ENHANCING THE ENGINEERING CURRICULUM THROUGH HOLISTIC ENGINEERING

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Abstract – The idea of a holistic approach to engineering design and education has been envisioned as a means to meet the perceived and emerging needs for innovation in the 21st century. Many engineering educators, practicing engineers and engineering students have already recognized the gaps and areas of potential improvements in the knowledge acquisition process implemented in current engineering degree programs when compared to current societal and technological issues and developments. We have explored opportunities to integrate practical communication and professional engineering experience through topics such as: sustainability, globalization, public policy, innovative design, health and safety, and ethical implications of emerging technologies into the current engineering curriculum. To achieve this, an experimental course was designed focusing on the aforementioned topics. Using real-life case studies to combine these themes, the course allows for group problem-solving exercises that would enhance the collaborative experience for students, and increase the appreciation for the profession of engineering. The results of the effectiveness of the holistic approach and case-based learning are discussed and respective recommendations are being made upon the findings. This paper also provides insight as to how educators can incorporate these themes into the pre-existing classes at university or into a stand alone course.

Keywords: holistic engineering, global engineering, public policy, sustainability, globalization, ethics

1. INTRODUCTION

Society and humanity have progressed drastically over the past few generations. Countries, regions and people have all become more interconnected and are a part of not only their own communities, but also communities that have developed and reach across the entire planet.

Engineers as a network of professional problem solvers have been heavily involved in these global communities and the engineering profession is evolving from one that focuses on targeted, isolated issues, to one that embraces challenges that incorporate physical, economic, environmental and humanitarian aspects [1]. This evolution was the motivation for this paper.

Engineering educators loudly communicate that engineering is about considering all facets of a problem and coming up with the most contextually appropriate solution. Unfortunately, “all facets” are not evenly implemented in the current engineering curricula which should be not only concerned with the technical aspect of the problem, but equally so with the complexities of the financial, social and time constraints and implications. However, within the undergraduate experience, students can involve themselves with activities outside of the classroom to “round out” their education. By being heavily involved in extra-curricular activities such as Engineers Without Borders Canada (EWB), their respective Engineering Society, the Engineering Student Societies’ Council of Ontario (ESSCO) and the Canadian Federation of Engineering Students (CFES), students are able to hear from industry representatives, engineering organization representatives, and their peers about the opportunities within the field of engineering to address complex and widespread issues. This presents engineering as a profession that is exciting and universally valuable, something that the current engineering curriculum does not necessarily present explicitly.

This paper is an extension of an undergraduate capstone design project that was constructed to research and make recommendations on the perceived gaps in or possible extensions of current undergraduate degree programs. The current foundation of programs provides a very adequate technical base, but also leaves room for improvement in global or holistic applications [1]. The intention is to create a learning environment that informs and inspires students, to help them understand where they

fit into the larger system of the world, even if their future careers are very specific and technical in nature.

2. BACKGROUND

Across Canada, engineering programs have been strategically adapting to the recent shift to “outcome-based” means of assessment for accreditation. These outcomes include the traditional application of engineering skills and design skills, but also address communication, teamwork, ethics, contemporary issues and the impact of engineering from a global societal context [2]. In this new century, where the threat of global warming has emerged, space travel is more feasible and information sharing and communication happens instantaneously, engineers must now make that leap towards being leaders, entrepreneurs and advocates, combining technical knowledge with the ability to communicate with the various stakeholders in an effective and ethical manner.

Currently, there is a slow propagating thought about a shift towards holistic thinking within engineering education. The term ‘Holistic’ is defined as “... relating to or concerned with wholes or with complete systems rather than with the analysis of, treatment of, or dissection into part” [3]. In the engineering context, the term describes “engineers who manage, lead, and understand complex, interdisciplinary systems that bring the power of engineering thought to issues spanning and connecting technology, law, public policy, sustainability, the arts, government, and industry” [4]. Engineering educators across the globe are beginning to discuss the future needs of humanity and how engineers can effectively serve these needs. In the current information age, engineering is still taught at many schools in a manner of the past industrial age, and there is little focus on discussing the place of engineers within the global community as well the importance of appreciating this relationship with society [1].

From a student perspective, there is an increasing awareness that a new way of thinking is needed to solve the increasingly complex problems of the twenty first century. Currently, engineering students are required to take classes on ethics, liberal studies and technology and society courses [2], however engineering students are not prefaced with the importance of rounding out their education with these topics, and while social issues are discussed, they are not related to engineering specifically. That being said, explicitly linking the technical aspects of engineering to society is paramount in training effective problem solvers for the 21st century [5]. With some exposure to multi-disciplinary, inter-disciplinary and trans-disciplinary approaches to engineering and design, students will be better prepared for their future careers in industry or research fields.

3. PROBLEM DEFINITION

Regrettably, engineering education has not evolved at the same rate as the global society, and undergraduate engineering students are not necessarily receiving the skillset to be global, holistic problem solvers upon graduation [6]. If educators are not graduating this calibre of students, then they are not meeting the needs of industry, and more importantly, society. The current education system is lacking interdisciplinary problem solving - both amongst different technical streams and different faculties - and while there is recognition of these needs [1], they must be addressed using methods that encourage feedback and are less rigid to respect the rate of change at which technology and society evolves.

4. METHODOLOGY BRAINSTORMING

To address the identified issue, several conceptual approaches aiming towards probable solutions were developed. The first was to simply gather content that conveyed the desired message and to present it in a traditional lecture style, with assignments and projects to apply concepts learned in class. The second was to develop stand-alone learning modules that could be given to students to read or watch on their own depending on the medium. These modules would include interactive quizzes or games to track learning and reinforce concepts learned. The third was to add a creative element to the classroom delivery and present the class as a co-op term in a mock consulting company. Students would be ‘employees’ of the company and as a class they would have to solve real-life problems brought in by ‘clients’ based on the knowledge gained from the lecture material. The final idea was to develop an intensive week-long course that would be optional for students to take as a conference style event offered during a semester break, or between semesters. This course could be offered regionally rather than at every institution to promote networking of students between schools.

5. IMPLEMENTATION

Before narrowing down the possible solutions to the holistic engineering challenge, a few constraints were necessary to provide engineering faculties with a framework that allows professors to teach students the importance of thinking holistically about engineering work in today's society. These include:

- students should be able to define what an engineer does and what it means to be an engineer in society;
- students should have an understanding of public policy and be aware of how engineers can get involved in the policy process;

- students should be aware of why sustainability in design and manufacturing are important and be able to apply the concepts of life cycle engineering, and
- students should have an understanding of globalization and its effect on engineering, and how what engineering is performed in Canada is affecting the rest of the world.

The functional requirements for the perceived solution were determined by the expected outcomes and what students should take away after experiencing the new educational product. It is our belief that these include:

- students will be inspired and driven to seek opportunities in engineering for environmental, social, medical and human development/poverty issues;
- students will be able to identify the issues that are emerging from new technology, how to mitigate the negative aspects and reduce the amount of impact, while leveraging the positive outcomes, and
- students will have respect and knowledge of the importance of ethics and policy matters in the field of engineering and be able to determine between unethical and an ethical situation in a proactive manner.

Based on the assumed constraints and the desired outcomes, the methodology design concept selected was that of setting up the class as a mock consulting company. Success in the course would be based on participation and results of proposed client solutions along with performance review. Employing this format not only provides a portal to demonstrate the importance of holistic engineering through realistic client cases, but also allows for the development of professional skills students may not encounter during their educations if they are unable to participate in a co-op or internship. Framing the course around a business environment allows for tutorials to be transformed into boardroom style meetings, teaching the students formal communication skills and experience with agendas, minutes, motion-writing, presenting proposals, and design reviews or updates.

6. RESULTS AND DISCUSSION

Without the opportunity to develop a full course for trial purposes, opportunities to gather feedback from educators, industry members and current students were extensively used to refine the idea before piloting. After this consultation and research into the newer programs being offered at the top forward oriented engineering schools in Canada and the United States, six main topics emerged as potential modules for the course: Engineering and Public Policy [7]; Globalization [8,9]; Sustainability

[9]; Health and Safety Standards [2]; Innovative Design [10]; and the Implications of Emergent Engineering fields [9].

Experimental trial runs of specific lecturing topics were presented during class-time and during extra-curricular events. During this prototype validation phase it was beneficial to take audience feedback and observations from a qualitative standpoint. Having been such a change of pace for students, we expected there to be a lot more questions than answers coming out of the pilot sessions, and understood the importance of being flexible with our content after testing. The experimental results revealed that building a demand for material such as this would be a slow process and may even take cultural change within the average student before it truly gains steam. Because of this, it is of utmost importance to cater to some of the needs of those who are the most hesitant when exposed to the idea of holistic engineering.

By design, and also due to the topic matter, the presentations themselves were very open to input from the audience. Modules were presented to third and final year engineering students, which guaranteed representation from all engineering programs offered at UOIT, as well as feature the most experienced students from an academic and possibly industry perspective. In addition, by using this method as opposed to a call for an audience, we avoided self-selection, to not only hear from enthusiastic students, but also see if there was any negative reaction to the topics of discussion. Most interesting of all would be to discover whether the overall level of engagement for the content was increased over the more technical engineering courses. This was evident in the number of students that understood the role, or lack thereof, in the engineering profession with regards to the public policy making process, as well as government interaction in general.

The most impactful sections of the module had to have been the case study sections. Each was chosen due to their engineering relevance, ongoing status as a news item and the multidimensional aspect, all of which welcomes great debate. At first, this was not a welcome aspect to the presentations as the students did not know much about the issues at hand in the first place. As the case studies unfolded, many got a grasp of the basics and provided their input on the topic, however many were not engaged due to a perceived lack of a stake in the issue. Even while not being directly involved, either from a labor standpoint or a customer standpoint, engineers need to be familiar with the unfolding of certain events and the implications for future reference. In addition, it seemed as if students were not aware of the level of general public awareness of engineering and/or the perception of the engineering profession. There was a sense of assumed authority for engineers in the general public, which has been proven false in too many realistic situations.

Many of the topics can be approached from an engineering ethics point of view, which was met with a lack of enthusiasm, even when the referring to the Iron Ring and obligation, which could point to the lack of emphasis on engineering ethics before the final year of studies. When emphasis was made on using sociological and cultural analysis, students did not understand the value of approaching design in this manner, even when presented with case studies. One conclusion that could be gathered was that a more effective means of getting the point across needed to be found, possibly by using more relatable scenarios and by adding collaborations with the Humanities faculty. The more a student understands the impact that engineering can have on human wellbeing, the more they will be encouraged to think holistically when designing. Whether the impact engineering work is economic, socioeconomic or cultural, the feedback loop for some technologies is slow moving and students may not see the connections in the current curriculum.

As a specific example, a presentation was given to a small group of engineering students from a wide variety of disciplines and years of study, which gave a general introduction to holistic engineering, and required the group to partake in a hands-on activity, mapping out all connections to the word 'energy'. At the end of the activity, a question was asked based on the results of the mapping. In this case it was asked, "Why does the engineer developing a new coal extraction process care where he fits in this system?" The group came up with answers such as, "They should care because mining is connected to the environment" or "They should care because everything in our map is connected to the government, and they have a lot of power over the system".

Feedback was gathered from the participants of this session and they expressed that the themes discussed in the presentation contributed to their degrees by giving a context to the technical knowledge they acquire. The fast majority of respondents indicated they would like to see similar concepts included in their classes, but that they felt the current curriculum does prepare them for working as an engineer. Other major feedback included the demand for case studies and applied learning in classrooms, and simply showing where the material is applied will foster interest in many classes.

The case studies included in the learning modules prepared aimed at providing relevant applications of the themes discussed. They included:

- *Finding the Sweet Spot of Sustainability in the Energy Sector: A Systems Approach to Managing the Canadian Oil Sands* - Sustainability Module - This case study provides a recent account of the current Alberta Oil Sands situation. It argues that a systems approach must be taken to determine the future of the project and provides insight as to where negotiations are

now between stakeholders and questions what might be done to move those negotiations forward [11].

- *Brooklyn Bridge Documentary* – Extreme Engineering Module – A PBS produced Ken Burns documentary about the construction of the Brooklyn Bridge. It is a very clear-cut example of how emerging technologies, although very well thought out on paper, can prove to have unforeseen consequences [12].
- *Copenhagen Play* – Emerging Technologies Module – A very different and creative take on case studies, the play "Copenhagen", by Michael Frayn, suggests what may have been discussed during a 10 minute talk between Niels Bohr and Werner Heisenberg in 1941, which gives a powerful insight into the ethical and societal issues surrounding technological developments [4].
- *Dubai Towers* – Emerging Technologies Module – A current day engineering phenomena, the Burj Khalifa is the world's tallest free-standing structure. The Nakheel Tower is a proposed tower that would be 1km tall. While information on the project is slightly more difficult to come by, these two projects provide an opportunity to discuss the potential issues with extreme engineering projects with regards to safety during construction and operation and if they outweigh the potential benefits of building "up" instead of "out" [13,14].
- *One Laptop Per Child* – Globalization Module – An example of a well-intentioned attempt at providing education to the world's poor that suffered from the lack of sociological research, input from educational experts and follow-up after the initial release [15,16].
- *Eglinton-Scarborough Crosstown LRT* – Engineering and Public Policy Module – A case study on the debate and related political manoeuvring involved with the project and its implications. The history of the project and less than guaranteed future is a good look at the relationship between engineers and policy makers, as well as an exercise in evidence-based debate [17-19].
- *Design Driven Innovation* – Innovative Design Module – Case studies on paradigm shifting consumer products that were conceived by holistic means, using research and teams consisting of many different academic and practical backgrounds [10].

It should be noted however, that not all students are welcome to this model, or the topics that are covered. Careful preparations must be made to preface the learning

experience and topics covered, something that on a curriculum sized scale might be better served with the strategic placement of guest lectures and industry site visits early on in a program map to give more credence to the ideas being proposed in later years. The topics presented can also be considered controversial, especially if the lectures or case studies profile ongoing events. The presenter must remain as objective as possible, and at the same time encourage debate and discussion amongst the students.

7. CONCLUSION

The research and testing completed indicates that while the current engineering education system provides a comprehensive technical knowledge base, improvements could be made with the inclusion of holistic engineering ideals in existing classes or as a dedicated topic. To adequately prepare students for the globalized industrial world, simple adjustments can be made to current curriculum that does not require large time or financial investments. Altering the delivery method of this topic from traditional lecture style also offers an opportunity to engage students and promote professionalism and communication skills not necessarily supported by the traditional teaching model. Case based learning is important, especially with regards to the topics that are proposed, which themselves of interest to educators, industry and more importantly students.

The open dialogue between the engineering faculties and students, along with “Global Engineering” programs from organizations such as Engineers Without Borders, and regional engineering societies, shows that there is a shift towards a new way of thinking. This can lead to new educational innovations that can be built from the ground up by students and proposed as viable alternatives to faculty developed programs. Curriculum design from this perspective is valuable in outcome-based accreditation as it is not only about the quality of the students upon graduation that matters, but the overall satisfaction that students and graduates have when they compare their undergraduate experience to their experience in industry. Through the collective innovation of the engineering education sector, private and public sectors, engineering societies, as well as students themselves, a difference can be made to produce the well-rounded, life-long learners that engineers must become in order to serve the world.

From an educator’s viewpoint, this shift is not only an incentive to update the current curriculum with new content, but to develop new means of delivery, taking advantage of the latest in technology and ensuring that programs can become more adaptable to students’ needs in the future. From the student viewpoint, these initiatives are a welcome change, however more input from students and recent graduates should be encouraged and ultimately implemented, as they directly experience the strengths

and pitfalls of the current education system, as well as the needs of engineering employers.

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