Teaching Design, Synthesis and Communication to First Year Engineering Students at the University of Toronto

Susan McCahan, David Bagley, Peter Eliot Weiss, Kimberly Woodhouse, and Will Cluett
Faculty of Applied Science and Engineering
University of Toronto

Introduction

One of the central tenets of new engineering curricula is an introductory course that provides students with a framework for engineering practice. This enables them to begin learning aspects of systems engineering and design, along with communications, teamwork and other professional skills, thereby gaining some sense of the excitement of the engineering profession. The Engineering Faculty at the University of Toronto has developed such an introductory course for its first year students that draws resources from across its various disciplines. It uses existing strengths in design, preventive engineering and social impact of technology, human factors, and language across the curriculum. The course development team started by defining the student needs that were unmet by the previous first year program and then constructed a list of goals for the new course in terms of expected student accomplishments. This list was reformulated into a set of learning objectives, which were then clustered to form a cohesive course outline. The new course, entitled Engineering Strategies and Practice (ESP), is a two-course sequence (26 weeks total) that was offered on a pilot basis for 100 students in the 2003-04 academic year.

There are many different elements that have been developed for design courses.[1] The two-course sequence that was piloted this past year combines a number of these elements and has some special attributes. There is a major design project carried out for a real client. The team of instructors is a mix of engineering professors, communication instructors, and industry professionals. In addition, considerable class time is allocated to understanding how human, social, and environmental issues are brought into the design process. This is done, in part, through a seminar style approach. Overall, the resulting course is a departure from a typical design course.

Course Outline

The course plan can be roughly broken down into four parts. The major material introduced in each part is as follows:

- Part 1. Introduction to design, team skills, professional writing, and reverse engineering
- Part 2. Human, social, and environmental issues in the design process; Introduction to oral communication, and critical reading
- Part 3. Project management and project planning
- Part 4. Major design project

Each part builds from the previous material such that once skills are introduced they are practiced throughout the rest of the course.

In Part 1. students were given a rapid introduction to the design process, team skills, and professional communication with additional material on reverse engineering. This part of ESP uses a typical lecture based learning approach with tutorials. Students were introduced to the basic steps in the design process from assessing a client's need through delivering a final detailed design. The fundamentals of team development and dynamics were discussed. And the basics of professional writing were introduced. The students were also introduced to the concept of reverse engineering as a method of gathering information and critically evaluating existing designs.

The tutorials are a key component of Part 1. The tutorial sessions were, in fact, used as workshops for the students to practice the skills introduced in the lectures. The class was put into teams to work on a model design project. They went through the process of team formation, setting up team rules, and writing a team purpose statement. They worked through the initial steps of the design process including; assessing the client's need from a client statement, performing some background research around the project area, brainstorming to generate ideas, and choosing a subset of ideas to propose to the client. As part of the model project the students individually produced several pieces of writing such as a memo to their supervisor and a short proposal letter to the client.

The students were then given existing products to analyze using the methods of decomposition and evaluation taught in the lectures. They look at the function and form of the items and how the items use energy. The students this year analyzed an electric versus a hand-driven eggbeater. With a basic introduction to gearing, the students are able to "discover" that the gearing in the electric beater reduces the speed and increases the torque from the motor to the beaters. However, the gearing in the hand-driven beater is used to reduce the torque and increase the speed of the beaters. The students are able, then, to compare and contrast how the difference in the energy source affected the design of the components and controls.

Part 2 of ESP introduced the concepts of human factors, social issues and environmental issues as part of the design process. This introduced the idea that in the design process the engineer has an obligation to consider a wider range of constraints including the external costs of a design and that consideration of these factors can result in a more creative and fundamentally more sound design of a product, installation, process, or service. Part 2 consists of a lecture component and a small group seminar component.

Including material on ethics and the social context of engineering in first year design courses has been done before (see, for example, Dym[2]) but rarely are these issues presented as constraints that, when appropriately considered, will lead to better engineering design. Much engineering design now, however, is subject to scrutiny by a wide variety of stakeholders, technical and otherwise. The lecture component of Part 2, then, was designed to specifically present material on human factors, economics, preventative engineering, life cycle assessment, and industrial ecology. The concepts developed by Vanderburg[3] and used as the basis for his first year course informed a basic tenet of Part 2 – that identifying and addressing key social and environmental constraints during the design process instead of afterwards will lead to more cost-effective and socially responsible design (the concept of preventative engineering). The ideas of Vicente[4] provide a particular focus on the human interaction with technology and further emphasize the need for considering broader issues. Both texts served as additional references for the students and both authors presented guest lectures during Part 2.

In place of the workshop type tutorials found in Part 1, in Part 2 the students were put into small group seminars (~10 students per group). The use of small group seminars as a mechanism to provide depth and relevance for first year students is not new, although typically engineering faculty do not teach these courses. Stengel[5] described his experience teaching a full-term engineering seminar course to a class of 15 students who were selected from a much larger application pool. A particular component of his course was the requirement for reading a broad range of sources with discussion on the readings occurring weekly in class. In this case, however, the readings were selected by a single instructor and were used to deepen the foundations for technical discussion, not to specifically explore human factors, social and environmental issues as constraints for engineering design.

The seminars in Part 2 were one of the most unique aspects of the course for several reasons. First, the entire class was divided into seminar-sized groups of approximately 10 students, thus allowing seminars to be incorporated into a much bigger class than is normally considered. Second, the leaders for the seminars were both faculty members and alumni from industry. The use of alumni provided needed resources but also provided students interaction with practicing engineers. Third, each seminar had a topic chosen by the seminar leader, not the course instructor, which was an aspect of engineering with substantial social, political, human, and/or environmental issues attached to it. Several examples included solid waste disposal in Toronto, deregulation of the electricity market in Ontario, tissue engineering, etc. Finally, the readings were also chosen by the seminar leaders and were taken from the lay press, government documents, technical journals, and other sources.

At the beginning of Part 2 the students were given information on how to critically read a document and they went through a mock seminar session designed to prepare them for the actual seminars. For the seminar sessions the students were given readings to prepare. The groups met for three consecutive weeks, two hours per week, to discuss the issue. During the seminars the students made one short presentation to their group on an aspect or point of view related to the seminar topic. They also wrote an opinion paper as a summative assignment from the seminar sessions.

Part 3 of ESP focused on project management. Basic project planning methods were discussed in lecture and the students learned to use project scheduling software. At this point the students were divided into teams for their major design project. They received a client statement and developed an initial project plan that was further revised throughout the semester.

In Part 4 the students worked in teams through a full design project. Throughout the design project the students were expected to apply what they learned in the first three parts of the course. The projects for this course came from the community. This year there were 18 projects from private sector companies, non-profit agencies, and community organizations. The clients are asked to provide time for meetings with the students and they receive a final report from the design team at the end of the project.

This aspect of the course is based on the successful model developed at NorthWestern University for their EDC course.[6] Design projects from outside clients or sponsors are typically multifaceted and open-ended and therefore rarely resemble the problems that students see in their other first year engineering course work. Such projects provide students with exposure to working with a real customer who is committed to the problem and wants to see some solutions. While many engineering design courses use problems posed by industry, it is pointed out by Dunn-Rankin et al.[7] that the industry interaction is a critical part of such a course. The experience with similar sponsored projects described by Todd et al.[8] is that students become more motivated to achieve a successful product or service because they feel personally responsible to the sponsor. The feeling is reciprocal because being involved with the project makes the client into a real stakeholder and therefore an important part of the educational process.

From the outset, the sponsors were made aware of the course objectives and the limitations of the students in the course (i.e. first year students with no real depth of technical knowledge). They were encouraged to allow their design group to be innovative and creative, giving the students the all-important opportunity to fail as well as succeed.[9] At the end of the ESP course, the client was not obligated to implement the design solution the students developed, nor was the student's grade based on whether the solution was adopted but rather on how well they followed the design process.

During the term, the students groups met weekly with project managers (professors) at the university to review their progress. The project managers also reviewed drafts of communication that the teams developed such as email to the client, scripts for client interviews, etc. During Part 4 the design teams delivered three major reports on their project: a conceptual design report, a preliminary design report, and a final design report. Each of these documents served a dual function: first, as piece of collaborative professional writing for the course; and second as an interim or final report to the client outlining the progress or outcome of the work.

The design project with an outside client served the important purpose of integrating the package of skills that form the fundamental learning objectives in this course. Communication skills, team skills, a systems approach, independent learning, problem solving, and the intermeshing of human, social, and environmental factors with engineering were brought together in the context of this project. We have used on-line surveys extensively to gage the students' perception of the course and their self-assessment with respect to the learning objectives. Interestingly, although ESP is not purely a communication course per se, nor do the students perceive it as this, the majority reported that their communication skills, in particular their writing skills, significantly improved as a result of this course. And the vast majority reported that the content learned in this course is important to their professional development, suggesting that they tangibly understood these skills to be engineering skills.

Features

One of the exceptional features of ESP was the diversity of instructors involved in the pilot. This year there were engineering faculty, language faculty, professionals from industry, and teaching assistants involved with the course. This team approach represented a challenge in terms of managing the course and providing a coherent flow to the content. However, it gave the students multiple resources and exposure to a variety of role models.

Language and engineering faculty were in both the lecture and tutorial settings from the beginning of the course. This team approach meant that the students had multiple support resources for help with their writing, team issues, and projects. It also gave the students an understanding of the parallels between the engineering design process and the process of designing a document or other communication.

As at the University of Alaska Fairbanks[1], the communications faculty reflected a broad range of specializations, including English, Linguistics and Theatre. This practical approach to communication actually integrates a long tradition of rhetorical theory. Students learn a set of rhetorical tools that reach back to Cicero and Aristotle (e.g. "*ethos*", the "*tropes*"), but which get integrated firmly into the contemporary context of engineering communication.[10, 11] In addition, the foundational logic for communication draws on the work of contemporary communication, logic and learning theorists such as Bakhtin[12], Toulmin[13], Austin[14, 15, 16], Jauss[17] and others. The value of such a theoretical basis is twofold:

- First, it elevates writing instruction from becoming a trivial "tips" list by giving students a deeper appreciation of communication as a thinking and decision-making process, and
- Second, it permits a principled approach to writing and oral communication that goes well beyond what is ordinarily found in Technical writing textbooks, or that students may bring with them from high school.

Our aim was to have the first-year students build a sophisticated rhetorical understanding that would enable them to navigate complex communication situations they would meet when working on projects for actual clients in part 2 of the course and, in the future, in academic or industrial environments.

Writing was integrated and ongoing in the process, reflecting the philosophy of our own Language Across the Curriculum program as well as similar approaches implemented in institutions across North America over the last thirty years.[18] As in similar design courses[6, 8, 19], the communication component required a variety of "deliverables" including an engineering notebook, weekly status reports for the project manager and design reports for the client. These were evaluated in a complex manner; grades and the more familiar kinds of suggestions that would improve quality came from teaching assistants. But, project managers had to sign off on anything that was actually going to a client; so a new set of criteria were introduced concerning what would be appropriate and professional, precisely the kinds of information engineers learn (often painfully) on the job.[20]

In the planning stage we had people from industry signed up to served as seminar leaders in Part 2 of the course or as project consultants in Part 4. However, several of the people who served as seminar leaders were so enthusiastic about the experience that they returned in Part 4 as project consultants. Having this level of industry involvement did require organization and a significant amount of communication to set up, however, the result both for the students and the industrial staff was extremely positive. The industry volunteers enjoyed the opportunity to get involved with the students. And they were impressed with the general level of participation in the seminars and quality of the discussion.

The seminars were a unique feature of this course. While we occasionally have seminar courses in engineering in upper years or our graduate programs, we had not tried freshman level seminars before. Other universities have implemented freshman seminars, but rarely led by engineering faculty and not specifically to deepen exposure to engineering design issues.[5] Seminars were proposed in the original plan for ESP to accomplish several learning objectives: support the lecture material in Part 2 by examining an application to a specific engineering area selected by the seminar group leader; provide students a first opportunity to present an oral presentation; and begin to train the students to read critically.

The seminar gave the students essentially a case study on the relationship between human factors, society, the environment, and engineering. This, in many cases, included a discussion of ethics as well. In this way the content of the seminar reinforced and supported the material that was being presented in the lectures in Part 2.

The students delivered a short, individual, oral presentation in the seminar and were marked on participation. Their presentations were 3 to 5 minutes long with no visual aids. The group had already met at least once before the students had to present and the group size was fairly small. This provided a somewhat friendly atmosphere for them to take a first try at a presentation. Despite this, many of the students were extremely nervous but managed to deliver a reasonably good talk. The students then had two more opportunities to make presentations later in the course (in Parts 3 and 4), but the seminar gave them a chance to begin to develop their speaking skills.

And finally, the seminars were designed to train students to read critically. Each group had a range of material to read in preparation for the discussion. Many of the seminar leaders used the first session to walk the students through a critical analysis of at least one of those readings. In subsequent meetings the students were called upon to contribute to the discussion by applying information from the readings to the issue at hand.

The seminars received more favourable comments from the students than virtually any other aspect of the course. The comments generally fell into three categories. First, there were students who liked the seminars because they were fun, or a break from their other courses. Second, there were students who liked this mode of learning as a supplement to the lecture material. And finally, there were students who preferred this mode of learning to the traditional lecture style method. This was particularly interesting because we do not use seminars often, if at all, and because it suggests that we have students with a learning style that is not well matched to our usual teaching methods. As our courses rely increasingly on PowerPoint lectures that all to often have the feel of a "canned" performance, seminars represent an interactive mode of "live" learning that is fundamentally different. Particularly as undergraduate courses become increasingly large, a seminar can give a student that "small class" experience in the freshman year. Using seminars as part of a course may be a mode of teaching that should be given more consideration in technical courses.

Conclusion

Engineering Strategies and Practice was designed to set the framework for the engineering curriculum and for professional skill development. It has a clear emphasis on design and communication. The design component is used as a methodology to accomplish several of the learning objectives. It is also a vehicle for understanding and practising problem solving and for developing communication skills. In addition, design problems naturally require a holistic approach to problem solving that takes into account social, environmental, and human factors as design constraints. They offer students a larger view of the scope of engineering, which will gradually be filled in by engineering discipline as they go through their undergraduate program. The course is viewed as foundational; the objective is to start encouraging students right away in first year to synthesize and integrate their knowledge in the broader engineering context. The pilot for the course has been successfully completed. Planning is now underway to begin to scale up the course.

Bibliography

1. Burton, J.D., and White, D.M., "Selecting a Model for Freshman Engineering Design," J. Eng. Educ., vol. 88, no. 3, p. 327, 1999.
2. Dym, C.L., "Teaching Design to Freshmen: Style and Content," J. Eng. Educ., vol. 83, no. 4, p. 303, 1994.
3. Vanderburg, W.H., The Labyrinth of Technology, University of Toronto Press, 2000.
4. Vicente, K.J., The Human Factor: Revolutionizing the Way People Live with Technology, A.A. Knopf Canada, 2003.
5. Stengel, R.F., "From the Earth to the Moon: A Freshman Seminar," J. Eng. Educ., vol. 90, no.2, p. 173, 2001.
6. Hirsch, P. and Shwom, B., "A Joint Venture in the Classroom," ASEE Prism, p. 40, Nov. 2000.
7. Dunn-Rankin, D., Bobrow, J.E., Mease, K.D., and McCarthy, J.M., "Engineering Design in Industry: Teaching Students and Faculty to Apply Engineering Science in Design," J. Eng. Educ., vol. 87, no. 3, p. 219, 1998.
8. Todd, R.H., Sorensen, C.D., and Magleby, S.P., "Designing a Senior Capstone Course to Satisfy Industrial Customers," J. Eng. Educ., vol. 82, no. 2, p. 92, 1993.
9. Marin, J.A., Armstrong, J.E., and Kays, J.L., "Elements of an Optimal Capstone Design Experience," J. Eng. Educ., vol. 88, no. 1, p. 19, 1999.
10. Aristotle. Aristotle on Rhetoric: A Theory of Civic Discourse. Trans. George A. Kennedy. New York & Oxford: Oxford University Press, 1991.
11. Bizzell, P. and Herzberg, B., The Rhetorical Tradition: Readings from Classical Times to the Present. Boston: Bedford Books, 1990.
12. Bakhtin, M., Speech Genres and Other Late Essays. U of Texas P., 1986.
13. Toulmin, S., Uses of Argument, Cambridge, 1958.
14. Austin, J.L., "Performative Utterances." *Philosophical Papers* Oxford: Oxford University Press, p. 233, 1979.
15. Fish, S., "How to Do Things with Austin and Searle: Speech Act Theory and Literary Criticism." *Is There a Text in this Class?* Cambridge: Harvard University Press, p. 197, 1980.
16. Keir, E., "Speech Acts." *The Semiotics of Theatre and Drama.* London: Methuen, p. 156, 1980.
17. Jauss, H.R., "The Theory of Reception: A Retrospective of its Unrecognized Prehistory." *Literary Theory Today* Ed. Peter Collier and Helga Geyer-Ryan. Ithaca: Cornell University Press, p. 53, 1990.

18. Ford, J.D., and Riley, L.A., "Integrating Communication and Engineering Education: A Look at Curricula, Courses, and Support Systems," J. Eng. Educ., vol. 92, no. 4, p. 325, 2003.
19. Miller, R.L., and Olds, B.M., "A Model Curriculum for a Capstone Course in Multidisciplinary Engineering Design," J. Eng. Educ., vol. 83, no. 4, p. 311, 1994.
20. Winsor, D., Writing Like an Engineer: A Rhetorical Education. Mahwah, NJ: Erlbaum Publishers, 1996.

DAVID BAGLEY

David Bagley is a Professor of Civil Engineering at the University of Toronto. His current academic interests include sustainable wastewater treatment and sustainability of engineering systems in general. He holds a B.S. from the Colorado School of Mines, and an M.S. and Ph.D. from Cornell University.

WILL CLUETT

Will Cluett is a Professor of Chemical Engineering at the University of Toronto. His current academic interests are in the areas of chemical process identification, control and design. He holds a B.Sc. from Queen's University and a Ph.D. from the University of Alberta.

SUSAN MCCAHAN

Susan McCahan is a Professor of Mechanical Engineering at the University of Toronto. Her current academic interests include the thermodynamics of phase change systems, renewable energy systems, and design education. She holds a B.S. from Cornell University, and an M.S. and Ph.D. from Rensselaer Polytechnic Institute.

PETER ELIOT WEISS

Peter Eliot Weiss is Associate Director of the Language Across the Curriculum Program in the Faculty of Applied Science and Engineering at the University of Toronto. His current academic interests include the engineering of staging effects in Renaissance Italy and communication. He holds a B.A. and M.F.A. from the University of British Columbia, and a Ph.D. from the University of Toronto.

KIMBERLY WOODHOUSE

Kimberly Woodhouse is a Professor in Chemical Engineering at the University of Toronto. Her current academic interests include scaffolds for tissue engineering constructs for soft tissue applications and professional skills development. She holds a B.Eng. from McGill University and a Ph.D. from McMaster University.