AC 2009-2287: THE ENGINEERING SCIENCE PRAXIS SEQUENCE: CHALLENGES AND OPPORTUNITIES WHEN INTEGRATING SUSTAINABLE DEVELOPMENT INTO THE ENGINEERING DESIGN CLASSROOM

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Praxis III – promoting an interdisciplinary approach to solving global problems through a course focusing on sustainable development and engineering design

Abstract

This paper will discuss how Engineering Science, a division within the Faculty of Engineering at the University of Toronto in Toronto, Canada, has developed an undergraduate curriculum to foster engineers that can meaningfully contribute to sustainable development. In particular, Engineering Science has developed Praxis III, a course for second year Engineering Science students, which takes both a systems engineering and an interdisciplinary approach to solving complex global problems and begins to integrate issues surrounding globalism and sustainable development. This paper will describe the broader curriculum context for this course, the content and format of Praxis III as it existed in the 2007 and 2008 academic years, the training in problem-solving that students receive, the lessons learned, and future plans.

Introduction

Context

The University of Toronto, located in the multicultural city of Toronto, Ontario, Canada, is itself a multicultural institution. It "offers an education on a global scale" with "students and faculty drawn from around the world" where many of the faculty members are "international leaders in their fields". The University of Toronto has been "recognized as Canada's top university and one of North America's best public research universities"[1]. By Canadian standards, the University of Toronto is a large institution serving approximately 52,000 undergraduate students across three campuses[2]. As such the University offers a diverse set of undergraduate programs, both in arts and science as well as in engineering.

The Faculty of Applied Science and Engineering at the University of Toronto is "Canada's largest engineering school and is widely recognized as one of the best in North America", attracting "…the top math and science students from across Canada and internationally."[2] The Faculty offers eight core undergraduate Engineering programs – Chemical, Civil, Computer, Electrical, Industrial, Materials, Mechanical, and Mineral – and one elite program, Engineering Science. The core eight programs comprise approximately 3,300 students, while an additional 1,000 are enrolled in Engineering Science[4].

Engineering Science "…offers a unique and dynamic program designed to provide superior students with an undergraduate education in the most innovative disciplines within engineering"[5]. The Engineering Science curriculum is divided into two sections, the Foundation and the Options, each lasting two years (four academic terms). The four Foundation terms "…provide a strong foundation in science, math, technology and design", and include courses that cover classical mechanics, structures and materials, quantum physics, systems biology, fluid dynamics, robotics design, thermodynamics, linear algebra, calculus, computer programming, and electrical fundamentals[6]. Engineering Science is by nature a multidisciplinary program that enables students to work within and across disciplines.

In their third and fourth years, students select a discipline-specific option from a unique set of continuously-revised, multidisciplinary programs that are not typically offered at the undergraduate level: Aerospace, Biomedical, Computer, Electrical, Infrastructure, Nanoengineering, Physics, and Energy Systems. Throughout their education, Engineering Science students are exposed to significantly greater depth of engineering theory than their counterparts in the core eight engineering programs offered at the University of Toronto. This approach to engineering education results in a relatively high proportion, on the order of 50 percent, of Engineering Science students pursuing Master's and Doctoral degrees.

To provide balance to the extensive theoretical education they receive during the Foundation years, Engineering Science students are simultaneously exposed to a wider variety of hands-on design projects than is typical for many engineering programs. An example of one of these projects is, in their second year, students must build a fully functional, autonomous mechatronic robot without the benefit of any prefabricated parts or kits.

Praxis Sequence of design courses

In conjunction with a second year mechatronics design course, the four Praxis courses focus on integrating theory with practice, design with communication, and engineering with broader society.

The three key goals of the Praxis Sequence are to:

1) Have students apply their theoretical knowledge to the solution of new problems and to develop new knowledge to further their problem solving abilities;

2) Dispel the traditional notion that engineers must prioritize economic, safety, and functional concerns over environmental and social impact and to view impact from a sustainable development perspective; and

3) Provide training in the professional skills of leadership, cooperation, partnership, and delegation, which are necessary to solve complex problems.

The Praxis courses are a dynamic series of courses, changing and adapting each year to improve student learning and engagement, as we learn from past offerings of these new and innovative courses.

What makes Engineering Science unique is that we run these engineering design and sustainable development courses, the Praxis Sequence, as mandatory courses in the first and second year of undergraduate studies. Typically, universities run these courses much later in the undergraduate program (or not at all at this academic level) and typically, they are optional courses. Engineering Science is also unique in the broad range of topics and approaches that students take in these design courses.

The first course in the Praxis series, Praxis I, is offered in the first semester of the first year of Engineering Science. In this course, students work in groups to complete a bridge design in response to an instructor-developed Request for Proposal (RFP). The bridge design must be fully documented, including both reference works, engineering calculations, and engineering drawings, and must be accompanied by both analytical and descriptive explanations of the design. The second course in the series, Praxis II, is offered in the second semester of the first year. In the first stage of this course, small groups of three or four students begin by developing an RFP that identifies and documents a problem relevant to their local community. The RFPs from the class are pooled and a subset chosen to proceed to the second stage of Praxis II. During this stage the student teams develop and prototype solutions to the RFPs. The solutions are presented, through a poster display and oral presentation, and a public showcase.

Praxis III builds on both of its predecessor Praxis courses, in particular Praxis II, by further emphasizing and providing resources to support group work, design strategies, problem framing, and design communication. It also introduces concepts related to globalism and sustainable development (SD).

Although Praxis III has yet to reach its full potential, one of its strongest points is that it treats design for SD as a normal part of any engineering design. Typically, in university engineering programs, SD is separated from the rest of the engineering disciplines and taught as "environmental engineering". On the one hand, this gives students interested in SD an opportunity to fully explore this topic. On the other hand, and more importantly, it treats SD as a separate issue that "regular" engineers may ignore, as it is viewed as the purview of the environmental engineer. During the EESD (Engineering Education for Sustainable Development) 2008 conference, where we presented a paper on Praxis III, a consensus of participants agreed that what the engineering profession needs is highly specialized engineers in all fields of engineering – civil, electrical, mechanical, industrial, etc. – who design sustainably in all their work. This consensus position revealed that the profession does not need a new breed of environmental engineers; rather we need to change the way we do engineering so that sustainable design is the result. This is a prime goal of the Praxis III course – to introduce students to how to carry out engineering design which results in sustainable design.

As befits any work of engineering design, the Praxis Sequence has been under continual re-development, since its inception. The revisions have been prompted by both internal and external factors, including student feedback on workload and complexity, various engineering competitions and initiatives, changes in the broader University of Toronto curriculum, and the availability and interest of guest speakers. Even with these revisions, the core values and learning objectives of the various Praxis courses have remained fundamentally unchanged.

Course inspiration

One important source of inspiration for Praxis III was the Design Science Laboratory (DSL) – a 10-day intensive design workshop run in New York City since 2004 through the Buckminster Fuller Institute, the United Nations, and the United Nations International School. The DSL provides " rigorous, hands-on training in the problem solving, planning and design methodology called Design Science, pioneered by Buckminster Fuller and other visionaries. Participants engage in a whole systems and anticipatory approach to develop strategies to solve global and local problems that is based on innovation and thrives on transparency" [9]. Engineering Science student Alexandra Heeney attended the DSL in the summer 2006 and worked as a consultant with the Division in summer 2007. Her interactions with both programs revealed a strong synergy between the goals of Praxis III and the Design Science Laboratory, which in turn led to Praxis III incorporating selected aspects of both the DSL structure and content, including the integration of the consideration of the United Nation's Millennium Development Goals. These goals "…which range from halving extreme poverty to halting the spread of HIV/AIDS and providing universal primary education, all by the target date of 2015 … form a blueprint agreed to by all the world's countries and all the world's leading development institutions"[10].

A final source of inspiration for Praxis III came from the work of Engineering Without Borders Canada (EWBC). This organization has recently shifted its approach to overseas development from the more traditional "…identification of solutions, followed by a trip overseas to implement them" to a more participatory and emancipatory focus on "…building capacity rather than the delivery of technological goods"[13].

Praxis III course design

Praxis III was designed to help promote the Engineering Science slogan, "Engineers for the World" (E4tW). E4tW is a shorthand that describes engineers who are not only conscious of how their actions and designs will affect the environment, humanity, and the broader world, but who also actively seek opportunities to help improve the state the world. Praxis III is the vehicle for introducing the E4tW concept and for providing Engineering Science students with a first opportunity to put the concept into practice. Praxis III "…focuses on how engineers interpret and respond to issues affecting large-scale, evolving, socio-technical systems."[7] Praxis III introduces sophisticated engineering analysis and design tools, such as system dynamics modelling and systems engineering, which are better suited to more complex situations than those introduced in Praxis II. The course also explores the limits of formal design methods and techniques when dealing with complex systems.

Learning objectives

By the end of the 2007 revision of Praxis III students were expected to be able to[7]:

- Use "Systems Thinking" to model a socio-technical system;
- Use "Design Thinking" and "Design Science" to design a change to a socio-technical system;
- Anticipate the outcomes of introducing a means to effect change on a socio-technical system;
- Manage and justify design activities using formal design processes and project management tools;
- Practice and refine core design uses of solid modeling tools, etc.;
- Find, understand, and critically assess engineering research articles;
- Employ academic, engineering research articles when designing, constructing, and validating a system model or conceptual design;
- Employ discourse and sentence level revision strategies in their own revision practice; and
- Present a formal, fully supported group oral presentation.

These learning objectives were revised in the 2008 revision of the course to[8]:

- Locate, assimilate, and correlate published research and design activities within a technical domain;
- Find, understand, and critically assess engineering research articles;
- Explain key relationships between engineering design and engineering research;
- Understand and credibly predict the social and technological impact of an engineering design;

- Employ academic engineering research articles to enhance credibility when designing, constructing, and validating a system model or conceptual design;
- Employ discourse and sentence level revision strategies in the revision process;
- Manage and justify design activities using formal design processes and project management tools; and
- Present a formal, fully supported group oral presentation.

The revised learning objectives reflect continuing efforts within the Praxis Sequence to avoid prescribing particular tools and processes, in favour of providing more abstract goals that students can meet using their choise of specific approaches.

The learning objectives for Praxis III, as with all Praxis courses, cover both design and communications. This pairing of objectives is intended to emphasize that a design is only as good as the effectiveness with which it is communicated.

Design challenge

A key goal during the design of Praxis III was ensuring that students did not perceive the design as being a "paper project" that existed solely within the context of the course, but rather perceive the course as directly linked to a "real world" design initiative.

Shortly prior to the start of the 2007 course, the Buckminster Fuller Institute announced the 2008 Buckminster Fuller Challenge (BFC). The Challenge sought entries that described "…a solution that has significant potential to solve humanity's most pressing problems in the shortest possible time while enhancing the Earth's ecological integrity"[12]. Competition entries needed to consider long-term effects and consequences of their proposed solutions as well as to provide ecologically and socially appropriate solutions, which could be broadly adopted by a variety of different people in different contexts. The competition was open to all entrants without regard to affiliation or education. Given the existing links between the Design Science Laboratory and Praxis III, the choice was made to adopt the Buckminster Fuller Challenge as the design challenge in Praxis III.

As a result of the 2007 student feedback, the direct link to the Buckminster Fuller Challenge was severed when desigining the 2008 revision of the course. The Challenge requires that submissions be made by October 30, which provides only seven weeks for students to identify, understand, and propose a viable solution. Based on class assessments, the 2007 students felt that they had insufficient time to engage in the depth of analysis and understanding necessary for them to be confident in their proposed solutions. The Praxis III design challenge was altered to be "…develop a Research and Design proposal that addresses a complex social or humanitarian problem, along the lines of the Engineering Grand Challenges and the United Nations Millennium Development Goals" [8].

Deliverables

The direct link to the Buckminster Fuller Challenge in the 2007 version of the course required that students identify a specific design challenge and propose a credible design solution within a seven-week span. Because the Challenge required neither a sizeable document nor a formal presentation of results, Praxis III added a revised design proposal and a presentation as additional deliverables at the end of the term. The overall schedule of deliverables included:

- Research Review Paper, in which students identified and reviewed a recent article from an engineering journal that they believed would support their design solution;
- Buckminster Fuller Challenge entry, with a “pass/fail” draft due one week before submission;
- Formal Design Presentation, with a “pass/fail” draft due one week before submission; and
- Formal Design Report, with a “pass/fail” draft due one week before submission.

For the 2008-2009 version of the course, the deliverables were reduced, again in response to student concerns regarding workload to:

- State of the Art Report, in which student teams identified different means already in use to address some or all of their design challenge;
- Research Review Paper;
- Research and Design Presentation; and
- Research and Design Report.

The primary means of workload reduction was the elimination of the “pass/fail drafts”.

Execution

From September to December 2007, Praxis III was offered to 185 students over 13 weeks of instruction; from September to December 2008, Praxis III was offered to 163 students over 8 weeks of instruction.

Logistics

Two instructors, one focusing on design and one on communications, co-lectured for one hour per week. The lectures introduced key concepts in design, systems thinking, and technical communication, with the goal of providing students with starting points that they could explore in more detail as they completed their work. The lectures also presented additional perspectives to the students such that they had to move beyond a traditional, function-oriented engineering mindset.

Each week the students had a two-hour tutorial during which they worked in permanent, small teams of nominally five students to complete the overall design challenge. The tutorials were intended to “provide a mixture of focused activities and opportunities for group work and consultation with teaching staff.”[7] Each tutorial room contained nominally 25 students and was led by either by one or more Teaching Assistants (TAs) or the course instructors. The TAs comprised a mix of graduate students, who were selected for their interest in the mandate and approach of the Praxis courses and for their having completed the Engineering Science programme, and of Engineering Science undergraduate students who had previously excelled when taking their iterations of Praxis II and III.

Given the fluid and evolving nature of the course, the focus on reflection and metacognition inherent in the course learning objectives, and the continuing flux associated with the concept and tools of sustainability, TA training focused on the Praxis approach to teaching and learning and not on the specific topic of sustainability. While the TAs were introduced to, and expected to explore additional definitions of, “sustainability”, their training focused on means to support students as they develop and apply their own definition(s) of sustainability in the context of their assigned activities.

Finally, and perhaps most importantly, the two course instructors made themselves frequently available for one-on-one consultation with individuals or teams outside of scheduled class hours.

External resources

The link between Praxis III and the Design Science Laboratory implied a further link to the United Nations Millennium Goals. The 2007 revision of the course was linked to the Buckminster Fuller Challenge, which provided the students with additional resources for both focusing the project and developing workable, systems-oriented designs for sustainable, ecologically friendly solutions. Students were able to benefit from documents provided by the BFC, such as the "Design Science Primer" [11], that outlined useful design practices compatible with the vision for the course. They were also able to leverage the extensive online archive of materials, in text, audio, and video form, describing the works, vision, and approach Buckminster Fuller brought to his design practice. The 2008 revision of Praxis III augmented the BFC resources with those provided by the United Nations on the Millennium Development Goals[10] and those provided by the National Academy of Sciences on the Grand Challenges for Engineering[18].

Students were also encouraged to make use of online resources such as videos from the Technology, Entertainment and Design (TED) talks that cover a wide variety of topics related to global problems, to help students choose topics for their projects.

Results

Each class organized itself into approximately 40 teams, each working on a unique project. The top projects tackled a variety of topics, many of which would not be considered traditional fare in an engineering design course. In the 2007 revision of the course top projects included:

- Solving the Water Crisis in Squatter Cities in Developing Countries
- Designing a New, Preventative, and Humanistic Engineering Curriculum
- Tackling Poverty Through Agriculture
- Curbing Depression: Prevention through Social Networking
- A Model to Provide Clean Drinking Water
- The Good Samaritan Project - Addressing the issue of the bystander effect

In the 2008 revision of the course top projects included:

- Combatting Malaria Through Vector Management
- Detection and Neutralization of Anti-Personnel Landmines
- "Learn in Full Experience (LIFE) Education System" – Achieving Primary Education in Rural India in Relation to Child Labour
- Urban Secured Controlled Agricultural Production (USCAP)
- Drinking Water Purification in Sub-Saharan Africa

Not only were the topics varied, but so, too were the approaches: from capacity building, to designing to devices, to creating models for selecting appropriate technology.

Praxis III takes a broad view of what constitutes engineering design practice and of the problems to which an engineering design mindset can be successfully applied. This view is consistent with that of Engineers Without Borders Canada and the National Academy of Engineering, as embodied by the Grand Challenges for Engineering [18].

Instructor perspective

As both a co-taught course and a course focusing on non-traditional approaches and applications of engineering design, Praxis III presented challenges beyond those of a more traditional, single-instructor engineering design course. Both of the instructors had worked together teaching previous Praxis courses, and had developed a successful working relationship. Essentially the only area of contention among instructors has been how broadly to interpret "engineering design" and by extension how much to limit or guide the directions taken by the student teams. For example, while both instructors agreed that the provision of clean water was a legitimate engineering design challenge, they disagreed on whether the same was true for developing an engineering curriculum or improving community mental health. For the most part this disagreement was resolved by allowing the few teams who chose to tackle a "non-traditional" challenge to do so and then reflect as instructors on whether the learning objectives for the course were met. Based on the results of the 2007 version of the course, the instructors chose to introduce students in the 2008 version to the "capacity building" model of sustainable engineering, which deals explicity with non-traditional engineering design issues.

For both instructors one of the most challenging aspects of teaching Praxis III is accepting that the student-generated projects and solutions will exhibit less nuance and greater naïveté than would those developed by the instructors or the Teaching Assistants. This difficulty manifested itself in both the formative and summative feedback provided to the students, and in some of the discussions that took place with individual teams in tutorial. TAs and instructors both had to accept that given their more limited set of experiences to draw upon, the students would make certain assumptions, for example that corruption can be solved by installing monitoring software and hardware in all computers, that were neither viable nor appropriate.

A final challenge for both instructors was accepting the ambivalence some students felt towards the notion of sustainability and the role of the engineer in addressing complex socio-technical issues. Both instructors spent significant time with each student team discussing the different roles that engineers play in society and the different challenges that engineers are called upon to help solve. While some teams both accepted and embraced this expanded vision of the engineer, many did not. Such teams generally felt that their role should be to address purely technical, well-defined challenges identified and framed by others. For both instructors, who each believe that such a perspective diminishes the role of the engineer and is inappropriate given the emerging global challenges that must be addressed, it was difficult to accept this position and to ensure that students who espoused these beliefs were not unfairly assessed.

Student perspective

Praxis III succeeded at providing students with complex problems to tackle using a systems approach to sustainability in design. The top performing teams excelled at all aspects of the course, successfully identifying a legitimate problem in need of solving and using a system-oriented approach to developing a well-thought out solution. The performance of the remaining teams ranged from good to ineffectual, in large part correlated to their levels of engagement with the notions of sustainability and of the expanded role of the engineer promulgated within Praxis III.

Many groups encountered great difficulty with the problem identification and framing stage of the course. Although their research led to good solutions to the problem identified, the overall result could not be termed “a solution to the world’s most pressing problems”. Other groups encountered the opposite problem. They identified an excellent problem to focus on, but developed a solution that was naïve and unworkable, or which would result in even greater problems should it be implemented.

A testimonial from one of the course’s top students concisely summarizes how many of the top Engineering Science praxis students felt about the Praxis III course:

> “I thoroughly enjoyed the flexibility in Praxis III as it allowed groups to pursue an area of their own interest rather than someone else's, and our group took advantage of this to apply engineering to something not typically associated with it, which was social networking and depression. I believed that by allowing us to figure out what is feasible, interesting, and a pressing problem in the world, Praxis III really embodied the vision of Engineering Science, which is to be an engineer for the world. On the flip side, all the variety understandably resulted in some problems and misunderstanding between teams and the TAs as it was hard sometimes to get consistent feedback and advice. I believe it was well worth it though!”[23]

Although no written account is available, anecdotal evidence based on informal discussions between students and the instructors and between students and course TAs, suggests that those students who did not enjoy the course would cite many of these same characteristics as negatives. This anecdotal evidence was consistent with the comments made by the students at semi-formal, mid-term feedback sessions hosted by the Division of Engineering Science.

Anonymous course evaluations solicited by the Faculty at the end of the term resulted in scores that were consistent with other courses in the Praxis Sequence. These scores ranked Praxis III higher than similar design courses offered within the Faculty and at the same level as other courses taught by the same instructors. These evaluations confirmed the anecdotal evidence that student reactions to the course were polarized with few mid-range evaluations and a tendency to award either the top or bottom score in most categories.

Lessons learned

Ensure students are guided through an iterative design process through course structure and assignment design

It is key to ensure that students follow an iterative design process in order to ensure the success of their final designs and projects. Because design is by nature a difficult research-intensive process, it can be a daunting task. When students grapple with their designs, especially when the directions given are purposely vague and provide minimal structure, their tendency can be to procrastinate when making decisions and producing deliverables[25]. This coupled with time constraints due to the large Engineering Science workload and the short length of the term, cause many students to delay the writing until shortly before the deadline, leaving them with insufficient time for preparation of the final document and oral presentation of the project. It is thus necessary to ensure that the course strongly guides students through the desired, iterative design process. We have found that this is generally best done by requiring interim deliverables, which force iterations in a low-stress environment where feedback is readily available.

In both 2007 and 2008, the final design deliverables were strongest on topics that students had already been required to address in previous interim deliverables, either for marks or as pass/fail. In 2007, the preliminary design report forced students to further focus the design problem they were tackling, as well as to purposefully develop design requirements. As a result, the final report and presentations reflected strong thought in problem definition, requirements analysis and research into existing solutions. However, the requirements and literature surveys were relatively weaker than the 2008 offering, as literature surveys were not emphasized as part of the preliminary design reports in 2007, while these were emphasized in 2008.

In 2008, there was no interim deliverable specifically focusing on problem definition and requirement analysis. As a result, in the final reports, the problem definitions were often glossed over and not justified, and the requirements were vague – often without metrics and often resorting to pro-con lists. However, in 2008, students were required to write a SOTA report detailing a literature survey of exisiting solutions. Accordingly, the scientific analysis of existing solutions to the problem was strong across all student groups in the more recent offering.

What is clear from the results of these two course offerings is that students learn material and skills better if there is a specific assignment on it, if constructive feedback is provided on a more frequent basis and if complex tasks are broken into more manageable components, which are then built upon throughout the term. This approach provides course instructors with more information about how the groups are doing, enabling them to better adapt the course and help students.

For example, it might be appropriate to require students to submit some of the following small deliverables:

- 1-2 page description of the problem definition, with justification for why this problem was chosen, including information on how the problem chosen can have a widespread positive impact on solving other (related) problems;
- 1-3 page report on requirements (constraints, criteria) with appropriate metrics wherever possible (allow an appendix to justify the lack of metrics where fuzziness is a problem). It may be appropriate to require a section on SD requirements, economic requirements, social/cultural requirements, in addition to other design parameters;
- 2-3 page report on existing solutions with respect to the outlined requirements; new developments and changes to the requirements list which arise from this new research;
- 1-2 page report on preliminary high-level design concept;
- 1-2 page report on and including an engineering model relating to the problem or solution;
- 3-5 page report with an in-depth description of the design concept and further development of design;

- Final design report which includes all of the above components, with appropriate revisions according to instructor/peer feedback and new information which has arisen from each of the stages of the design process; and

- Frequent in-class presentations on various portions of the above, forcing students to solidify and communicate their ideas, practice their communication skills, and get feedback (as well as use other groups as a springboard for ideas).

Each of the above assignments could be reasonably broken down and completed within a 1-2 week period. If graded in a timely fashion, students would be provided with useable feedback throughout the course. Additionally, this would break down the difficult projects into smaller, simpler ones, while also giving students additional practice with engineering communication in a lower-risk environment. Increasing the number of deliverables would also help instructors in adapting the course throughout the term to better meet student needs.

Student interaction with instructors is key to success in design courses

Key to student success in design courses such as Praxis III are opportunities for students to interact with the course instructors and tutorial leaders. Teams met with their tutorial leaders on a weekly basis to discuss problems and to touch base on progress. The course instructors were also very available for extra consultation outside of class hours. Top-performing teams would often spend several hours with the course instructors discussing problems they had encountered. Struggling teams also made use of extra hours with the course instructors to receive guidance and direction for their projects. Based on class assessments, many teams informally cited the individual team interactions with the instructors as the most important part of the learning process in the course. Student assessments indicated that individual team interactions were even more important than the lectures because students were able to get help and feedback specific to their project. Since each team tackled very different topics, one-on-one interaction with experienced designers and communicators, in the form of the course instructors, proved to be a valuable resource.

It is difficult but necessary to ensure a unified vision amongst course staff

To promote stability across the Praxis Sequence, Engineering Science has adopted an informal policy of assigning TAs to multiple Praxis courses. This policy has had mixed results. Having participated in multiple courses, the TAs are better able to demonstrate and leverage the linkages inherent in the Sequence. Their familiarity with the course instructors has also allowed for increased efficiency and flexibility in course design and delivery. In any given Praxis course, roughly 75% of the TA complement has worked in a previous Praxis course.

Although there are similarities among the Praxis courses, the differing nature of the projects and the different course foci makes it difficult for a TA to mesh equally well with each course. Similarly, having a group of eight TAs and two instructors working with diverse student teams on a highly unstructured and open-ended challenge made it difficult to communicate a cohesive vision and a consistent message to the students.

A final difficulty in staffing was ensuring acceptance of the overall vision for Praxis III. Some TAs came from more traditional engineering design backgrounds and lacked a comprehensive understanding of sustainable design concepts. However, the breadth of background amongst TAs did enrich the scope and breadth of feedback available to students, though sometimes at the risk of being inconsistent with some of the core course values.

Ensure there is adequate technical expertise to guide students and to evaluate the diverse array of projects

Because of the wide diversity of projects that students chose in 2007 and in 2008, it was difficult for the instructors to provide technical feedback on project content for all the projects; the focus tended to be on process-related matters. Because of the limits on technical expertise, instructors found it challenging to evaluate all the projects for viability – both in the requirements stage and the final design. To address this problem of technical expertise in the future, it may be helpful to invite engineering experts in the faculty (e.g water, material etc) to a special tutorial designed to provide students with the opportunity to ask technical questions and obtain informal feedback on a particular design from both the course instructor and an engineering expert in the field. Their feedback would not necessarily factor into the student's grade, but would provide them with useful information to ensure the feasibility of their project. Effective project evaluation for these varied technical problems is difficult without limiting the project topics.

Ongoing efforts are needed to enhance student engagement

As with student achievement, student engagement with Praxis III was polarized. This experience mirrors a general trend in the Praxis Sequence. Those students who were more comfortable with ambiguity, preferred argument and discussion over giving 'correct' answers, and believed in a more expansive and qualitative view of engineering and design, are those who excelled and enjoyed the course. These students were also more likely to engage in intellectual and moral struggles, often arrived at through frequent and intensive student-driven, one-on-one instructor interactions, which characterize successful engineering design education. It should be noted that these students devoted significant amounts of time to the course, well beyond the guidelines suggested by their instructors.

Students who adopted the mindset that there is a "correct" answer to a design challenge, that engineers have an inherent right and ability to impose solutions, and that factors other than cost and safety have no place in engineering, tended to do poorly in the course. These students also tended to be sceptical of the E4tW catchphrase, seeing it as a lessening of the engineer's role and status. The net result of these beliefs was that these students were less engaged with the course and in turn less likely to seek opportunities to engage in discussion with instructors. As a result these students floundered and their results were substandard, leading to a cycle of disengagement and poor performance. Such students tended to devote less time to the course, and in those cases where they were working with more engaged students this lack off effort contributed to some team dynamics issues.

The focus of both the 2007 and 2008 course offering of Praxis III was on solving humanitarian problems. The challenge to the instructor was that many of the problems being addressed – and the solutions therein – were not purely technological, some students viewed these problems as being important, but disjointed from the role of the engineer. This sometimes meant that students devalued the work they did in the course as "not engineering" and therefore "not important". This problem is increasingly aggravated by the sequence of engineering design courses in the Engineering Science curriculum.

With the integration of SD more fully into the Praxis Sequence of courses and with smaller assignments over the term that build on each other in the development of the students' project designs, it is anticipated that student engagement will be improved.

Balancing a broad range of topics while trying to incorporate SD is difficult but necessary

One of the challenges of teaching an intensive design course, which uses systems theories that are introduced to students for the first time as part of this course, is the magnitude of material that needs to be covered. Instructors need to balance the following: expository information about systems design processes and analysis, suggested good design principles, with engineering design methods, and instruction on written and oral communication for a technical and engineering audience.

Praxis III has now been run for 4 years, and has endeavoured to balance this broad range of topics to engineering students, whilst also having students work through group design projects. Integrating SD into all the Praxis courses will help to achieve this balance as early courses can introduce concepts, which are then built upon in the later courses. This will allow for the spreading out of the material and provide greater opportunity to increase student proficiency in these design concepts.

Proposed changes for the next iteration of Praxis III

As a result of the lessons learned the following are the proposed changes for the next iteration of Praxis III:

Increase scaffolding through interim deliverables

From past years, we have learned that regardless of student ability, it is possible to dramatically improve overall results, including student take-in of important information, processes and practices, by mandating a series of interim deliverables which build on each other and which force students to go through the thought processes of a good engineering designer. We plan to increase the number of interim deliverables and revise what deliverables we will require. More interim deliverables will help break down a complex design process into smaller, easier steps. This will encourage student engagement and help to avoid student procrastination, while also enabling course instructors to better monitor student progress, providing more help, as needed.

Increase availability of information and inspiration

Increased availability of information and inspiration could be done by:

- Have copies of books and journal articles on engineering design and systems design readily available during class and tutorial hours, to encourage students to flip through these resources for ideas;
- Give handouts with suggested search engines, journal databases, and other sources of inspiration (e.g. for our course, TED, UN documents, and Design Science topics would be useful); and
- Put students in an environment where they constantly have access to information (e.g. locate tutorials in a computer lab) to encourage students to always look for new sources of information and to substantiate their claims and ideas with hard evidence and research.

Integrate SD across the Praxis Sequence

In order to ensure a cohesive vision across the Praxis Sequence regarding what engineering design is and how sustainable design factors into this process, we plan to integrate sustainable design practices into all the Praxis courses, starting from the first term in first year. SD concepts can be introduced in a variety of ways, including:

- Dedicate at least 1 lecture in each of the Praxis courses to introducing and describing sustainable design concepts (e.g. life cycle analysis, backcasting, environmental assessment etc.);
- Give examples in lecture of sustainablitity considerations directly relevant to the project topics that students are working on (e.g. what SD considerations are most relevant for bridge design in the Praxis I bridge design course);
- Train TAs and course instructors in SD concepts and encourage them to challenge students about how they have considered SD in their designs, throughout the design process in the course; and
- Require SD considerations as part of the course expectations and grade students on the effectiveness of their design for SD.

In the future, we intend to examine how to integrate SD across the entire engineering curriculum, to connect all the technical concepts that students learn to real-life applications and how they can ensure they are carrying out sustainable design as "Engineers for the World".

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