nearly impossible for one medical specialty to be able to diagnose across medical specialties. Again, diagnosis is analogous to the engineering problem definition stage as discussed by Siller and Johnson (2010). Both medical diagnosis and engineering problem definition require that doctors and engineers ask smarter questions and acquire the appropriate data necessary for decision making.

3 Trends in Medical Education

Medical education began undergoing a transformation in the early 1980s when patients began complaining about the lack of time that physicians spent with them. At the same time, it was also acknowledged that many individuals in society suffered from chronic illnesses that demanded a regime of health management rather than being cured. Certainly some specialists such as surgeons still needed to be taught how to perform surgeries but this came at a later point in medical education. In the case of medical education, the reform was driven by the medical accreditation agency. Over about a twenty year period, the medical education pedagogy was changed from information mastery to team based collaborative critical thinking. The approach now was patient centered with groups of students, in teams, deciding on tests for the case study patient, and then developing a strategy for health management. Groups of teams then debated their approaches with active learning replacing the passive learning approaches of traditional lectures. Flipped classrooms were introduced to provide students the opportunity to do preliminary work on their own and then work in teams on solving small problems and developing management plans for the significant chronic problems. The students also learned that what works today might not work tomorrow or the next day and that the plans always have to be reconsidered and redeveloped. For example, patients with a chronic illness often develop a second chronic illness with unknown medicine interactions.

It has been very hard for medical educators to adopt this new active learner approach but the accrediting agency has been quite forceful in holding medical schools to the new standards with threats of dropping accreditation, if necessary.

It should be pointed out that managed care was not the only reason for change in the medical education curriculum. Other issues centered on the need for re-examining the length of medial education programs, not being learner centered in general, inflexible and not outcomes based. For a much fuller account of the medical education reform discussion, see Irby et al. (2010).

4 Implications for Engineering Education

Does it make sense for engineering educators to examine what the medical education community practices in this regard? If this is the case, should engineering education include topics such as diagnostics and management, similar to current medical practices that now focus on diagnostic and management of illnesses rather a cure, recognizing that a cure is not possible in many cases and the important problem is to sustain life as effectively as possible. We believe the answer to this question is ‘yes.’

Sheppard et al. (2009) describes a need for more hands-on engineering education based on project-centered learning. We believe that this method would be very effective in the development of skills and techniques for problem management but that it does not include the necessary elements to include problem definition unless the students also develop their own team based projects. We have actually tried this in a course that is described in the next section.

Active learning has been promoted by educators for many years. An active learning course does not have to be a hands-on course. Active learning may even be incorporated in traditional lecture courses by having the lecturer stop about every 15 min and introduce a question that the students work on for a few minutes, again in groups, and then report to the class. No matter how this is done, to develop engineers who are better at problem management will require new approaches to engineering education.

5 Engineering Education for Sustainable Development

At this point it should be clear that we believe that engineering education needs to transition from the fundamental principle of engineering as problem solving to engineering as: problem definition, some problem solving and problem management for chronic problems. Several years ago the authors decided to develop a new course for first year engineering students at our home institution. We chose the National Academy of Engineering Grand Challenges as the context for introducing students to the engineering profession and its various disciplines. The Grand Challenges have many connections to sustainable engineering, including topics related to energy, e.g. solar and nuclear power, along with the issue of global warming, e.g. carbon sequestration. A panel chose these topics, as it is believed that they both represent the major challenges for the early decades of this century and they are problems that can be "solved" during this time.

As we started to teach this course, we became increasing convinced that these challenges do not represent problems that shall be solved! For example, the issue of energy will probably never be solved in the traditional manner wherein a solution is created that eliminates the issues around energy, i.e. the energy problem goes away. Instead, for each new fuel source found and developed new issues are created such as the long-term supply of fuel and the resulting impacts to the environment. This is most obvious with non-renewable sources such as carbon based or fossil fuels that are being consumed much faster than they are replenished. But this is also the case with renewable sources, for example wind turbines are having unintended negative consequences on the habitat of wildlife, such as birds and bats, and increasingly, noise issues. The more time we spend on these challenges the more our thinking and teaching approach shifted towards a focus to understand there are no ultimate solutions to these sustainability-related problems—they will always remain with us. This became a significant educational challenge: how do you teach engineering students the value of working on problems without solutions?

Educating engineering students to see beyond the predominant rhetoric of problem solving can be difficult as it runs contrary to why many students entered engineering in the first place. Based on our experience it might be better to start in the early years before the standard message is too deeply embedded in their mindset. The first step we take with the students in our class is to have them define what they see as the great challenges we will face in this century. The student responses have always been to identify global challenges, e.g. energy, health, water as big broad challenges. Contrast the students' thinking with the specificity of the NAE list that includes: making solar power more efficient and nuclear fusion power practical. When one reviews the NAE list it becomes clear that the manner in which they defined the challenges look more like solution statements instead of problem statements, whereas our students focus more on the fundamental problems. This observation helped us realize that students who are not already deeply trained in finding solutions define problems more broadly than engineers who have expertise in particular classes of solutions.

To build upon this broad-thinking mentality of first year students we have developed an approach where we engage the students in developing a deeper and broader understanding of the challenges, and then later discuss how engineers contribute to these efforts. We believe that getting students to understand the definitional aspects of a problem is a critical step for both the NAE Grand Challenges and the bigger issue of developing a sustainable world. The students are encouraged to think in a divergent manner while trying to define and understand the challenges. It appears that first year engineering students have a capacity to see the many connections that make the Grand Challenges interdisciplinary in nature and that there are no simple solutions on the horizon. One of our concerns is whether they can maintain this outlook as they progress through a curriculum that values solutions to the types of local problems found in math, science, and engineering textbooks?

So what should we do next? Returning to our observations from the medical profession is helpful. Medical doctors are now a part of a larger enterprise, typically referred to as the "Health Care System." So even though doctors cannot cure (solve) all illnesses, they contribute to the management of those chronic health diseases while also contributing to local solutions, such as surgeries that do at times provide cures, or solutions, to individuals. We believe this observation has parallels in engineering for a sustainable world. There will be local solutions that come from engineering but engineering also has to better position itself to be a contributor to a much larger system, what we tentatively think of as the Technology Enterprise, similar to the manner that medical doctors contribute to the health care system—as partners with many more contributors working together, e.g., skilled nurses, pharmacists, insurance boards, medical researchers, etc. As Miller (2014) indicates "… sustainability is implemented through policy and regulation." For engineers to contribute to this technology enterprise working on sustainability they must be prepared to work with policy makers, regulatory agencies, and society in general. This represents a movement away from a focus on local solutions to more global problem management.

For many years engineering educators have been encouraged to broaden the curriculum, e.g. ABET Inc. (2013) learning outcome (h) which states that engineering graduates should have: "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context." Unfortunately this has proven to be difficult. Our contention is that much of the difficulty arises because faculty see no role for non-STEM courses in problem solving and therefore we fail to show the relevance of this outcome to the students' future careers. With a shift to positioning engineering within a broader enterprise of technology, similar to the health care system, we can highlight the value of this learning outcome, and similar ones, so that engineers understand that long-term management aspects of sustainability requires the contributions of many professions working together. This move to pedagogy for problem management naturally strengthens the relevance of the humanities and social science that are major contributors to management techniques. For engineers to naturally operate in the greater technology enterprise, similar to medical doctors in the health-care system, requires a new approach to engineering education.

The medical profession has also recognized that chronic diseases do not go away. In fact, they often lead to additional diseases that can then lead to conflicts between medication treatment and health management. Similarly, as with chronic health issues, chronic challenges such as energy production often lead to related challenges, e.g. access to clean water (recognizing that a large portion of water use is for energy production). Therefore engineering also faces the situation where technological approaches for one chronic challenge can be in conflict with technical approaches for a related challenge. In engineering education we have stuck with the reductionist approach championed by science for many years that often ignores these recurring interactions between related challenges and proposed *solutions*. The time has come to change this paradigm. The activity of sustainable engineering does not end with a solution because environmental conditions are in constant flux. Management, which is now necessary, is an ongoing activity that must be continuously re-examined and redeveloped as new information is acquired. Preparing engineers for this new reality must embrace management as part of the new foundation for engineering education.

We do believe that our developing approach for our first year class is a step in the right direction, and working with first year students is the place to start, even though we have not addressed the issue of management very well. In the fall of 2014 we added a new component to the class: the EWB-International design challenge (2014). Similar to the approach to developing medical students' diagnostic abilities before they have mastered all the required knowledge content, this project involves engineering students working on challenges before they have developed all of the knowledge mastery of the engineering curriculum. Students get quickly engaged in working on the challenges and discover areas of missing knowledge as they develop a better definition of the problems at hand. They also quickly recognize the role of engineering as being a team member that requires many areas of expertise.

Finally, although we have introduced the concept of problem definition into our first year course, in part because the students are so good at it, the next step of introducing long-term management of challenges still eludes us. Several questions arise: What does a good pedagogy for developing this type of management look like? What does management of chronic technological related challenges look like? When should management be introduced into the curriculum? That is why we are looking to draw parallels from the medical education system as they also recognize the role of management in the health care system in which they operate.

6 Recommendations and Conclusions

In the previous section we identified some starting questions we think need to be addressed if engineering education is going to shift in a manner similar to medical education. But it is important to point out the medical education is also still in a state of transformation. Therefore, we recommend that a joint workshop be developed for the interaction of both medical educators and engineering educators to further consider the parallels that exist between these two professions. We have much to learn from each other. The transformation of engineering education, like medical education, is not a problem to be solved but an ongoing endeavor that requires a management approach. Like other great social issues, we need to start working in interdisciplinary teams to transform our educational approaches and engineering and medicine can learn from each other.

Engineering can no longer be characterized as problem solving especially in a world trying to grapple with the ideas of true sustainability. Engineering has to be re-characterized as problem definition, some problem solving and problem management. Otherwise engineering will quickly be viewed in an instrumental manner by society—resulting in a very limited role. This needed re-characterization requires a modification of the engineering curriculum and pedagogy. Moving toward active learning scenarios and project centric, team based study represent a good first step in this direction. It also requires the development of a more formal structure to the foundations of this re-characterized profession, a topic being explored by the authors in a paper in development.

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Author Biographies

Thomas J. Siller has spent 27 years teaching both general engineering and civil engineering, and researching in engineering education. He joined the Civil and Environmental Engineering department at Colorado State University in 1988. He has taught numerous courses related to civil engineering, with a focus on geotechnical engineering. For the past 7 years he has taught a first-year engineering course based on the U.S. National Academy of Engineering's Grand Challenges.

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Principles, Implementation and Results of the New Assessment and Accreditation System "Engineering Education for Sustainable Industries" (QUESTE-SI)

Jurgis K. Staniškis and Eglė Katiliūtė

Abstract

While the importance of evaluating the education of sustainable development programmes has been widely recognised, very limited information is available on the topic. QUESTE-SI project was funded by the European Commission under the Lifelong Learning programme ERASMUS (2010–2012). QUESTE-SI stands for "Quality system of European Scientific and Technical Education for Sustainable Industry". The project was coordinated by EFMD, the Management Education Network, and ENQHEEI, the European Network for Quality of Higher Engineering Education for Industry. The QUESTE-SI evaluation and accreditation focuses on the institutional unit (department) that is responsible for one or more programmes. A key point is to ensure that each graduate learns the sustainability aspects related to the concerned education domain. A fair evaluation of social responsibility and sustainability education is not limited to teaching and learning methods or curricular content—it depends on parallel efforts in all dimensions. The main objective of the paper is to present, analyse and discuss principles, implementation and results of the original assessment and accreditation system for higher engineering education. The system comprises all five roles of the university: education, research, infrastructure and management, students' involvement and society. More than 10 European science and technical universities have been accredited in accordance to the QUESTE-SI requirements. Kaunas University of Technology was represented by the Institute of

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Environmental Engineering with the M.Sc. Programme “Environmental Management and Cleaner Production” and the Ph.D. Programme “Environmental Engineering and Landscape Management”. The Institute of Environmental Engineering has been awarded the highest ranking and has become a fertile basis for a larger pilot project. The paper presents principles, methodology, results of QUESTE-SI evaluation and accreditation and the experience of pilot institution.

Keywords
Engineering education · Assessment and accreditation system · Sustainable industries · Social responsibility

1 Introduction

Traditional engineering education focuses on response to needs or demands of employers, industry and the marketplace. Such needs or demands, when focused on the acquisition of specific scientific and technological knowledge, practical skills, and competences, may result in a concise description of a limited set of learning objectives for an assessment. Currently, there is a growing concern for responsibility related to decisions that may have a negative impact on society, the environment and resources. Nonetheless, curricula reforms are still needed to better educate engineers on the implications that their work has on the environment and societies in our and future generations. A step to facilitate this is assessing the contribution of engineering education to sustainability (Watson et al. 2013). Over 600 universities worldwide have committed themselves towards sustainability by signing international agreements and conventions such as the Bologna Charter, the Halifax Declaration, the Talloires Declaration and the Copernicus Charter for Sustainable Development. It is hoped that these measures—being of special interest to the signatories—may catalyse more systematic action (Filho et al. 2015; Lozano et al. 2013).

Several tools have been developed to assess university sustainability so far, for instance, the Auditing Instrument for Sustainable Higher Education (AISHE) (Roorda 2010), the Graphical Assessment for Sustainability in Universities (GASU) tool (Lozano 2006), the Environmental Sustainability Assessment Questionnaire, and the EMS Self-Assessment (Shriberg 2002). Many of these tools are focused on improving the sustainability of campus operations. The STAUNCH system (Lozano and Young 2013) is aimed at helping universities to assess the depth and breadth of their SD-related curricula in a holistic and systematic way and to produce standardised and comparable results. A challenge that remains is how to assess the contribution and impact that curricula and university life may have on student personal life during studies and for their professional life in helping to make societies more sustainable.

In Australia, it was argued that a fundamental way to begin assessing whether universities were committed to sustainable development was to explore whether the universities and the business faculty/school vision, mission and graduate attribute statements espoused values related to sustainability. The research has revealed that it is crucial to ensure consistent institutional communication and policies in relation to education for sustainable development. When education for sustainable development is not integrated into all functions and levels within universities, the mere espousing of its virtues is just a hollow rhetoric (Lee et al. 2013). The UI GreenMetric Ranking of World Universities is one of the first attempts to make global ranking of university sustainable behaviour. Five criteria of ranking have been determined based on information provided by respective universities that demonstrates commitment to going green and being sustainable, namely environmental settings and infrastructure, energy and climate change, waste, water, and transportation. The system employs 42 indicators divided into five categories to determine the ranking scores. One of the advanced features of the UI GreenMetric is that the ranking can be sorted by campus setting (rural, semi-urban, urban, overall ranking) or by type of higher education institutions (comprehensive, specialized higher education institutions) in the overall ranking. By using this feature, each institution or end user can make a fair comparison and group universities by their scores (Suwartha and Sari 2013).

The findings of the study at the University Sains Malaysia revealed the four constructs that can be considered to assess the sustainability practices of the university from students' perception: community outreach, sustainability commitment and monitoring, waste and energy, and land use/planning (Nejati and Nejati 2013). The world-wide survey of engineering students suggests that, overall, the level of knowledge and understanding of sustainable development is not satisfactory and that much more work is needed in educating engineering students in this field. While on average students appear to be relatively knowledgeable about environmental issues, it is apparent that significant knowledge gaps exist with respect to the other two (social and economic) components of sustainable development (Azapagic et al. 2005). Therefore, the evaluation and accreditation systems based on non-ranking overall assessment from one side and facilitate good practises exchange among institutions from another side are still missing.

2 The New Evaluation and Accreditation System QUESTE-SI: Principles and Methodology

The QUESTE-SI project is focused on the evaluation of university-level engineering education with respect to strategy and action directed to the issue of social responsibility and sustainability. A prerequisite for participation in QUESTE-SI is evidence of an institutional quality assurance system which satisfies national Quality Assurance (QA) requirements. QUESTE-SI evaluation focuses on the institutional unit (department) that is responsible for one or more programmes. The unit may submit more than one program for evaluation, provided that they have a sustainability emphasis or a theme. All submitted programs should at least be in the formal planning or at implementation stage. A key point is to ensure that each graduate learns the sustainability aspects related to the concerned education domain (http://plone.queste.eu/).

In some U.K. and Canadian universities sustainability engineering topics are moved from the “more-general” to the “more-specific”. Students are no longer introduced to broad definitions of sustainable development or phenomenon of climate change. Instead, students are introduced to aspects of systems theory, industrial ecology, resilient and regenerative infrastructure, supply-chains, and global/humanitarian engineering (Nesbit et al. 2013). The list of topical areas for QUESTE-SI is open and unit may choose sustainability topics according to their interests, capacities and objectives. A fair evaluation of social responsibility and sustainability education (SRSE) should not be limited to teaching and learning methods or curricular content. SRSE cannot be developed in a vacuum; it depends upon parallel efforts in other dimensions: (i) education and curriculum, (ii) the institution, faculty, or unit, (iii) student involvement, (iv) research and innovation in cooperation with industry. A strategy for SRSE education recognize that tomorrow’s engineers will need new “transverse” skills such as crisis communication and management, policy analysis and formulation, interdisciplinary approaches to problem solving, but above all, a broader view of problems, their causes, consequences, and preventive solutions. Thus, a key point when defining and evaluating learning objectives is whether they include the ability to anticipate the consequences of decisions and to act appropriately (a proactive rather than reactive approach). Another principle to consider is “contextualization” or “contextual awareness”. This means that an engineer has the breadth and depth of vision needed to understand why certain kinds of knowledge and skills are necessary and to view actions, problems, solutions and consequences in a broad context that may be scientific, technical, economic, legal or social in nature at the same time. The question for evaluation is whether the curriculum and methods of teaching and learning develop this awareness.

The institution should be a model of sustainable innovations, research and development, and sustainability culture. QUESTE-SI believes that attention should be given to the presence and realization of sustainability strategies at institutional and unit department. Active view of social responsibility and sustainability should be in the policy-making of educational institutions. It means that a well-defined short, middle and long-term strategy for sustainability should be in the institution. Institutional and department strategy should focus on objectives, planning, implementation, and on results that serve as performance indicators. The root of students’ involvement is their active participation in the culture of social responsibility and sustainability that go beyond the formal curriculum. Such activities may be based in national, regional or community agencies, NGO’s and volunteer organizations. Some outside activities may complement the curriculum as sources of information and experience, and may complement the use of problem-led or project-based learning techniques. In other words, QUESTE-SI is interested in activities that help to cultivate student interest and involvement in sustainability, for example, contact with industry, advising and information practices, and support extra- or co-curricular activities. In the research and innovation dimension, a strategic direction for institutional and unit choices of sustainability topics for research and development should be demonstrated. This contemplates co-operation with industry, business firms, peer institutions, and research agencies, other institutions, and organisations. QUESTE-SI looks for evidence that R&D activities also serve to enrich the curriculum, teaching and learning.

Recognition is given jointly to the institutional unit and programs to reflect the fact that recognition first applies to the evaluated programs. The QUESTE-SI approach to evaluation is multi-dimensional and has a developmental emphasis. With each of four sustainability dimensions, there is separate rating of the extent of progress toward the realization of specific objectives for the area. To emphasize the diversity and richness of institutional efforts, QUESTE-SI approach to recognition takes into account four dimensions: education and curriculum, the institution and unit, student involvement, and research and innovation. Recognition is multilevel and multidimensional. Having passed over an initial threshold for recognition, institutions are rated separately and cited for achievement with each dimension (Philips and Budkowski 2010).

The QUESTE-SI award is conferred by a body in light of self-assessment report and auditors visit report and recommendations. The self-assessment report comprises three parts: (1) questions that require a brief and well-focussed narrative response, (2) an institutional inventory, and (3) a rating of progress in terms of objectives and indicators. QUESTE-SI is focused on the context for institution sustainability effort, the organization and development of SRSE-related programmes and activities, finally, the origins of strategic initiatives and the deployment of policies between institutional levels. An institutional inventory has to show where the efforts of unit are situated in an institutional context, and full range of topical or subject areas, joint efforts with other departments where teaching staff, support personnel, or facilities are shared. Parts 1 and 2 of the report are limited to approximately eight pages; part 3 requires filling a dozen of objectives per dimension in a tabular sheet, associated with elements of proofs. The evaluation produces a formative judgment on the extent to which the evaluated unit reaches or exceeds a threshold level of sustainability effort, overall and within each of the four dimensions. It is important to recognize the diversity of institutional choices, actions, and outcomes. The efforts of each institution will rest upon different assumptions. Thus, an institution that is strong even in one of four dimensions will be recognized for that effort (Philips and Budkowski 2010).

Different studies show that despite of formal theory, in the end, it is the educator's personal theory, self-constructed, whether explicit or not, that influences his or her daily pedagogical choices. The ultimate goal of these interrelated dimensions of contemporary education is the development of responsible societies and sustainability is one of the expected outcomes (Sauve 1996). A panel of auditors was established for the QUESTE-SI evaluation. It was composed of former auditors for high educational institutions or engineering program managers, and included representatives of the industry. Its members were provided with specific evaluation kits and have been trained to audit institutions and to provide advice and guidance during the evaluation process. Each audit visit took place during two days plus a few hours for the preparatory meeting of the audit team consisting of three members, including the reporter. Some exchanges were engaged between the reporter and the institution before the visit for the clarification of some objectives or achievements. This allows very detailed sustainability and social responsibility analysis (in the case of good self-assessment report), or some kind of support to institutions in order to identify and clarify progress points under low performance (Rouvrais et al. 2014).

3 Results

The project has surveyed various networks of academic institutions, rankings, quality assurance systems, and models to enhance the development of the triangle of knowledge to identify the awareness of and commitment to sustainability as a strategic approach to sustainability, including sustainability in the study programs, involvement of the European Institute of Innovation and Technology, membership in certain networks. More than ten European science and technical universities have been accredited in accordance to the QUESTE-SI requirements, for example, Brno University of Technology, KTH Royal Institute of Technology, Vienna University of Technology, Telecom Bretagne, Instituto Superior Tecnico (IST, Portugal). Kaunas University of Technology was represented by the Institute of Environmental Engineering with the M.Sc. program “Environmental Management and Cleaner Production” and Ph.D. program “Environmental Engineering and Landscape Management” (Staniškis 2012). A short summary of the assessment results in all four dimensions is presented below.

Institute of Environmental Engineering was recognised as the most successful department in KTU dealing with SRSE issues. The Institute has knowledge and capacity to provide substantial contribution in sustainable development process at Kaunas University of Technology acting as a source of knowledge on sustainability for the entire University. The Institute has developed strategic priorities and a strategic plan for the future based on the KTU strategy and takes into account the key sustainability issues. The MISSION of the Institute—to disseminate sustainable development principles in Lithuania and all over the world through application of innovative sustainable solutions by means of interdisciplinary research, topical studies and continuous spread of knowledge and values. VISION of the Institute—a unique international leader in the field of sustainability based on interdisciplinary research and advanced studies.

In the area of education and curriculum development, APINI combines a traditional education in the engineering sciences with studies in the natural and social sciences with the ultimate goal of educating scholars who are uniquely situated to undertake serious research and policy assessments to tackle sustainable development challenges. The M.Sc. and Ph.D. programmes include a set of rigorous core requirements in the engineering, social and natural sciences designed to provide a deep understanding of the interaction between in all three areas, and provide students with the flexibility to pursue in-depth research in a broad variety of environmental issues. The programmes' graduates have unique combination of diverse skills and deep insight into the most challenging problems of future human welfare. Together with experts from industry and governmental institutions, students in the programmes conduct research in a wide variety of areas including climate change and its social consequences, causes and solutions to extreme material and energy resources inefficiency, energy systems, water resources, waste management systems, ecosystems, corporate social responsibility, environmental economics and eco-design. Students also benefit from being part of APINI research programmes and projects that focus on sustainable development (see Table 1).

Many graduates pursue academic careers in interdisciplinary graduate and undergraduate programmes with focus on industry and the environment as well as in more traditional engineering disciplines. Others choose non-academic positions in governmental institutions, NGOs or private firms engaged in environmental and

Table 1 Dimension 2: education and curriculum

	Objectives	Indicators or evidence
2a	The programme plan includes the scientific/technical knowledge, practical skills, and non-technical subjects essential for teaching and learning sustainability in the context of the topical target areas chosen by the faculty	The programme documentation clearly identifies the subjects to be taught, the sustainability-related learning objectives and outcomes, and the way in which outcomes will be assessed
2b	The programme plan reflects an institutional or department rationale for the selection of sustainability-related topics, the associated methodologies, techniques and tools, including the use of project-based or problem-led education techniques	The documentation explains how, why, and by whom these choices were made, with particular attention to the design of learning projects and problems
2c	The teaching and learning plan comprehends the "transverse skills" that graduates will need to recognize and effectively deal with sustainability problems	The programme has identified what it considers to be transverse skills. It is clear why, where, and how such skills will be developed and verified
2d	The programmes under review are designed to give graduates the broader "contextual awareness" needed to deal with sustainability issues and problems	Contextual Awareness is a "transverse skill" that cuts across different disciplines and types of problems
2e	The institutional unit has taken steps to address sustainability learning objectives, outcomes, and competencies in the external quality assurance and internal review systems	Documents or reports for internal and/or external quality assurance confirm that sustainability teaching and learning is suitably evaluated

sustainable development projects. During 16 years of Ph.D. programme and 10 years M.Sc. programme, the emphasis was placed on research at the boundaries between social, natural and engineering sciences, and these programmes have become very popular and highly rated. Almost all Ph.D. graduates have accepted academic positions as tenure-track professors or post-doctoral fellows, or are employed at high-level positions in the private sector and governmental organisations.

Sustainable development is one of the major topics of APINI research. The monograph “Sustainable innovations in Lithuanian industry: development and implementation”, written by APINI researchers presents more than 60 projects in the field of sustainable development and cleaner production implemented during the last decade. New projects start nearly every year, and most of them have a sustainability aspects covered. The research results presented in the programs’ doctoral dissertations are based on integrative, interdisciplinary research that is needed to explore science and policy issues in the area of sustainable development. Integrated Assessment methods and concepts (e.g. transitions, modelling, scenario analysis) are instrumental to provide answers to the central questions of sustainable development (see Table 2).

APINI members have carried out a number of applied environmental studies dealing directly or partly with sustainability issues. A substantial share of these studies has been ordered by the Ministry of Economy of the Republic of Lithuania. Apart of that, APINI has contacts with various partners in Lithuania and abroad, like universities, research institutions, NGOs, authorities and international organisations. APINI also aims to promote SRSE issues among students, as well as staff members, through environmental non-curricular on-campus activities. For example, APINI initiated waste recycling campaign “Žalieji Rūmai” (“Green University Building”) in 2010 and “Žaliasis Universitetas” (“Green University”) in 2012. “Žaliasis Universitetas” is the first environmental campaign that was launched for the whole campus. APINI has participated and invited its students to participate in the biggest environmental community campaign in Lithuania “Darom” (“Let’s do it”) for cleaning territories from waste.

The Institute of Environmental Engineering was awarded one of the highest rankings’ (Fig. 1) and has become a fertile basis for a larger pilot project at university level. Programs and institute staff facilitated the development of the entire university as a model for sustainable operations, research and study, sustainable regional development.

Fifteen institutions have participated in the final evaluation and accreditation phase. QUESTE-SI has no plans for publication of these evaluation ratings in a way that might inspire competitive rankings. There is an intention to help the institutions and map their strengths and limitations of programs and activities. The average evaluation of institutions according each dimension is presented below (the maximum rate—4) (see Fig. 1).

The Institute of Environmental Engineering at KTU has received the QUESTE-SI label with a score of 3 in three dimensions and 4 in one dimension. Level 3, as defined by the label, corresponds to an institution unit which

Table 2 Dimension 4: research and innovation in cooperation with industry

	Objectives	Indicators or evidence
4a	The research agenda of the institutional unit/department includes subjects clearly related to sustainability	The institute has a credible estimate of the percentage of its members teaching or doing research on sustainability issues (Such information may be found in existing reports or publications.)
4b	The Institution (or its units) contributes to sustainable development through formal partnerships or working relationships at regional, national or international levels	There is evidence of such activity in institutional and/or institute level reports, publications, and in reports issued by external R&D partners
4c	The institution, its schools, or units produce a significant amount of credible research or scholarship in the broad area of sustainability The student aspect of research	The amount of institute research with sustainability aspects very strong: more than 61 % Research has received external recognition The amount of student research with sustainability aspects in the context of their academic programmes very strong: more than 61 %
4d	The unit has active and specific linkages with industry, technological business, and the engineering profession Such links are a source of useful current information on sustainability problems, issues, and possible solutions	Evidence of specific linkages is found in university and institute reports and publications, as well as in materials produced by external partners The institute and programmes demonstrate that information obtained via external links has been applied to the benefit of teaching and learning (this was observed in several well-chosen examples)
4e	The engineering school and unit are visibly involved in associations, professional or technical bodies and organizations that are actively committed to sustainability	There is evidence that external activities have had a positive effect on the conception, planning, and development of sustainability strategies within the institution and its units. The issue is what was learned in this way and applied
4f	There is an operational strategy for sustainability-related research, development, and innovation projects in cooperation with industries, business firms, educational institutions or pertinent organizations	As above, evidence can be found in internal and external publications, reports, articles, etc. Such material is in print and/or electronic media
4g	Results of sustainability research, development and innovation projects are communicated to the students; this serves to enrich the curriculum and to stimulate student interest	Evidence may be found in selected examples of course descriptions and student projects in which sustainability research content has become part of the learning experience
4h	The provision for sustainability-related research, innovation, and cooperation is sustainable in itself; i.e., adequate funding, research and project management support (including the initial pursuit of grants and subsidies)	There is evidence that sustainability research and development activities can be sustained; i.e., a budget that is commensurate with objectives, capable personnel, a business plan, and preferably, the support of an institutional office for research management. Existing management documents or excerpts of them support the argument

Fig. 1 QUESTE-SI certificate

- Institution, faculty or unit (strategy) 2,33
- Education & curriculum 2,40
- Student involvement & cultural development 2,46
- Research & innovation 2,33

demonstrates a high quality level in the dimension. Level 4 demonstrates outstanding quality and can be considered as a model of excellence.

4 Conclusions and Considerations

It is difficult to understand how an institution that delivers sustainable education might not be sustainable itself. That's why according QUESTE-SI, the high education institution should be a model of sustainable operations, research and development, and sustainability culture. The evaluation considers the institution and unit rationale for its choice of objectives, the actions taken, and the extent to which objectives have been realized.

The non-ranking objective of the QUESTE-SI will facilitate good practice exchanges among evaluated institutions and it will be beneficial not only for institution evaluated, which will get a more objective view on its strengths and weaknesses, but for the evaluators as well who will be able to identify best practices possibly useful for their own institutions. Comparatively low average QUESTE-SI evaluation rate shows that even in advanced high education institutions the leadership is rather light. There is a complex management challenge, i.e. to overcome possible conflicting and restraining forces and face resistance to changes.

Even if teachers' or researchers' individual initiatives are often promoted, quality assurance processes should help to promote interdisciplinary approach integrating sustainability issues in research and curricula, campuses, and institution strategies and vision. QUESTE-SI process has revealed that students could be good stakeholders in the quality assurance process. Besides their experience in learning and in campus, they can strongly influence the process via a bottom-up approach in all types of institution's activities towards sustainability and social responsibility.

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Developing Change Agency for Sustainable Development—Experiences from a New Chemical Engineering Course

Magdalena Svanström

Abstract

The chemical engineering programme at Chalmers University of Technology in Göteborg, Sweden, has had compulsory courses on environmental science, environmental engineering and sustainable development (SD) at bachelor level for many years. This paper reports on curriculum development projects performed in 2013 and 2014 aimed at improving the quality of the program curriculum with regard to the compulsory content on 'environment and SD' and on experiences of planning a new course that was developed as a result of these projects: Perspectives on chemical engineering. The curriculum development projects contrasted the existing curriculum to syllabi from upper secondary school, to needs expressed by industry, alumni and engineering students, and to state-of-the-art engineering education for SD, and ended up in, among other things, ideas to be implemented in a new course in the first year. The new course focuses on introducing chemical engineering and the professional role of the chemical engineer, and developing change agency for SD. The new course was given for the first time in late spring 2015. In the course, the students are doing a smaller individual change project in which they change something in their daily life for a week and assess the impact and reflect on the challenges in making the change. They also do a larger group project in which they make a sustainability assessment of a considered sustainability-motivated change in chemical industry, including reflecting on the challenges of achieving change. Industry representatives help to guide the students in the project. The course also introduces basic concepts and tools like life cycle perspective, mass balances, biorefinery and industrial symbiosis. Special care was put into attempting to constructively align

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teaching and learning activities and assessment to the overall goal of developing students' change agency for SD.

Keywords
Action competence · ESD · Education for sustainable development · Engineering education · Curriculum change

1 Introduction

The important role of education for achieving sustainable development (SD) has been highlighted by e.g. the UN in the proclamation of the decade for education for SD (DESD), 2005–2014 (final report available on: http://www.unesco.org/new/en/unesco-world-conference-on-esd-2014/esd-after-2014/desd-final-report/), and the follow-up Global action programme (GAP) on education for SD (ESD), see http://www.unesco.org/new/en/unesco-world-conference-on-esd-2014/esd-after-2014/global-action-programme/. One of two objectives of the GAP is: "to reorient education and learning so that everyone has the opportunity to acquire the knowledge, skills, values and attitudes that empower them to contribute to SD—and make a difference". In line with this objective, this paper addresses the empowerment of engineering students to contribute to SD in order for them to "make a difference", focusing in specific on what is often referred to as 'change agency' or 'action competence'.

1.1 Change Agency for Sustainable Development

The specific learning that is targeted in ESD has been described in many different ways. In fact, one of the major challenges in ESD is still the lack of detailed and universally accepted descriptions of the learning that needs to be targeted. Often, however, the core idea of ESD seems to be the same and therefore, dissimilarities in existing descriptions are likely primarily a result of a lack of efforts to find consensus on a common framework. Wiek et al. (2011) made a review of literature on sustainability in higher education and concluded that there is "convergence that sustainability education should enable students to analyze and solve sustainability problems, to anticipate and prepare for future sustainability challenges, as well as to create and seize opportunities for sustainability", and also that "there is convergence in the educational literature about the critical role of defining key competencies and specific learning outcomes in order to successfully design and teach in academic programs".

Svanström et al. (2008) made a review of texts on ESD competences and found that they commonly describe notions like systemic or holistic thinking and the integration of different perspectives, skills such as critical thinking, change agent abilities and communication, and that they all in some way address attitudes and values. Using literature review, expert workshops and surveys, Wiek et al. arrived at a description of ESD competences that focused on five areas: systems thinking competence ("to analyze a sustainability problem from a holistic perspective"), normative competence (to "assess a problem and its context comprehensively with respect to sustainability"), anticipatory competence (to "construct non-intervention scenarios about how the problem might play out in the future"; they also described a combination of anticipatory and normative competence as to "envision sustainable future states in contrast to the non-intervention scenarios"), strategic competence (to "create intervention strategies to avoid undesirable scenarios and realize sustainability visions"), and finally, interpersonal competence (to be able to work in "close collaboration with researchers from other disciplines, and stakeholders in government, businesses, and civil society").

Already in the 1990s, similar ideas were described within the context of environmental education, under the term "action competence". According to Jensen and Schnack (1997), "[o]ne of the overall objectives of environmental education is to build up students' abilities to act—their action competence—with reference to environmental concerns" and more specifically, they state that "the aim of environmental education is to make students capable of envisioning alternative ways of development and to be able to participate in acting according to these objectives". The similarities between these statements and the much later texts on ESD are striking, although ESD can be claimed to have a broader scope than environmental education with environmental issues not necessarily being in the center of attention.

The notions of 'change agency' and 'action competence' are central in these descriptions and highlight the need for action, which is a central idea also in the objectives of the UN GAP that aims to "empower" people to "to contribute to SD—and make a difference". Almers (2013), based on a review of literature, summarized important aspects of action competence as (1) commitment; (2) willingness and courage to act; (3) knowledge about consequences of and root causes to problems; (4) knowledge about and a capability to develop visions and possible solutions to a problem; (5) knowledge about how to influence and change conditions; and, (6) to be able to put this knowledge into practice.

So, what does this mean for current engineering education? Are we already promoting the development of change agency for SD to a sufficient level today? If not, how can we teach for, and assess, this learning? This paper discusses these issues for the five-year chemical engineering programme at Chalmers University of Technology, Göteborg, Sweden, and ongoing efforts to address a perceived gap.

1.2 The Chemical Engineering Programme and Its Context

The specific five-year chemical engineering programme has had compulsory courses on environmental science, environmental engineering and SD at bachelor level for several decades. In fact, since the 1980s, there has been a requirement that all five-year programmes at the university contain at least 7.5 higher education credits (hec) on "environment and SD" (E&SD) on bachelor level. This shows the strong commitment and the long-term effort of the university to contribute to SD. For a long time, this compulsory content on E&SD was not described in any detail but in recent years, recommendations for what type of learning to address have been developed. In a document from 2009, developed in a consensus process involving interested teachers and programme directors at the university as part of a three-year reform project on ESD (described in http://www.chalmers.se/sv/om-chalmers/miljo-och-hallbar-utveckling/tidig-satsning-pa-miljo-och-hallbarhet/Documents/ESD_report.pdf), the following learning outcomes relate the strongest to change agency:

- Use problem solving, critical thinking and creative thinking, be able to communicate and cooperate, and be able to discern power issues in different decision-making processes in order to prepare for life-long learning and for becoming an effective change agent for SD
- Apply and shift between different perspectives in order to understand the situation of other stakeholders, and in order to be able to determine the viability of different options
- In a structured way reflect on his or her professional role and responsibilities as a professional and as a citizen in relation to SD.

At master level, there is today a university-wide learning outcome for the master thesis, that the student should demonstrate:

- The capability to identify the issues that must be addressed within the framework of the specific thesis in order to take into consideration all relevant dimensions of SD.

In Sweden, there are also external requirements that push in the same direction. The University law states that all activities at universities must promote SD, and in the national degree ordinance for engineers, there is even specific mentioning of what this might mean, e.g., the student shall demonstrate:

- The ability to develop products, processes and systems, taking into account people's situations and needs and society's goals for economic, social and ecologically SD, and
- Insight into technology's possibilities and limitations, its role in society, and people's responsibility for how it is used, including social, economic, environmental and work environment aspects.

It is a pity that the notions of change agency or action competence are not so strong in the degree ordinance, however, in order to promote SD, as required by the university law, one can argue that universities may do this most efficiently by preparing their students to "make a difference" for SD.

In 2013, a review was made of all engineering programmes in Sweden by the Swedish Agency for Higher Education. It turned out very positively for the university as a whole with the highest relative number of programmes achieving the highest grade in the whole country, and the five-year chemical engineering programme being one of these successful programmes. With regard to the two bullets in the degree ordinance given above, the first one was deemed to have very high goal fulfillment and the second one only high goal fulfillment. In fact, for the first goal, it was specifically mentioned that: "Courses like "Chemical engineering, environment and society", "Chemical environmental science" and "Products and processes in a sustainable society" are good indicators that the student has the possibility to reach a high goal fulfillment"—these courses are all part of the compulsory course load on E&SD in the programme. For the second goal, it was stated that "compulsory activities that can ensure that the students get a holistic view of SD that includes how economic aspects are interconnected with and in some cases counteract SD are missing" (the full report, in Swedish, is available at: http://www2.uk-ambetet.se/download/kvalitet/bio-kemi-miljo-energiteknik-2012.pdf).

Even with this relatively high goal fulfillment in the evaluation, one cannot claim that the programme's role in preparing the students to actually act towards SD was fully evaluated, although the assessed competences may make up an essential part of that ability. Further, the students in the chemical engineering programme, along with many other students at the university, have been complaining for many years that the compulsory courses are not appropriately considering their preknowledge and their specific specialization, making the courses seem not so relevant to the students and thereby achieving a low grade in student and alumni evaluations. In fact, this issue was addressed, university-wide, by a specific quantitative goal in the annual five-year plan for 2012–2016 with regard to the employability of students: "The average score on the alumni survey concerning how satisfied alumni are with their education as a whole is at least 8 (out of 10), and the average score on the question about their knowledge in the area of E&SD is at least 6.5 (out of 10)".

In an internal review of the engineering programme curricula within the field of chemistry, physics and mathematics at the university, performed in 2011–2012, concern was raised, among other things, over the quality of the courses on E&SD in the chemical engineering programme. At the same time, programme directors were writing self-evaluation reports for their programmes within the review of the Swedish Agency for Higher Education, and this issue was therefore a hot topic also for them. It was decided that a working group would start reviewing the compulsory E&SD courses to suggest how the perceived issues could be addressed. The curriculum review and reform projects that were performed, described below, resulted in, among other things, an outline of a new course.

1.3 The Scope of the Paper

This paper reports on the curriculum development projects performed in 2013 and 2014 aimed at improving the quality of the programme curriculum with regard to the compulsory content of E&SD, which resulted in an outline of a new course: Perspectives on chemical engineering. The paper also reports on the preparations for the new course and some experiences from giving the course for the first time, in particular in relation to change agency for SD.

2 The Curriculum and Course Development Projects

Two different curriculum development projects were performed that provided input to development of the new course. The curriculum development projects contrasted the existing curriculum to syllabi from upper secondary school, to needs expressed by industry, alumni and engineering students, and to state-of-the-art engineering education for SD, and ended up in, among other things, an outline of a new course in the first year. When the curriculum development projects were carried out, it had already been decided that there would be some changes in the programme curricula (chemical engineering and chemical engineering with physics, respectively) in terms of e.g. the size of some courses; see Table 1 for details.

As Table 1 shows, the major differences in the suggested new curriculum are thus the new course in the first year and the apparent disconnection between energy technology and some E&SD content, at least in terms of that it is moved from that course context.

2.1 The Two Curriculum Development Projects

A working group was appointed in November 2012 to review the courses on E&SD at bachelor level in the two five-year programmes chemical engineering and chemical engineering with physics. The stated reason was the lack of quality perceived by students, in that context described as “normative content, overlaps and

Table 1 E&SD courses in the chemical engineering programme curriculum when the reform project started, and suggested new curriculum

Year	Old curriculum	New curriculum
	Course, total size (E&SD content)[a]	Course, total size (E&SD content)[a]
First	Chemistry, 18 (1.5)[b]	Chemistry, 18 (1.5)[b]
First	Chemical engineering, environment and society 4.5 (4.5)	New course, 6 (6)
Second	Energy technology and environment 4.5 (1.5)[b]	Energy technology, 3 (0)[b, c]
Third	Chemical environmental science, 4.5 (4.5)[b]	Chemical environmental science, 4.5 (4.5)[b]
Third	Processes and products from a sustainability perspective, 7.5 (3)	Processes and products from a sustainability perspective, 7.5 (3)

[a]Given as higher education credits (hec) according to the ECTS system; 1.5 hec corresponds to one week of full-time studies
[b]This course is also part of the chemical engineering with physics programme
[c]This course was later moved to the third year to enable a strong connection to the Chemical environmental science course

lack of progression”. The group consisted of four teachers and five students in the programmes and the methods used included a review of descriptions of programme curricula and course syllabi and of earlier evaluations of programmes and courses, and discussions within the group, with industry representatives and with course examiners and programme directors. The report was delivered to the programme directors in May 2013 and it contained, among other things, the following recommendations:

- Ensure that courses build on the students’ preknowledge from earlier levels of education
- Introduce an industrially relevant project in the Chemistry course in the first year
- Continue the project in the new course for the chemical engineering students in the first year
- Revise the new course for the chemical engineering students in the first year thoroughly in comparison to the old course and focus on the professional identity
- It is suggested that the department employs a ‘professor of the practice’ to strengthen the compulsory courses on E&SD

Already in June 2013, a new working group was appointed, consisting of four teachers in the programmes, with the task to suggest purpose and learning outcomes for the E&SD content in the following courses: Chemistry, the new course and Chemical Environmental Science. The group reviewed syllabi from upper secondary school to ensure that the first-year courses would continue from that level and it reviewed recommendations and requirements from local and national degree ordinances. It also looked at all ESD related learning outcomes from compulsory E&SD courses at the university.

A first description of purposes and learning outcomes was sent out to a larger group for feedback and a final version was reported to the programme directors in December 2013. The results cannot be reported in detail here; the learning outcomes for the new course are discussed later. The suggestions differed from former practices primarily in the following ways that are relevant for this paper:

- Some basic tools and concepts such as safety data sheets, life cycle perspective, industrial symbiosis, bio-refineries and risk assessment were more strongly emphasized
- Change management was made explicit in learning outcomes
- Handling ethical dilemmas was made explicit as a learning outcome.

2.2 Course Development Projects

The author of this paper, who had participated in both described curriculum development projects and has been teaching in this field since the 1990s, was appointed to be the examiner of the new course and was given some money to perform a special course development project in 2014 to outline the details of the course according to the suggestions from the curriculum reform project. In discussion with the programme director, the course was given a name and an additional learning outcome that focused on presentation techniques to address also one of the so-called generic and transferrable skills addressed in the programme. More details on the new course are provided later. Special care was put into aligning teaching and learning activities and assessment to the overall goal of developing students' change agency for SD; constructive alignment, see e.g. Biggs and Tang (2011), has been the recommended tool for curriculum design at the university for many years. A matrix showing how learning outcomes mapped to teaching and learning activities and assessment in the course was discussed with teachers that would participate in the new course and also with teachers that would teach in relevant courses that would come before and after the new course in the curriculum to provide feedback for further refinement and to allow for planning of progression in learning within this field throughout the curriculum.

Another project was started in the fall of 2014 and aimed at developing the industrially relevant projects that had been suggested by the first curriculum development project. The new student projects would be performed by groups of students, first in the Chemistry course and then in the new course. This course development project was performed primarily by the examiners in the courses and a newly appointed 'professor of the practice', whose appointment was also recommended by the first curriculum development project. The purpose of this relatively new type of appointment at the university is described in the university's appointment regulations in the following way: "One way of expanding the university's competence in the latter stages of the undergraduate education is to engage people with advanced engineering skills and longstanding professional experience of engineering projects. They may have acquired specialist competence in either the public or private sector". The person that was part-time employed for this purpose was a chemical engineer with a very long experience from different levels in chemical industry. He also had a lot of networking experience, e.g. as a leader for the West-Swedish chemistry cluster, encompassing organizations from university, research institutes, industry and public authorities.

The student projects were developed in collaboration with industry and carried out within the Chemistry course from November 2014 to February 2015. In all, about 60 students were involved in 12 projects focusing on six different tasks in five different large companies in forest, petrochemical and chemical industry. The project in the chemistry course focussed in particular on chemistry and the properties of molecules in everyday products. The new course is given back-to-back with the Chemistry course, and the students continue their projects on new aspects in the new course.

3 The New Course: Perspectives on Chemical Engineering

The new course focuses on introducing chemical engineering and the professional role of the chemical engineer, and on developing change agency for SD. The name, Perspectives on chemical engineering, suggests that the course aims to explore multiple perspectives of chemical engineering. The purpose of the course is described as: "The course introduces chemical engineering and offers different perspectives on chemical engineering in a broader sense, with SD as a starting point. A particular focus is put on identifying needs for change and consequences of and obstacles to achieving such change".

The learning outcomes are expressed in the following way: "after completion of this course, the students should be able to:

1. describe chemical and chemical engineering industry and its specific preconditions and challenges, including social, economic and environmental aspects
2. use mass balances to estimate the size of mass flows
3. describe what is meant by life cycle perspective, biorefineries and industrial symbiosis, including the ideas behind these concepts and the challenges that come with them, including social, economic and environmental aspects
4. describe the challenges involved in changing chemical and chemical engineering industry, including social, economic and environmental aspects
5. describe the challenges involved in changing their own or other people's behaviour
6. perform a simple environmental impact assessment for a change in chemical or chemical engineering industry
7. discuss relevant presentation technology for different contexts".

Teaching and learning activities include lectures, exercises, individual assignments, an individual project and a group project. Assessment of the different learning outcomes is made by means of written texts (individual assignments and project reports), oral presentations (of project results), participation in some activities, and a written examination in the end of the course. In the following, two of the teaching and learning activities that relate strongly to change agency, and thus the part of the purpose described as "identifying needs for change and consequences of and obstacles to achieving such change", and learning outcomes 1, 4 and 5, are described.

The project that involves the same student groups as in the chemistry course, and continues the work in the same industrial setting, but with a different focus, makes up almost half of the course. The focus is on chemical engineering and its industrial and societal context. The students perform a sustainability assessment of a considered sustainability motivated change in industry, e.g. a change from a petrochemical feedstock to a bio-based one in a certain process. This assessment includes making an environmental impact assessment, something that is required by law in Sweden when important changes are considered in industry. The students are asked also to focus on the change process itself and reflect on if the considered change is likely to happen and why or why not. Their learning is assessed by means of a written report and an oral presentation. The idea is for the students to get insight into the sustainability challenges of industry, of efforts to overcome the challenges, and of what efforts are successful and not and why.

In the course, the students are also doing a smaller individual change project in which they identify a change in their daily life that might have a positive impact on sustainability. They then make this change for a week, assess the impact quantitatively in a relevant way, and reflect on the challenges in making the change. They hand in an individual report that describes what they have done before they are all gathered for a seminar. At the seminar, they first briefly present and discuss their findings in small groups, and the most important findings are then presented by each group to the whole class. The idea is for the students to get insight into many different ideas and actual attempts to decrease the sustainability impact of consumption and understand what typical opportunities and challenges there are in achieving this change, and also understand what might bring about large and important positive impacts and what might be less important to change in everyday life.

The new course was given for the first time in late spring 2015.

4 Discussion

This paper is an attempt to explore the idea of change agency for SD in chemical engineering education. The first question one may ask is whether it is a relevant goal that students develop this change agency during their studies. Given the strong focus on change agency in ESD literature in general, as was discussed in the introduction, it seems to be relevant as a goal. Given the important role that engineers and technical companies have in shaping the technical systems, products and services in society and the strong connection to both environmental impacts and human well-being, it seems particularly important that engineers are well-equipped in this sense. Further, it seems unlikely that it would be enough to start developing this competence after the university studies have ended.

Change agency, however, is still an elusive concept. What it means in practice and how we should teach for and assess this competence is not yet well described in literature. This forces the individual teacher to start exploring the concept on his or her own, discussing ideas with peers, trying out ideas and reflecting on and documenting effects, much like the effort described in this paper. Each such effort may take us one step further towards understanding the full implications of this concept and hopefully, over time, this will lay the foundation for more rigorous research studies. Since the concept it still so elusive, the next question that needs to be asked is more difficult to answer: does the new course contribute to developing change agency for SD for the students, and if so, how and why? One way to address this question, is to reflect on whether the aspects of action competence outlined by Almers (2013) are addressed.

The aspects ‘commitment’, and ‘willingness and courage to act’ are not explicitly addressed and definitely not assessed within the course. However, one may argue that the experience of performing the different projects may make the student more prone to doing similar things in the future. In particular, the individual project involves both envisioning and carrying out change. In fact, it could be followed up whether students actually adopt some of the practices they have tested and if they even adopt practices that they were told about by other students. When asked during the final seminar of that project, several students replied that they would continue to do at least some of the tried out activities and a few replied that they would test something that other students had tested.

The aspect ‘knowledge about consequences of and root causes to problems’ is definitely part of the course and is, for example, part of different assessed activities that the students do, both because they select indicators that are relevant for their specific project and also, if possible, assess the consequences. However, it is often difficult to estimate consequences of different actions. In the individual project, 19 students tried out changes related to their diet, e.g. to eat vegetarian food. They all found that it is very difficult to assess the impact of different diets and concluded that consumers need appropriate guidance that is not yet available. For the eight students that made changes to their waste management practices, however, it was fairly easy to conclude that this does not dramatically change their total impact. In calculating impacts, the three students that made changes to their transportation practices discovered important allocation problems, e.g. how much of the impact of one bus ride that should be allocated to one person. In terms of root causes, an interesting reflection that came from some of the 11 students that had tried out a change related to their personal hygiene was that showering has now become a matter of having a relaxing time rather than getting clean.

Further, ‘knowledge about and a capability to develop visions and possible solutions to a problem’ is something that could potentially be more explicitly taught in the course, e.g. if the students got to formulate their own tasks in the group project (a potential solution to a sustainability challenge in chemical industry), and it would be possible to assess to some extent even in the written examination with an essay-type question.

In terms of ‘knowledge about how to influence and change conditions’, the students are specifically asked to address challenges to and difficulties in achieving change, both in the group project and the individual project. Learning outcomes 4 and 5 specifically point this out. In the group project, it became clear to many students that the challenge is often not a technological one but rather about other things, such as making new products attractive and affordable to consumers and finding bio-based feedstocks in large enough amounts.

Finally, to ‘be able to put this knowledge into practice’ is something that the students do practice to some extent in the projects for specific situations, and that can also be partly dealt with in the assessment, even in terms of their ability to translate their experiences to other contexts.

5 Concluding Remarks

It is clear that the students do get the chance to develop some important aspects of change agency in the course but that there are things that can be improved. They do get experiences from a change process but will they get appropriate experience of taking action? Further, how well they develop some of these aspects may be difficult to assess.

The described course is given in the first year and alone makes up only a small fraction of the full chemical engineering programme. Development of change agency is something that must also be addressed on a programme curriculum level and an analysis of the whole programme and discussions with many other teachers is therefore warranted. What could progression in learning towards change agency in chemical engineering education look like? How can different courses address different aspects? These things need to be further explored.

The effort described in this paper is only a first step towards understanding how to better develop change agency among students in chemical engineering. It has raised new questions on what makes up this competence and how it can be taught for and assessed and how it can be dealt with on a programme level. On-going research efforts on e.g. problem-solving (e.g. Lönngren 2014) and systems thinking (e.g. Lönngren and Svanström 2016; Claesson and Svanström 2015) for SD will likely provide useful elements to the understanding of this complex competence.

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Sustainable Development for Engineers Through a Thematic Restructuring of Experiential Learning

Paul M. Winkelman, Jason Penner and Ara Beittoei

Abstract

Complex engineering projects often require interdisciplinary approaches and the ability to understand and navigate professional, cultural, social, and political contexts in order to find sustainable solutions. Piloted in 2011, the Faculty of Applied Science at the University of British Columbia offers APSC 461 and 462, *Global Engineering Leadership*, to better prepare graduates for a broader scope of engineering practice. The courses emphasize four key themes: leadership, ethical community engagement, participatory planning and understanding differences. These four themes provide a strong framework for student learning as they are intended to problematize the technical mindset of traditional engineering practice (e.g., linear and hierarchical thinking; a western, scientific worldview). In APSC 461, drawing on a pedagogy of Community-based Experiential Learning (CBEL), the four themes are explored through a series of talks (guest speakers, instructor), student-led discussions and workshops, and collaboration on a community project proposed by a local organization. Students further engage in the concepts through written reading responses and reflections. The preparation provided by the four themes becomes even more important for those who continue in the international service learning course module of APSC 462. This practicum is hosted by an agro-ecology centre in a rural community in Mexico. Anecdotal evidence suggests these themes support critical reflection and student preparedness to work with community partners. More formalized

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studies are required to properly assess the impact which will, in turn, inform future development of the courses.

Keywords
Sustainability · Engineering education · Community-based experiential learning · Pedagogy · Technical mindset

1 Introduction

The world is becoming increasingly interconnected with growing concerns around complex problems like climate change, inequality, planetary boundaries, and international development (Kates et al. 2001). These challenges often require interdisciplinary approaches and the ability to understand and navigate professional, cultural, social, and political contexts in order to find sustainable solutions (Wiek et al. 2001). The role an engineer can have in such approaches necessitates a response from engineering education to address the non-technical requirements of engineers. Recent research into engineering education calls for preparing engineering students that can be better leaders and ethical practitioners of the future (National Academy 2005). Today's engineers can bring their expertise to a broader range of issues than traditionally considered. They are playing more significant roles in local communities and international communities, health, social and environmental issues (Lima and Oakes 2006). However, engineering education typically focuses on providing graduates with technical knowledge and skills. There has been a disengagement between technical work in engineering courses, and public welfare and social justice issues. However, understanding the impacts of science and engineering on public welfare and social justice issues itself is a core professional skill (Cech 2014). In order to be able to develop students' knowledge, skills, and attitudes such that they are prepared to address these non-technical challenges, new pedagogies need to be employed covering a wider range of topics.

Based on the conviction that engineers are often called upon to take on leadership roles facing the challenges of global sustainability, the Faculty of Applied Science at the University of British Columbia introduced APSC 461 and APSC 462, *Global Engineering Leadership* in 2011. Building on the core value of service in leadership, the course learning objectives explore the roles of the engineer in a wide range of situations, social and cultural contexts, and levels of responsibility. Key concepts in leadership theory are identified and opportunities are presented for students to develop critical thinking. In addition, the courses seek to equip students with many of the graduate attributes as stipulated by the Canadian Engineering Accreditation Board (CEAB 2014) such as communication; professionalism; impact of engineering on society and the environment; ethics and equity; and lifelong learning (Croft et al. 2013). An important goal of the course is to provide students with experiences and education to develop and hone these knowledge and skills while enhancing the service ethic within their professional development. Finally, the courses seek to deepen the students' understanding of the interconnected nature of global challenges and develop within them a passion for leadership through service. These challenges are presented against a backdrop of sustainable development.

APSC 461 (formerly MECH 410E) is an on-campus course structured around guest lectures, tutorial discussions, readings, reflections and community based experiential learning projects. APSC 462 (formerly MECH 410P) is its optional, follow-up practicum where students continue their learning through International Service Learning (ISL) placements (to date, these placement have mostly been in Mexico with one group in Costa Rica).

At the core of APSC 461 are the pedagogical practices of community-based experiential learning (CBEL) (Centre for Community Engaged Learning 2015). Students collaborate on a project proposed by a community organization. To actively support these projects in the classroom, course content is informed by key technical elements of service learning: engagement, reciprocity, integration of project work and classroom learning, and critical reflection. Service learning involves working with and being introspective about what is happening in those moments of being in relationship with another, most often relationships between student and community. In order to further "legitimate" service learning as an academic practice, linkages are made to theoretical/conceptual components (Kronick et al. 2011). APSC 461 course projects include a research component and expand on traditional service learning to include research as service (Goss et al. 2010).

CBEL became the impetus for the thematic restructuring of the course. Anecdotal evidence from both community partners and students made it clear that students could be better prepared to undertake community projects for they had struggled with particular aspects foundational to community engaged projects. To improve student preparation, we generated three CBEL-inspired themes: ethical community engagement, participatory planning and understanding across differences. Together with the central concept of leadership, these became the four key themes of *Global Engineering Leadership*.

If these themes are to disrupt the traditional engineering mindset, we first need some insights into what that mindset might be, how it might be otherwise and what might be gained from other perspectives. To begin the exploration, we explore the engineering concepts of "technical" and "non-technical".

2 The Technical/Non-technical Dichotomy

The technical/non-technical dichotomy is commonly used within engineering. The Canadian Engineering Accreditation Board (2014), for example, states that the engineering program should be "designed to assure …an exposure to non-technical subjects that supplement the technical aspects" (p. 16). "Exposure" suggests that the study of the subject matter is limited, and “supplement” speaks of something not central to engineering itself, but perhaps something that provides a bridge to the non-engineering world.

Engineering is thus divided into two worlds on unequal footings. Faulkner (2000) provides an example of this in her study of software developers. A computer program is generally divided into two parts, the technical and the non-technical. The technical part performs the main function of the program and is known as the “meat”; the non-technical part consists of the user interface and is know as the “fluff”. Faulkner adds that these two are often viewed as being mutually exclusive: if one is “good at” or has a passion for one side of the divide, one cannot be “good at” or have a passion for the other side. As “mutual exclusivity” presupposes a dichotomy, the dichotomy itself merits a closer look. Faulkner (2000) maintains that the very use of dichotomies is a manifestation of technical bias.

Its limitations notwithstanding, the technical/non-technical dichotomy provides fertile ground for course development as it begins in familiar engineering territory. The first task is to deconstruct the traditional dichotomy. Faulkner’s (2000) “meat”/“fluff” distinction speaks of a value system and this will form the basis of the deconstruction. We begin by exploring possible meanings of “technical” as suggested by engineering usage, exposing underlying values. We then compare these values with those of the four proposed course themes with the goal of understanding their theoretical and pedagogical implications.

2.1 “Technical” as Used in Engineering

Technical drawing has been a mainstay of engineering programs for many years. Like many of its analytical cousins, it relies on mathematics for its legitimation: the drawing is done using standard geometric shapes and the standard views (e.g., front, top, isometric) assume a Cartesian coordinate system. As the number of basic shapes and standard views are few in number engineering students are expected to “see” the same object and produce the same drawing of that object. The “technical” therefore demands a high degree of conformity. As these drawings are typically used to manufacture parts, they become a communicative device, and “technical” also carries the sense of the unambiguous with all extraneous information removed (for instance, redundant dimensioning is considered “wrong”). With ambiguity removed, meaning is reconfigured as property and therefore independent of context.

Conformity, as implied by the “technical”, takes many forms within engineering. The “right answer” mindset is perhaps its most obvious manifestation, strongly supported by the mathematical concepts and models which form the backbone for most, if not all, the more traditional engineering courses. Kuhn (1970) offers some insight in this regard as he distinguishes between puzzles and problems. Puzzles are like problems in that there are multiple paths from the starting point to solution, but puzzles differ in that they imply a single, correct solution.

Conformity also takes some more subtle forms. Consider, for instance, the term “practical”. Engineers often think of themselves as those who are concerned with the “practical application” of science and mathematics. Being neither scientists nor mathematicians, engineers must therefore distinguish themselves, at least in part, with respect to the “practical”. But what does it mean to be “practical”?

To be practical, one must presumably have an established practice to draw on. As a practice speaks of repeatability, it must find its application in a reasonably wide spectrum of engineering situations. A practice is valued as it provides a direct path from problem to solution, favouring “linear thinking”.

What allows an engineering solution or approach to be “practical”? Weinberg (2003) notes that “[p]ower creates practicality” (p. 8) and shows how ethical questions can be side-stepped and reconfigured as “practical” in the framework of a dominant political and economic system. Hence, as engineers follow the practical, they tend to uphold the political system and the power it maintains. The widespread use of the term “practical” implies that, like the electricity they learn about in class, engineers are to follow the path of least resistance.

Political structures which maintain power are normally conceived of as being hierarchical. As engineers typically work in hierarchical structures (Nieusma and Blue 2012), engineering students expect this to be part of their future. Their educational program does little to challenge this assumed structure. The engineering program resembles a hierarchy as science and mathematics are presented as being “foundational” to engineering, providing prerequisites for “upper” level courses. Science itself uses hierarchies because, in the words of Herbert Simon, “nature loves hierarchies” (Mirowski 2002, p. 465). Simon has also had direct impacts on engineering through the his ideas of the “ill-structured problem” (Simon 1973) and the “sciences of the artificial” (Simon 1969), promoting hierarchies to facilitate problem-solving.

Conformity can also be maintained through shaming, as can be seen in Faulkner’s (2000) software developers who took great pride in their technical prowess and ridiculed the lack of such prowess in others. Ridicule is a form of shaming. Its power lies in the fact that shaming, unlike guilt, is not based on ethical or moral deficiencies. As such, forgiveness has no meaning and redemption becomes impossible (Visser 2002).

The technical is often presented as that which is not social. Nieusma and Blue (2012), for example, speak of engineering practice which “neatly separates out the ‘technical core’ from the ‘social context’” (p. 53). Faulkner (2000) speaks of the “social versus technical” (p. 759). One of the participants of her study speaks of humans as having emotions and feelings which can, unlike machines, be hurt; it is therefore preferable to work with machines. Machines, the participant reasoned, can be controlled, whereas people cannot be; engineers are taught to concentrate on that which can be controlled. As engineers move into sustainability, this mindset downplays the social in favour of the environmental, as the latter is more controllable.

3 Development of Key Course Themes

Sustainable development sets the backdrop for both course content and project work with local and international community organizations. The four key themes were created to provide partial grounding for the values implicit in sustainable development, serving to focus students' attention on the social, and better prepare them for CBEL. We explore each theme below, and the values they promote, from the perspective of the technical mindset (if possible) and from that of the "non-technical", (sustainable-development oriented) mindset. In so doing, we hope to show how these themes are mutually supportive as they facilitate a shift in thinking. Finally, we discuss the pedagogical implications of this shift.

3.1 Leadership

The hierarchical structures employed in engineering, both within the construction of the students' knowledge and in the institutional structures at their places of study and work, suggest a particular kind of leadership where the leader is at the "top" of a pyramidal structure wielding some kind of power to those below who essentially do the leader's bidding. The "right answer" mentality demands that there be some centralized authority against which the validity of answers can be measured. Authority and knowledge (truth) tend to coalesce. This view of leadership affects how engineers see themselves as both leaders and "subjects" of the leaders.

APSC 461 encourages looking at leadership more from the perspective of "servant-leadership" (Spears 2004). The idea is to deliberately move away from autocratic, hierarchical styles with a much stronger focus on community, caring and personal growth. Spears identifies a number of characteristics of the servant-leader, such as listening, healing and stewardship. Another concept is that of "leading from behind" where leadership is provided but its source is unclear. Adaptive leadership (Heifetz et al. 2009) pays close attention to a changing environment and distinguishes between technical problems (clear solution paths, often leaving underlying issues unresolved) and adaptive challenges (solutions requiring changes in people to achieve a longer lasting resolution).

Pedagogically, adaptive leadership means taking a constructivist approach to teaching and learning, moving away from the "sage on the stage" (King 1993) and troubling the notion of "expert", a problematic mindset in the context of development work (Devereux 2008). Classrooms instead become spaces for dialogue and knowledge construction with instructors as question-posing facilitators of discussions. Learners become subjects in their own learning where attention shifts from what the teacher says, to what learners do, inviting students to take a more active role in their learning (Vella 2002).

3.2 Ethical Community Engagement

The technical mindset deliberately seeks to pre-empt any consideration of ethical issues, appealing largely to mathematical constructs. Mathematics is posited as objective and value-neutral. As the measure of engineering intellect, those working out of mathematical constructs (the "meat") assume that those actively engaged in ethical problems (the "fluff") have inferior mathematical skills (due to mutual exclusivity) and become targets of shame. Organizationally, hierarchies within the work environment allow engineers working at lower levels to pass their ethical responsibilities to the authoritative figure closer to the top.

Ethical engagement, to achieve its full effect, cannot embrace only the technical mindset. Ethical engagement seeks understanding and necessarily suppresses urges to create conformity. Bias is ever present and its presence encourages us to recognize the importance of context and to wrestle with ambiguity. Mathematical constructs are human constructs and describe rather prescribe reality; as non-prescriptive, they cannot be used to constrain society. Indeed, the mathematization of engineering is itself the manifestation of a value. If "ordinary" engineers are to take ethical issues seriously as an integral part of engineering, they must move away from the hierarchical mindset and act according to their own convictions.

Ethical engagement is critical to CBEL pedagogy. Instructors draw heavily on the ethical principles and practices of community-based research in both the planning and delivery of the course. Principles include familiarity and sensitivity to communities, an emphasis on research being community-driven and the community partner's/members' needs taking precedence (Strand et al. 2003; Minkler 2004), and careful consideration given to research protocols and cultural differences (Ball and Janyst 2008).

Ethics and ethical engagement are further framed as a "Reflexive Praxis", which suggests there is no one-size-fits-all, universal set of ethics: "Every decision requires weighing out circumstances, considering who is involved, what the costs and benefits might be, and mobilizing what we believe to be right into the decisions and actions that we take in any given moment" (EIESL Project 2011). Students are continuously challenged to critically examine their own views, assumptions, convictions and actions, and to consider how power, functioning across social identities and creating dominant social systems, plays out in their projects. The new understandings are then brought to bear on the engineering discipline as a whole.

3.3 Participatory Planning

For the technical mindset, the stakeholders typically associated with participatory planning can be readily mapped to a pyramidal hierarchical structure. Engineers, with their specialized education and knowledge, see themselves at or near the top with the majority of the stakeholders closer to the bottom. The structure supports the “meat”/“fluff” dichotomy, placing greater importance on technical issues. Accommodating the needs of a wide range of stakeholders becomes “impractical”; concentrating on the technical assures a direct path from problem to solution.

If the needs and concerns of various stakeholders are to be heard, understood and potentially acted upon, engineers need to temper the self-concept of “expert”. Akin to the “honest broker” (Mitchell et al. 2004), “servant leadership” posits the engineer as a qualified person who can offer sound advice in the service of the communities affected by the proposed engineering project. Concerns may be challenged, but not summarily dismissed. The engineer is sensitive to issues of power and recognizes that participatory planning takes place within a political framework. Consensus is often not possible and trade-offs form a normal part of negotiation.

Within the classroom, students learn about participation by exploring what it means to actively engage and to move away from presumed hierarchical structures such as privileging academic knowledge over community knowledge. The greater pedagogical impact, however, is felt within community projects. As projects are developed from community partner priorities, community organizations fully participate in the project scoping. Students self-select projects based on interest; these projects are then further scoped, planned and carried out in close collaboration with community organizations and community members.

3.4 Understanding Differences

“Understanding differences” to the technical mindset means recognizing the differences so that they might be “fixed”, for the “right answer” obsession equates difference with deficiency. The “right answer” is the one with the best technical performance as this best demonstrates the technical skills of the designer. Those thinking otherwise must be shown the error of their ways; attempts to accommodate difference are dismissed as impractical as they distract one from problem-to-solution path.

In its non-technical form, “understanding differences” insists that there can be no single, right answer, for there are many ways of being, of living in the world. At the same time, the open mind must be tempered with knowledge and conviction to ensure that the engineering solution is not sidelined indefinitely in an effort to accommodate differences which ultimately have little impact. Differences create a break in the mundane and raise the possibility of the new. An attention to difference helps ensure that technology is in the service of people, not people in service of technology. Honest confrontation with difference encourages self-re-examination, a critique of one’s belief systems and a style of leadership that serves those in need.

APSC 461 intentionally forces students to understand and work across difference. It theoretically and pedagogically challenges ways of thinking and learning acquired through technical education. CBEL projects demand that students work across cultural and social differences among diverse communities. Guest speakers, readings and discussions address topics such as social identities, intercultural communication, and colonization and Indigenous issues. Students examine their own assumptions and biases, actively seeking an understanding of how different cultural and social identities, worldviews, disciplines and paradigms lead to different approaches, and different ways of framing projects.

4 Course Restructuring

Restructuring of the course was carried out to better integrate the four key themes. A greater proportion of course material was delivered by the instructor to ensure that the themes were explicitly covered. Guest speakers, however, still remained a crucial part of the course. Reflections, previously written in response to speaker presentations during class times, were reduced in number, and now explicitly link the key themes to the CBEL projects. These reflections are written outside of class, thus freeing time for more in-class discussion. Many of these discussions are student-led, encouraging students to participate and to take an active role in their learning. Qualifying CBEL projects are carefully scoped to provide opportunities for students to encounter the four key themes in a real-life setting.

5 Student Experiences in International Service Learning (ISL): APSC 462

APSC 462 is delivered through an international service learning experience where students build on the key themes introduced in APSC 461. The two-month placements are hosted by an agro-ecology centre in a rural community in southern Mexico. During these placements, students work on engineering-related projects that contribute to the organization’s and surrounding community’s longer term sustainable development goals. Past projects have included the design and building of a grey water filtration system, a solar water heater and the design, redesign and construction of dry composting toilets to address local and regional water resource and sanitation priorities. Students must also complete course assignments which include an extensive journal, three reflection papers (which build on the four themes of APSC 461), and a final paper reflecting on feedback from group members.

As part of an ISL program, APSC 462 students must meet the requirements of ISL in addition to those of the course. UBC’s ISL programs focus on four broad categories of student learning outcomes: awareness of self and relations with others, global issues, change agency and educational impact. In addition, ISL students also pass through three “stages”, participating in pre-departure sessions (which front-load learning themes and prepare students to work with community organizations), in-session workshops (facilitated by a staff member, students reflect on their experiences and draw connections to course and ISL concepts and themes), and a debrief workshop upon their return (where they reflect on the experience as a whole, make meaning of what they learned and how they can take it forward in their academic and personal lives).

The re-development of APSC 461 into the four themes has created greater synergies between the engineering aspects and the ISL components of the course, allowing for better integration of ISL projects and pedagogy. Though developed independently, the four themes of APSC 461 fit well with the four ISL learning outcomes categories. Being introduced within APSC 461, we believe these themes will better enable students to see their place as engineering students within the ISL learning outcome categories.

Anecdotal evidence suggests that these four themes are in the right direction. Although no formal data is available, qualitative interview data from past (i.e., "pre-theme") ISL students support the anecdotal evidence. A five-year study looked at the level at which students demonstrated learning in each of the four ISL learning outcome categories. As the categories and themes were similar, reanalysis of the ISL data from an APSC 461/2 perspective became possible and showed that students had been struggling in APSC 462 with the same or similar concepts as we are now aiming to strengthen in APSC 461.

Understanding and working across difference was the theme most challenging for past students. This presented itself as challenges with cultural differences, practical differences, such as ways of working and construction methods, as well as conceptual differences around concepts such as sustainability. At a higher level there seemed to be less attention to power and privilege and how these operated within their projects, placements and on a broader social level:

> My biggest challenge was getting over the work ethic down there. It was pretty unorganized, the organization we worked with, and so we weren't able to efficiently do the work that we wanted to do. I guess, being there at the start and not really being completely comfortable and not really knowing your coordinator and stuff that well, we didn't really feel like pushing too much to get things done – just kind of sitting back and seeing how things are doing around there but how things are done around there is quite slow so that was the biggest challenge for me (S09, post-experience interview).

A second and related challenge for students was participatory development. This also appeared in strong relation to the students' struggle with understanding and working across difference. There were many challenges to working collaboratively with local stakeholders in planning, designing and implementing projects. One student discusses the collaboration challenges between the student team, organization and a local community member:

> we were actually originally tasked with this retaining wall project by [Person X] and so we - that's very interesting - we kind of started this project at Organization A and we worked out of Organization A at our little makeshift office and we completed all our research there and then eventually established a contact with the construction guy who knew how to build these retaining walls out of tires and we completely disregarded any input from [Person Y] which, I guess - it's interesting why we didn't think of that but also why Organization A hadn't included him in the discussion of the project that was going on his property. (S10, post-experience interview).

Lastly, when students were asked to reflect back on their experiences and how they linked them back to their discipline and course content, all engineering students in the study made clear connections to content and concepts in APSC 461. One student described these courses as “fundamental”:

> the 461 – the pre-req –was –it kind of gave us an idea of a lot of concepts that tried to tie together development and engineering and also, like I said before, the traditional engineering curriculum is technical and it ignores the broader environment which we work in … I think it should be mandatory for all engineers. I think that the themes that are echoed throughout 461 and illustrated in real life in 462 are so fundamental to engineering and how it should be taught (S10, post-experience interview)

Student responses strongly indicate that APSC 461 is providing a conceptual framework for students to carry forward into the ISL experience of APSC 462. As more of the ISL analysis emerges, student experiences in APSC 462 will serve to create a dialectic relationship with APSC 461 facilitating the on-going development of the two courses.

6 Conclusion

Informed by theoretical study and student feedback, we believe that the integration of the four key themes into the courses have better prepared students for work with local and global community partners. Formal studies in the future will allow us to better assess the impact of these themes on student preparedness; current informal feedback from partners suggests that preparedness has indeed improved. This will also help with further development and changes to course structure and content.

APSC 461/462 provides a wonderful opportunity to explore a wide range of themes in an engineering context, thanks to the support of administrative faculty and community-engaged learning staff (both local and international), as well as the offerings of a large university with its diverse student body and wealth of knowledgeable people to draw on. Success also depends on building and shepherding relationships with local and international community partners. Should similar models be replicated elsewhere, course designers would need to consider the time and resources required to support partnerships to ensure mutual understanding of expectations with appropriately scoped projects. Further considerations could include greater alignment with national or regional accreditation requirements.

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