Work in Progress - Development of a framework to Assess Sustainability Knowledge (ASK) in Engineering Undergraduate Students

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Abstract - **Current engineering students will practice in a world of global climate change with reduced resources, in the context of an increasing global population and a desire to achieve social equity. In short, they will work in a world where sustainability is key to engineering practice. However, there is neither consensus on a set of sustainability concepts on which to base an engineering curriculum nor a standardized mechanism for assessing student learning. Engineering educators lack rigorous assessment tools to judge the success of sustainability education. Development of an assessment-oriented knowledge framework can help engineering faculty identify and structure sustainability-related content, develop methods to incorporate these concepts into the curriculum, and assess students' learning of sustainability concepts. This paper discusses preliminary results of a project designed to develop a research-derived model for curricular development on a critical topic for future engineers' education.**

Index Terms – Conceptual framework, Qualitative research, Sustainable engineering curricula, Sustainability.

INTRODUCTION

Sustainability has its roots in the UN's "Brundtland Commission report" [1], which put forward as "sustainable development" the actions that provide for current human needs and standard of living without compromising the ability of future citizens to meet their needs. In engineering terms, this requires the implementation of strategies that explicitly recognize non-infinite resource availability, environmental and ecological system disruption, population growth pressures, energy renewability, and limits of natural systems to incorporate pollutants without long-term negative impacts. This is no small challenge; the needs of sustainable development will require efforts and expertise of all engineers.

One approach to the integration of sustainable engineering (SE) is integrating sustainability with engineering design. In this process, we would expect to see engineers consider sustainability issues throughout their design processes, rather than as an add-on at the end of the process. We have adopted Atman et al's model [2] as a theoretical basis for teaching an engineering design process to novices. The three main (although non-linear) stages of this process are: problem scoping, developing alternative solutions and project realization [3,4]. Our research will map the Assessing Sustainability Knowledge (ASK) framework across this iterative process-oriented model of design to make it more relevant for mainstream engineering courses that incorporate teaching design.

METHODS

The project involves multiple phases, each designed to gather concepts that together form a framework of understanding around engineering sustainability. Each phase begins with concept distillation and weighting, followed by concept synthesis and framework drafting, in an iterative fashion [5]. We draw from three primary sources of data: a literature analysis, a set of interviews with engineering novices, and a workshop discussion with content experts. The outcome of this process will be a sustainability framework that represents both expert knowledge and student misconceptions of SE. The initial literature analysis is nearing completion; the other phases are ongoing through fall 2010.

Much of the data collected through these three stages will be analyzed qualitatively, first combining concepts collected through the literature analysis, student interviews, and initial expert brainstorm into a first framework iteration, then structuring subsequent iterations with the expert participants. This qualitative analysis follows Robson's flexible design framework [6] that is particularly strong at producing theories. Robson argues that, in contrast with more fixed designs, where the reliability and validity of data is more critical and therefore often require "tight pre-specification of the design prior to data collection" (p. 164), flexible designs are "driven" by research questions that must be linked to theory, either developed prior to or through data collection, and which must respond to changing and developing theoretical understandings of the research team. While qualitative analysis does not claim statistical generalizability or the ability to be generalizable over the entire population, it can provide an opportunity to expand and generalize theories, via analytic generalization [7].

The systematic literature analysis is not designed as a traditional literature survey; while it takes as its source of data published works on sustainability (defined broadly) in engineering education, it does not simply seek to categorize and summarize this literature. Instead, our goals were threefold: first, to collect a comprehensive list of skills, topics, concepts, and principles that are included under the umbrella

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of SE; second, to collect identified barriers to the teaching of sustainability in tertiary engineering education; and third (and most importantly) to identify primary dialectic tensions and issues surrounding SE education, including rhetoric used, assumptions made by authors, values implicit in those assumptions, and tensions that exist and must be managed. Throughout the analysis, we sought a diverse assortment of data sources and a discursive analytical approach. [8]

The literature analysis began with the collection of more than 150 peer-reviewed articles and conference proceedings papers on aspects of SE education. The collection was formed through a Web of Science search on appropriate keywords, author searches, reference lists from the papers themselves, and a few special issues published on the topic. To start, two of the authors selected papers for detailed analysis from this pool, based on initial interest and relevance as gleaned from abstracts. We read and met to discuss and analyze five papers per week over a period of two months. Through this process, we developed a basic working knowledge of the concepts represented in these papers, and began to identify and organize common themes. A full presentation of these themes, with examples, to the full research team helped assess a sense of face validity and determine new or different directions or tacks to take. We have followed a continuing systematic approach to the remaining papers, allowing new themes to emerge and refining current themes through discussion among the research team. In this WIP, we offer a revised description of our themes and examples for discussion; the further development of these themes will be incorporated into our expert brainstorm workshop structure.

Planned next steps will investigate student and expert perceptions of sustainability. Through summer 2010, we are conducting semi-structured interviews with approximately 25 undergraduate engineering students to collect a broad spectrum of student perspectives on sustainability, including information on when they first encounter sustainability in their engineering training (in school, in internships or co-op experiences, or elsewhere), their definitions of sustainability and their relevance (if any) to engineering (both their own chosen discipline and others), and the relationship between sustainability and environmental and social issues (if any). We will share our interview protocol as part of this paper's presentation. We are analyzing these interviews both deductively (using the themes identified through the literature analysis) and inductively (to capture new ideas, particularly around students' misconceptions of sustainability). The final step, to be completed by the end of fall 2010, involves a Delphi-inspired [5] workshop for experts in sustainability (including academic experts on design research, sustainable development, and green, ecological or systems engineering and industry experts such as chief sustainability officers or sustainability design team leaders). Comments from the workshop (including small group discussions and large group report-outs), and email conversations surrounding the workshop will be roughly but systematically coded for new concepts, relationships between concepts, and assessment ideas. These will be used to further refine the sustainability framework, and, through an iterative process with expert participants, to create a final revision of a framework of SE by summer 2011.

PRELIMINARY RESULTS

Preliminary results stem mostly from the three main goals of the literature analysis surrounding SE. First, our collection of topics, concepts and skills to be included under the umbrella of SE has yielded 48 items; these primarily came from twelve published collections of principles (for example [9-11]), but were also gathered from implicit and explicit inclusion of topics in all articles analyzed. These topics were categorized into six broad areas: traditional environmental goals, resource protection, design criteria, social/societal goals, business perspectives, and ethics/guiding values. Importantly, the range of items included as part of SE greatly exceeds the set from any one source: no single source included more than a quarter of the 48 items, and published collections of principles included, on average, items from fewer than four of the six broad areas identified above.

Second, as part of the translation of the concepts to educational practice, we have identified a set of 16 barriers: for example, the lack of agreement on the meaning and implications of sustainable engineering [12] leads to the perception that sustainability as a concept is too broad [13], and its interdisciplinary nature [14] requires faculty and administrators to break from their tendency to work within silos of specialist knowledge [13].

Finally, we have identified a set of fourteen issues and tensions inherent in the literature about SE; in particular, we have identified values of SE that may be in tension with either the philosophy or logistics of traditional engineering education. For example, a commonly occurring theme is the idea of the "super-engineer": the student or professional who not only excels in technological knowledge but also in new skills such as leadership, project management and who is aware of the social implications of engineering [15]. The super-engineer understands the ethical and value dimensions of engineering [16], emphasizes holistic systems working from an industrial ecological mindset [17], and avoids using an overly reductionist problem solving approach [18]. Ironically, the super-engineer characteristics may stand in conflict with employability and corporate expectations for an engineering professional [15,19]. Additionally, several authors note that SE may fundamentally represent an ethical question, and may prompt engineers to investigate the value propositions of engineering [12, 15-17]. We will present a broader range of themes at the conference.

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