Rethinking Problem Solving in Environmental Engineering

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Abstract

UNLESS someone like you cares a whole awful lot, nothing is going to get better. It's not.
~ Dr. Seuss (The Lorax, 1971)

Problem solving approaches and styles used by engineers for environmental challenges are changing in response to changing expectations from society, government, and industry. There is increasing emphasis on the concepts of and quantification of sustainability, cumulative effects assessment, proxy environmental baseline development, and risk assessment and mitigation for engineering projects in which complex and extensive environmental impacts are known or expected. This is particularly true for the Canadian province of Saskatchewan (SK) where a resource sector boom is underway.

There is unprecedented growth and change in the resource sector, focusing on potash and oil-gas reserves. Although the province is water-rich, the regions in which new and expanded mining operations are planned are located in areas where access to surface water is limited, despite being in a water-rich century from a historical perspective. Climate change pressures that are anticipated to result in drier overall conditions coupled with less frequent, but more intense precipitation events, combined with the significant new demands on water resource allocation for the mining sector, while meeting the needs of a growing population and very large agriculture sector make for a complex set of challenges requiring a more holistic approach from the engineering community.

How we prepare new engineers for these new realities, both at home and globally, requires more focus on lateral problem solving skills and enhanced understanding of required inputs for improved decision making in the context of sustainability.

1 Introduction

Problem solving skills are the hallmark of any engineer, regardless of discipline or practice. More often, teaching and learning models are now pointing to the value of case studies and service learning projects to build context, relevance and experiential learning opportunities into curriculum. These serve numerous benefits including student recruitment and retention in post-secondary education (PSE), but also in the constructing and honing of problem solving skills.

Problem-based learning in engineering is considered to be one of the most difficult, but most rewarding, teaching and learning methods to engage students on current issues, demonstrate application of knowledge and skills introduced in the course content, and introduce students to connections and interactions with previous course work. Although problem-based learning is well-known and accepted in engineering, the introduction of clients may be less so. However, there are significant value-added components to inclusion of clients, cases, and service-learning opportunities in the classroom to enhance learning for project management, professional communications, and team work. It also brings to students a sense of urgency and pride related to developing and achieving a real-world solution. Buchal & Lu (2012) in their application of Singh *et al.*'s (2007) integrated model

note that collaborative knowledge building provides exceptional opportunities for engineering design education, particularly in the problem-based learning classroom (de Eyto *et al.*, 2008). In engineering education, the articulation of research in words is an essential component. However, engineering education cannot stop there. It must include a mixture of design elements, figures, charts and statistics, safety data and models, outcomes and impacts (Buchal & Lu, 2012).

The National Survey of Student Engagement in the USA notes that Canadian universities (focusing on those in Ontario primarily) are falling behind in two key categories of first-year student recruitment, retention and satisfaction (NSSE, 2012). These are (1) active and collaborative learning and (2) student-faculty interactions. A shift to valuing students more as learners than vessels to be filled with information and recognition that female learners are increasing proportionally across Canada can be well served through a variety of teaching methods that include problem solving approaches in the classroom and beyond.

Financial pressures on PSE institutions to recruit and retain students in an economic climate such as that currently existing in Saskatchewan, Canada lend themselves well to problem based learning with focus on service learning and community experiential opportunities. Indeed these pressures on higher education, such as changing demographics, competition for youth, increase in degree-granting colleges, and changing expectations and opportunities in workplace and workforce can result in more innovative and active teaching and learning scenarios as PSE institutions work to maintain relevance and to retain those students enrolled.

In Saskatchewan (SK), the oil and resource sectors have prospered greatly in the past 5 years, bucking the trends of global financial crises. The province is one of few (alongside oilsands heavyweight, Alberta) to be experiencing increases in GDP, investment, and job creation. More traditionally an agrarian-centric society, changes and growth primarily in sectors related to oil-gas extraction and mining for potash (agricultural fertilizer) and uranium are creating job opportunities to skilled engineers and tradespeople. The changes in demographics are also resulting in spinoff jobs in related fields and in those required to support in-migration from both within Canada and abroad (Elliott, 2012).

Significant and competing demands for water resources and pressures creating by a changing climate all create interesting and complex decision-making and problem-solving cases, scenarios and learning opportunities for faculty and learners alike. Application of business-model case study teaching, development of service learning programs, and design of client-based student consulting projects can all support recruitment and retention of students as well as collaboration and engagement with industry.

2 Teaching and Learning Models

In developing client-based and service-learning projects in the Environmental Systems Engineering program at the University of Regina, project templates were modified from the business model and implemented in two senior engineering courses. Here students were engaged in either on-campus service projects or a client-derived problem solving and recommendations exercise. The results from these experiences were used to modify teaching and learning approaches as well as the project design and templates themselves. All modifications and revisions to documentation processes and intended outcomes were implemented to better engage and demonstrate engineering approaches to problem solving and perspectives in the final products. Only minor revisions were made to the client-based learning model in business for group task reporting and documentation; more significant edits were required to guide rubric development and outline student learning objectives.

The courses for implementation were chosen as vehicles for evaluating the problem-based learning method via both client-derived case work and service-learning projects for achieving several benefits and outcomes including: 1) project management and team work, 2) professional communications and network development, 3) problem analysis through application of skills and knowledge learned to date, and 4) applied research on the impact of engineering decisions on society and environment. Together, these guide students to learn more about how their decisions and approach to analysis can affect society and environment and to allow students to demonstrate their body of knowledge and abilities in a team atmosphere (Buchal & Lu, 2012; de Eyto *et al.*, 2008). As a side benefit, this approach to teaching provides a more active learning environment that was meant to address comments from previous offerings of the course in which students did not clearly understand the importance and application of the course material.

3 Client and Student Outcomes

Project Selection: Project identification was completed with the goals of promoting sustainable infrastructure development, increasing networking opportunities for students, and promoting service. Using the client-based approach, a competitive environment was established in which all student groups worked on the same project throughout the semester in an attempt to provide to the clients a wide variety of possible solutions and recommendations for optimal design and decision-making. Under the service-learning approach, a large list of possible projects from 2 or 3 clients was assembled, with only one student group permitted to work on any one project. In this case, clients were provided with single-source outcomes to a diverse set of defined problems.

Client Expectations and Requirements: This teaching and learning model depends heavily on development and maintenance of the client relationship. Deviations from the carefully set expectations of the client-student relationship can quickly erode students' confidence and understanding of the desired product and outcomes. Students are encouraged to interact with clients throughout the semester, gathering data and information, making connections and digging more deeply into the source and importance of the project.

Student Expectations and Requirements: Through these learning models, direct application of theories and methods from class to project development, design, and approach is achieved. Within this, there is a need to ensure that instruction does not focus solely on the problem-based learning assignment but continues to deliver to full range of curricular requirements. This approach tends to build stronger teamwork elements and allows for the instructor to mentor students through the process more effectively and in a more focused manner.

There are several project deliverables throughout the term that students are required to produce either a project proposal or project scoping memorandum, progress reports and project management documents, research methods plans, draft reports, client presentations and final reports. Students investigate, analyze, and design a solution to the real life opportunity or problem presented by the client using the tools of their profession. To maintain student engagement, it is important to clearly identify how material being taught in class relates to the project on a regular basis.

Students are divided into groups and provided with advice on team dynamics, cultural differences, and how to work efficiently and communicate effectively as a group. Teams are required to hold regular meetings and take minutes at those meetings documenting, at a minimum, major decisions made, tasks assigned and their corresponding due dates. As would be typical in consultancy billing, individual students are required to keep record of their own activities including tasks completed, when they were

carried out, and how long was spent on each. These documents are used in assigning individual student grades, meaning that all group members are responsible for ensuring that work is distributed equitably, completed satisfactorily and submitted on time. Students are evaluated on and rewarded for individual contributions to the final project, minimizing the opportunity to rely on others' hard work and diligence to earn a high mark.

Depending on project style and data requirements, research ethics approvals are often required to ensure that information collected from people via interviews and surveys meet the ethical and legal requirements for managing data and personal information.

4 Client-Based Projects Results

The inaugural client-based project competition involved both a municipal government client as well as their external business consultant. The intent of the initial meeting with the students was to provide sufficient background information as to excite the students about the potential impact their work might have and to discuss the most relevant, salient points for consideration in the students' group work. Further, it had been intended that a consultative scoping process would be completed between the clients and students to ensure that the major deliverables were well defined. Here, the scoping process was intended to demonstrate to students the importance of taking time prior to developing research and design concepts.

With a small class of 15 students registered in their 2nd year of study (due to lack of proper prerequisites allowing early registration for the 4th year course), this inaugural client-based project competition was conducted. Because of the inexperience of the student relative to the original design of the teaching and learning model and project itself, some outcomes were not completed with the same level of expertise, academic rigour, or project management and communications experience as had been anticipated.

Regardless of the students' academic preparedness for taking on the client-based project in this course, all students engaged in the required research and contributed significantly to the production of final group presentations and reports. Two "camps" of student engagement emerged as the semester progressed: (1) students who appeared to be both proud and excited about the prospects of working for a client and (2) students who appeared to be overwhelmed and nervous about working on a real-world problem with potential impact outside the classroom. These differences are likely due to the course being populated by students who were out of sequence in their engineering coursework, taking this course a full 2 years prior to the intended progression.

Client Outcomes: For various reasons, focusing around the revelation that the student population was less well-prepared than originally anticipated, the client became more involved in the process than was discussed in the client expectations and requirements section. That is, the client asked for and was granted access to the draft reports, which is normally not advised since these are not always good representations of the final student products. As anticipated, the draft reports did not adequately reflect the client's desired outcomes leading the client to become concerned that the students would not be able to deliver a worthwhile final product. Several valid reasons, as discussed, can explain why the draft reports did not meet the client's needs and also can demonstrate the value of the process which includes submission of draft reports and the completion of double-blind peer reviews. However, since the client did not fully understand the pedagogical process and the value of the path correction opportunity at this point in the process, concerns were raised and communicated to students such that some students began to lose confidence in their abilities.

In future, client feedback and interaction at the draft report stage will not be permitted. To permit clients to preview research reports prior to the submission deadline can undermine both the teaching approach and student learning benefits, including confidence.

A single, compiled report was submitted to the client at the completion of the project, identifying and delivering the key aspects of the requested environmental assessment.

Student Outcomes: Students were surveyed at the completion of the course to identify areas of satisfaction and need for improvement. The survey included 30 Likert-scale statements on a 5-point scale and 4 open-ended questions where students were asked to comment on their experience throughout the client-based design project.

The results of the Likert-scale survey statements, where 1 indicates little to no agreement and 5 indicated high agreement, the students indicated that overall they enjoyed the project (4.15 ± 0.68) and garnered significant satisfaction from working on a real-world problem with potential useful impacts and implementation by a local municipality (4.64 ± 0.49). Further, the general consensus amongst the students was that they preferred the client-based model rather than working on a project defined by the course professor (3.86 ± 0.70); they further agreed that they prefer client-derived projects that may have real-world impact (4.13 ± 0.77). The students also indicated their agreement that having an assigned project was more meaningful to their learning at this stage in their academic careers than in having each group self-define their term project work (4.23 ± 0.59). The students agreed that the project supported their learning of the course content (4.04 ± 0.83), and that there was a direct link between the curriculum and the project tasks (3.82 ± 0.64).

Everyone agreed that keeping notes, meeting minutes, task lists, and timesheets supported their learning and reduced group conflict (3.69 ± 0.86). In their assessment of the value of the peer review assessment to both their own learning and the strengthening of their own group report, all students agreed that this process was informative and valuable to their learning (4.01 ± 0.70). From an instructional perspective, it was evident that the students enjoyed and put significant effort into providing detailed and thoughtful peer-review responses and feedback to their colleagues.

Future Directions: To continue to ensure that engineering principles are met and that outcomes based assessments are not only readily possible, but also underpinned throughout the learning process, continuing revisions of the grading templates, report and presentation guidelines, and client identification will occur. The intended project learning outcomes will be amended to include more evidence of project management particularly as associated with the addition of tendering process at the start of the client-based project. Further revisions will be made to optimize pedagogical outcomes (enhance learning) and minimize conflict. The addition of a formalized scoping activity and consultative process is intended to more clearly articulate desired engineering outcomes and student learning objectives, and also to more effectively engage clients with respect to anticipated deliverables.

Some students indicated a desire for more than 2 weeks' time to make adjustments and engage in further research between receiving their peer review results and the due date of the final report. The current design of the double-blind peer review process allows for 2 weeks for students to complete their reviews and another 2 weeks for groups to address and incorporate the suggested changes to the reports. Thus, the report drafts are due 4 weeks prior to the conclusion of the teaching semester. The timing of the double-blind peer review process must be balanced to ensure sufficient time for students to augment data collection and report writing following the peer review, but also allow sufficient time for course instruction and delivery of relevant lecture materials for application in the final project report.

5 Service-Learning Projects Approach

The inaugural service-learning projects were conducted in service of the University of Regina campus, focusing on Facilities Management (the department responsible for construction and maintenance of buildings and campus operations) and Health, Safety and Environment department (responsible for safety training, occupational health and safety licencing and reporting, and environmental sustainability). Projects were identified through consultation with engineers and scientists in both departments culminating in a list of 25 possible on-campus service-learning options.

Members of the client groups were not invited to engage formally in class until the completion of projects at which time students presented their findings in professional presentations. However, clients were informally engaged throughout as sources of data and other information, providers of tours and networking, and supporters of identifying off-campus and regulatory connections in support of project completion. Students were solely responsible for setting the scope of their projects following personal communication with client groups and stakeholders. As previously, the scoping process was intended to support learning by demonstrating the importance of setting early goals and limitations to adequately define intended project outcomes and impacts.

In the service-learning projects, a competitive environment was not established. Rather, all student groups (19 in total) conducted research and formulated responses and recommendations for 19 unique projects.

Client Outcomes: Lessons learned in the client-based project competition were applied for the service-learning projects in that client feedback and interaction at the draft report stage was not permitted. As noted, only informal interactions between clients and learners were included in the service-learning model, thus limiting expectations but also placing more emphasis on information provided by the clients in the final analyses.

Clients' satisfaction was very high in response to this approach with several new ideas submitted for subsequent courses and new on-campus clients requesting to be involved in future. Client feedback included statements such as, "I was really impressed with the level of student research and creativity demonstrated in their final report and presentation" and "The student presentations were exceptional". So pleased were the clients that word quickly spread across campus and into engineering professional and industry associations who have expressed interest in supporting future endeavours.

All final reports were submitted to the clients and also posted at the University of Regina Archer Library searchable database for public access and review.

Student Outcomes: Students were surveyed at the completion of the course using a survey similar to that delivered in the client-based project competition analysis in that it included 30 Likert-scale statements on a 5-point scale and 4 open-ended questions where students were asked to comment on their experience throughout the project.

The results of the Likert-scale survey statements are based on the responses of 40 students ($n = 40$), where 1 indicates little to no agreement and 5 indicated high agreement, the students indicated that overall they enjoyed the project (4.05 ± 0.85) and garnered significant satisfaction from working on a real-world problem relevant to their university campus (4.70 ± 0.45). Further, the general consensus amongst the students was that they preferred choosing a project from a defined list rather than defining their own project (4.4 ± 0.75); they further agreed that they prefer providing a service likely to have impact within their campus (4.01 ± 1.05). Feedback also indicated that the students agreed that the project was well-linked to course content (4.05 ± 0.87). However, learners indicated a need for

improved definition of project goals by the instructor. A result of 3.59 ± 1.05 for this category is within the scope of neither agreeing nor disagreeing that sufficient guidance was provided.

The minority of students indicated that they had experienced undue hardship finding time outside of lecture hours to meet and plan their project activities and task lists (2.55 ± 0.43). General agreement was noted regarding the tasks associated with project management and consultancy, such as taking and maintaining notes, meeting minutes, task lists, and timesheets amongst the groups (4.07 ± 0.88). However, some students did comment in their response that they only completed the internal group reporting documents for submission to the instructor, not during the course of the project work itself.

Questions specifically evaluating the value and appreciation for conducting "service" projects for the University of Regina demonstrate that students highly value the sense of accomplishment and service to their community (4.62 ± 0.48). Learners also highly value the opportunity to practice their presentation skills (4.42 ± 0.68) and understand that this practice is essential for demonstration their hard work to the instructor and clients alike (4.16 ± 0.81). Finally, the students clearly indicate that they value the opportunity to interact with clients as part of the learning process in becoming a professional engineer (4.56 ± 0.48).

6 Process Overview: From Problem to Results

For illustrative purposes, an example of the process from project identification, selection, research, data analysis and presentation of results is provided.

Prior to the start of class, the instructor formed teams of 3 students comprising a mixture of international and domestic students, engineering disciplines, and genders. In the first lecture of the year, students met their teammates and, as a class, reviewed the project expectations and list of potential projects as defined through consultation between the instructor and clients. Teams were encouraged to choose projects immediately so as to avoid disappointment in having their first choice allocated to another team.

Following project selection and team assembly, a moderator joined the class to support team development through the forming-storming-norming-performing process and in building self-awareness amongst students as to their strengths and weaknesses related to teamwork expectations. In the first three weeks of class, students were required to complete a scoping exercise and submit a formal memorandum outlining their intended objectives, deliverables, and limitations, as well as identifying whether or not research ethics approval was to be required in the performance of the research.

Throughout the course, various methods of research and data collection were discussed, in addition to presentation and application of the theories and models required for subject matter expertise. Students were required to submit a mid-semester evaluation of their teamwork skills, progress achieved, and problems faced and resolved. Further, a submission outlining the research methods and experimental designs was required.

Nearing the completion of the project, and consequently the course, the teamwork moderator was once again invited to a lecture period for discussion of best approaches for reporting and presenting their results in a professional setting. Students were then encouraged to complete their formal reports, along with permission-for-use documentation (as to the sharing and accessibility of their work), and begin preparation on their formal presentations. Teams were allotted 15 minute presentation times in a

coordinated schedule matching similar topics within lecture periods and clients and their guests invited to attend. Following these presentations, both clients and students were surveyed.

7 Context in a Resource Economy

Ground truthing at the University of Regina regarding approach to the design and delivery of service-learning projects and results of the inaugural client-based project competition indicate significant potential for application within the burgeoning SK resource economy. In fact, response from the engineering community via word-of-mouth has been exceptionally positive and supportive, to the point of industry associations offering not only project ideas but financial support. Inroads have been made within the potash mining sector, in particular, with anticipation of using the client-based project competition method.

Future student work will focus on service-learning and client-based projects that highlight and demonstrate concepts related to quantification of sustainability, cumulative effects assessment, proxy environmental baseline development, and risk assessment and mitigation for engineering projects in which complex and extensive environmental impacts are known or expected.

8 Conclusions

Implementing problem-based learning models can allow for emphasis of key course components, theories, and applications. In changing environments – economically, climatologically, and industrially – student learning must also change and adapt. Opportunities to apply new knowledge and ideas in the classroom and beyond must be leveraged to offer student learners a chance to test their potential and increase their network. Instructors must recognize that these methods require much attention to build and maintain client relationships, manage expectations of both students and clients, and ensure that learning outcomes are achieved by effectively linking lectures, laboratories, and project work. Feedback to date indicates very high learner satisfaction with these approaches and similar value expressed by past and prospective clients. Given the status of the SK resource economy, a multitude of opportunities to better engage and involve industry in engineering learning exist.

9 References

Buchal, R.O. and Lu, H. 2012. Engineering design education and practice as collaborative knowledge building. *Proceedings of the Canadian Engineering Education Association national conference*. Accessible online: www.ceea.ca

Elliott, D. 2012. Demographics for Business Trends. Sask Trends Monitor. Available online: http://www.sasktrends.ca/publications.html

de Eyto, A., McMahon, M., Hadfield, M. and Hutchings, M. 2008. Strategies for developing sustainable design practice for students and SME professionals. *European Journal of Engineering Education*, **33**, 331-342.

Singh, G., Hawkins, L. and Whymark, G. 2007. An integrated model of collaboration knowledge building. *Interdisciplinary Journal of Knowledge and Learning Objects*, **3**, 85-105.

National Survey of Student Engagement. 2012. NSSE Findings. Accessible online: http://nsse.iub.edu/