Teaching Radioactive Waste Management in an Undergraduate Engineering Program - 13269

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ABSTRACT

The University of Ontario Institute of Technology is Ontario's newest university and the only one in Canada that offers an accredited Bachelor of Nuclear Engineering (Honours) degree. The nuclear engineering program consists of 48 full-semester courses, including one on radioactive waste management. This is a design course that challenges young engineers to develop a fundamental understanding of how to manage the storage and disposal of various types and forms of radioactive waste, and to recognize the social consequences of their practices and decisions. Students are tasked with developing a major project based on an environmental assessment of a simple conceptual design for a waste disposal facility. They use collaborative learning and self-directed exploration to gain the requisite knowledge of the waste management system. The project constitutes 70% of their mark, but is broken down into several small components that include, an environmental assessment comprehensive study report, a technical review, a facility design, and a public defense of their proposal. Many aspects of the project mirror industry team project situations, including the various levels of participation. The success of the students is correlated with their engagement in the project, the highest final examination scores achieved by students with the strongest effort in the project.

INTRODUCTION

The University of Ontario Institute of Technology (UOIT) is the newest University in Ontario. Chartered in 2002, the first cadre of students was admitted in September 2003. The mission of UOIT is to provide industry, particularly those near the University, with "job ready" graduates. Seven faculties make up UOIT: Energy Systems and Nuclear Science, Engineering and Applied Science, Health Science, Business and Information Technology, Science, Education, and Social Science and Humanities. The University is a "Laptop University" where every undergraduate student is supplied with a laptop as part of their tuition fees. These laptops contain many industry standard software packages, as required to provide an industrial environment for the various programs to train workers for the 21st century.

UOIT is located in the heart of Ontario's nuclear industry, with the Pickering nuclear generating station located 30 km to the west and the Darlington nuclear generating station 20 km to the east, and the Cameco fuel conversion facility, the Cameco and GE fuel manufacturing facilities located somewhat further east (Figure 1). It is not surprising that one of the founding faculties targeted nuclear science and engineering. The Faculty of Energy Systems and Nuclear Science at UOIT offers the only Canadian Engineering Accreditation Board accredited undergraduate degree in Nuclear Engineering in Canada. This Bachelor of Nuclear Engineering (Honours) program was designed for the nuclear power industry and produces graduates with a knowledge of reactor design, power plant systems engineering, maintenance, and modification of nuclear reactors with a particular emphasis on the CANDU® system. The 48 course program was developed in consultation with an advisory committee comprised of many prominent member of the Canadian nuclear industry and academia. Each course consists of three hours of lectures a week, supplemented by tutorials and laboratories, spread over a thirteen week semester. In 2011, students were admitted to the Bachelor of Applied Science (Honours) in Nuclear Power program and the first class will graduate in the spring of 2013. This program is currently available to 2 and 3 year-program college graduates who are targeting future employment as nuclear power plant operators.

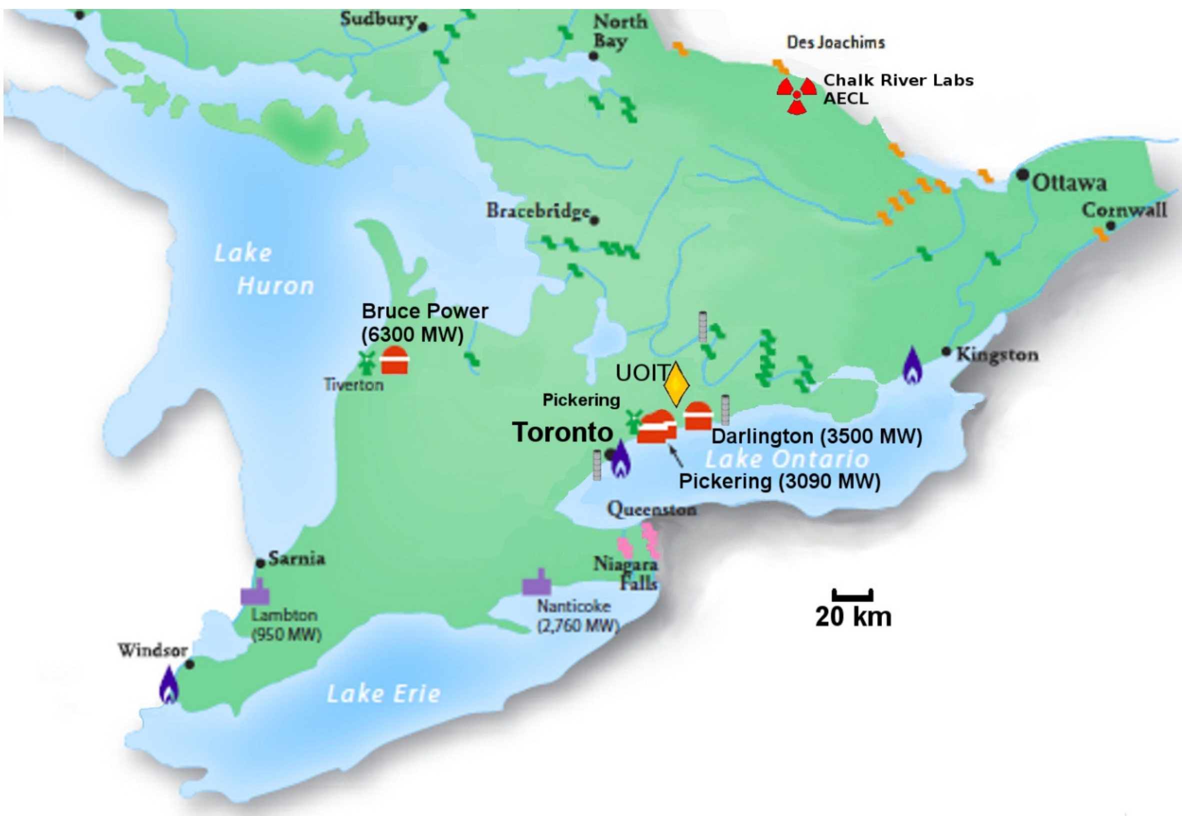

Figure 1. Map of Southern Ontario Showing the Location of UOIT and the Surrounding Nuclear Community [1].

The red silos are the nuclear power plants, the towers are fuel manufacturing plants, and the trefoil is the AECL research laboratory. The purple buildings are coal fired stations, the green “stars” are OPG wind-power sites, the blue drops are gas fired stations, and the green, orange, and pink blocks are hydroelectric dams.

Radioactive Waste Management - Design

One of the unique core course offerings for the UOIT BEng(Nuc) program is the final year radioactive waste management design course. This course is a full semester course covering the various forms of radioactive waste, and the production, storage, and disposal of waste, in Canada and around the world. To ensure the students have sufficient background for the study of radioactive waste management, the BEng(Nuc) program map includes two courses which are prerequisite to enrolling in the waste management course. The first is a course in radiation protection, which covers basic radiation safety, dose limits, risk, and both internal and external radiation effects; and the second is a course on environmental effects of radiation which includes biological effects of radiation, maximum permissible dose, and radioisotope release to and dispersion in the environment. The challenges are to train young engineers in the practices of managing radioactive waste, to develop their fundamental understanding of how to manage the various types and forms of waste for disposal or storage, and to instill a social awareness of how their practices and decisions influence and are influenced by the general public.

In an attempt to address these goals, the radioactive waste management course has been developed around two main themes – collaborative learning and self-directed exploration. Since these students expect to be placed in the nuclear industry within 4-12 months of completing this course, it is reasonable to challenge them with a work-place situation of working in a large team on a project that requires research and analysis to produce a report for public review. This major project, comprising 70% of their final grade, is the centrepiece of the course. The lecture component provides background information for their research, and some insight and direction for the work. The project is broken into many small contributions with a written report worth 15% (15 of the 70 marks allocated to the project) the culmination of the project. In an attempt to ensure that each student participates in the project, various individual contributions to the project have been identified for evaluation.

The issues associated with managing radioactive waste can be considered, in the extreme, to be issues associated with disposing of radioactive waste. Whilst storage of waste diminishes some of the long-term considerations necessary for waste disposal, they introduce other short term issues such as strong institutional controls and radiological protection measures. The course revolves around the environmental assessment of radioactive waste disposal, and pathway and scenario analysis. The choice of barriers is related to both the hazard and type of waste, with a constant reminder that barriers, although different, are also needed for storage of waste. Some of the similarities and differences are brought out in the lecture material. The design aspect of the course is emphasized here, highlighting the engineering basis for developing the requirements of the management system, then defining the barrier characteristics.

The Project

The world-wide expectation for sustaining the environment has changed the knowledge requirements for nuclear engineers. An understanding of current practices and process is no longer sufficient in light of the increasing public and political involvement when managing any hazardous materials. This is driving the design of management processes and facilities such that minimizing waste generation and reusing and recycling more material are vital considerations. The societal pressures for the user to pay for the management of their waste (the "user pay" philosophy), increasingly stringent environmental regulations governing release limits, and the diminishing availability of space are increasing the pressure to move from interim storage to final disposal of waste. The Canadian Nuclear Safety Commission (CNSC) regulates the nuclear industry in Canada and has set out a policy guideline for managing radioactive waste [2]. Embodied in Policy Guideline P-290 are the principles of user pay, expedient management of waste, long-term environmental and human safety, designing to minimize waste, and management practices commensurate with the hazard of the waste. In addition, the Canadian Environmental Assessment Agency (CEAA) has an Environmental Assessment (EA) process that is invoked by the CNSC as a condition of issuing a licence for a waste management facility.

In this waste management course, the project is an EA of a conceptual waste disposal facility. The project consists of four phases: a conceptual design, developing an EA comprehensive study document, a "public" defense of the EA, and a technical review of an EA. The class is divided into equal teams, no more than four teams per class. The teams are assigned a project from one of the following topics: fuel waste disposal, low-level waste disposal, intermediate level waste disposal, and one for either fuel storage or low and intermediate level waste disposal. Team progress is monitored via a tutorial devoted to project management. Attendance is mandatory. The students drive the project, but suggestions are provided for organizing and distributing the work, for controlling the level of detail required (or not required), and for managing the work.

The students are randomly placed in the teams, that is, they are not assembled by the students. An attempt is made to equalize the talent in a team by considering the student grade-point averages, internship experiences, and any significant inter-personal relationships. These are large teams (the smallest team in 7 years was 9 people) and many students have never worked together. These two features put the students in a new learning experience and put all the teams at an equivalent starting point. No team has a significant advantage of knowing work habits and relying on the smartest student. Leadership generally asserts itself early in the team forming[1] process, although leaderless groups have arisen. Leadership conflicts have arisen, but have been rare. The leader-less groups have managed to complete the work, and generally each participant's contribution has been good. However, those teams struggled to complete the work because they lacked a focal point for their efforts. The leadership hopefuls were left wondering why they were not taken seriously as leaders, the non-leader students were left realizing they need to take more ownership of leading a project. These students discovered the power of collaborative leadership in a peer group, and that it only works if they take responsibility for some part of that leadership. In the cases of leadership conflict, it usually arose because more than one strong leader/personality was in the group. This quickly resolved itself when the leaders realized they could work together. In only one instance was the conflict because the group disliked the style of the leader. That group soon realized that they would not succeed under a different leadership style, no matter how much more pleasant the condition. Consequently, they pulled together, decreased the leadership tension, and successfully completed the project.

[1] The four stages of team building are Forming, Storming, Norming, and Performing.

To prepare the students for the design phase of the project, they are given individual assignments to discuss the general characteristics of barriers used in waste disposal. They can choose from one of four topics: containers, engineered barriers, natural barriers, and waste forms. The assignment is general, only requiring a high-level definition of the broad design requirements for the barriers to function effectively for different waste disposal scenarios. The students are given an opportunity to chose a topic, but the last students to pick have little or no choice. To ensure that each team has a group of students with a kernel of knowledge on each of the barrier systems, care is taken to ensure that several students in each group study each topic. Experience has shown that a natural distribution of interest results in very few students who do not work on their first or second choice of topic.

When the teams are revealed, the first task is to brainstorm conceptual designs for their disposal facility. They have approximately two weeks to develop a simple concept, usually with sufficient literature background to justify their choice of barrier system. During this phase, team forming begins as the students recognize the capabilities of the individuals on the team and the leadership candidates are visible. Within two weeks, the storming phase of teambuilding begins. Conflicts in the choice of design paths emerge, student effort begins to become apparent, and the team leaders emerge. Generally, the effort in this stage of the work is good as each student attempts to avoid the designation of team passenger. Some of the preconceived notions of student performance, effort, and ability begin to breakdown as the students gain first-hand experience working with many other students. This step of the process ends with the production of a short, 2 – 3 page proposal for the waste management facility. During this stage of the project the students are within their comfort zone since this is an engineering exercise.

The main deliverable for the course is a comprehensive study document, the EA. However, to avoid scrimping on the design component, the comprehensive study guideline is not released to the teams until the design proposal has been generated, approximately two weeks after the start of the project. The guideline is the basis against which their report is evaluated. It is modelled on the template for a Comprehensive EA guideline for a nuclear waste disposal facility issued by the CNSC [3]. The guideline is a challenge to understand and developing that understanding is a source of continuing storming activity. The more analytically minded students soon recognize the document breaks down into requirements for content and structure for the EA report. Good leadership then draws this out and begins the process of allocating tasks to the team. In this phase, the experiential objective of the project is to engage the students in non-traditional learning that would be experienced in the workplace – the need to learn about a topic not entirely within their formal training. The diversity of the nuclear industry is emphasized in this project because some basic knowledge from various fields ranging from civil and mining engineering to chemistry and social science is required to complete the EA document. Clearly, expertise is not the goal, only a familiarity with the terminology and simple concepts of design and structure. It is in this phase that the team norming and performing occurs. The students choose topics from the guidelines and conduct research on the topics. There is a continuing need to focus the students in this phase to ensure that their research is both contained in scope and focused on the design of their facility. The objective is for the students to appreciate how the environment and their waste facility interact. Often, the dose calculated at the end of the project is not accurate, but the stronger groups can recognize the features in their design that lead to the low dose and what changes to the design might increase the dose.

Once the draft report has been completed, it is reviewed by another team. The review team is required to provide a technical review of the document, and produce technical questions based upon an EA guideline for the project. The review teams are selected such that two teams of similar waste management schemes are not reviewing each other's work. In this way, the knowledge gained during the project is shared amongst the class. Furthermore, the draft report is made accessible to the entire class for public review and comment.

The final phase of the project is to publically defend the project in a public "hearing". A modified public hearing process is used where the review team acts as the regulator and uses part of the class time to ask technical questions to the project team. The last half of the class is used for the students not on the review team or project team to ask any question that may be of interest to the public. As expected, the project team finds this hearing a challenge, while the audience members find it fun. The review team is neutral, but most students are astute and discover many nuances of the public-project interaction. The class evaluates the overall performance of the project team – how well do they present their proposal, how well do they answer questions, how convincing are they that their project is safe? While the first team to present is at a disadvantage in terms of the expectations of the session, the audience is also less "robust" and insecure in the depth to which they should interrogate the project team. The last team to present has the advantage of the previous sessions, but is now at a disadvantage because the audience is generally in a "no-holds-barred" mindset. The teams take care in choosing their presentation team, usually selecting the students that project the best public image. All students on the presenting team are expected to contribute to the presentation: preparation of presentation material, back-up material, answers to the draft questions posed by the review team, etc. Some may be present on the project team panel, but they may not present the project. The quality of their performance is graded as a team, although in extenuating circumstances a single member may be given a mark reduction for an unacceptable performance.

A management exercise for the students is for them to assess the performance of their teammates, a "performance review". They are given the role of a supervisor and asked to rate their teammates on their performance in categories of volunteering, sharing ideas with the group, quality of work, timeliness of work, accountability, participation, and ability to complete their task independently. Most students have been professional in their assessments of their teammates, and generally the rankings fall within a narrow range. The students who were not part of the project were generally unable to rank the performance of their teammates and tended to give "satisfactory" ratings across the board. Inevitably, some students performed poorly and were penalized on the teamwork component of their project mark. This has not been the case in every year or, until this year, the case for every team.

The largest and most difficult challenge is to encapsulate five to ten years work into approximately six weeks of project time. This is addressed throughout the course. The need to manage time on this project is essential, and some students find this time-management aspect the most valuable lesson learned in the project. Volunteerism and maturity are required throughout this project, and preconceived notions of student performance are often broken down by the mid-way point in the project. To some students, this is the most surprising aspect of the project. Students thought to be poor performers often rise in the eyes of their teammates, others fall.

Assigning individual marks to the project, and requiring students to pass their individual course components is an attempt to entice students to participate. Individual work in the course constitutes 45% of the mark, and each student must pass this component of the course to pass. Inevitably, those students who do not contribute to the project do not perform well on the individual components, suggesting that project "passengers" do not learn the course material.

The final examination is a test of their basic knowledge. One student was heard to comment that they did not know how much they learned until they wrote the final exam. Most students find the exam fair, and a test of their knowledge, not of their project. Students who limited their performance to a single topic and did not volunteer or avoided the meaty topics generally performed poorly on the final exam. The student performance assessment shows a weak correlation to the final examination mark (Figure 2). Although a stronger correlation might be expected, the students with a higher final examination mark generally were regarded as the hardest workers in the project, while the poorest performers inevitably scored poorly on the final examination. Not surprisingly, some student who do not perform in the group were strong enough students to succeed in the final examination. One might speculate that these students were intentionally underperforming in the project because they had secure employment, provided they pass the course.

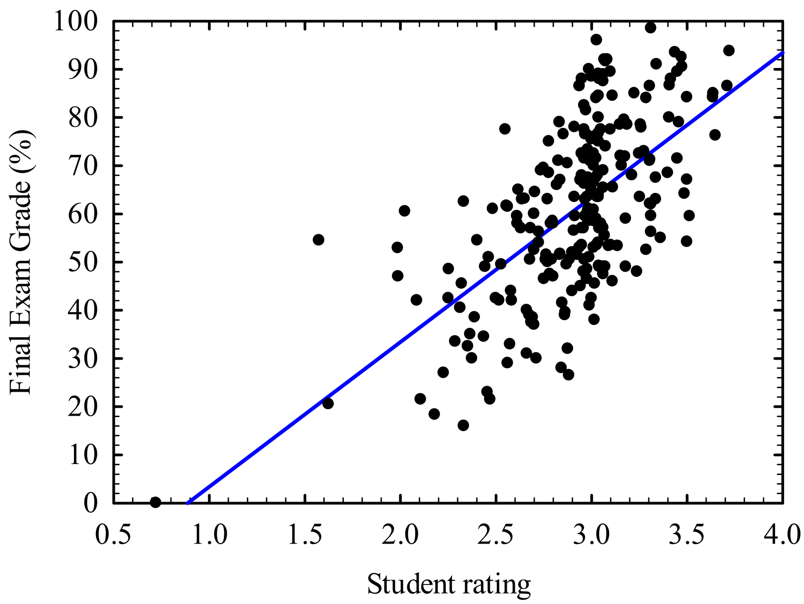

Figure 2. Regression Plot Showing the Correlation Between Student Assessment and Final Examination Result.

The sample size is 238 student evaluations taken over 6 years. The regression line has a correlation coefficient of 0.63.

The students rate their teammates on a scale from 0 to 4, with a value of 3 being fully satisfactory performance. The students are further instructed that they are not allowed to rank more than 1 student with a 4 (exceeds requirements) in any one category, although 2 students with a ranking of 4 are generally accepted. This is meant to force the students to assess who the best performer in a single category would be, but it also means that the group average may be shifted higher or lower depending on the strength of the group. The student ratings shown in Figure 2 were obtained by taking the individual ratings for a single student and averaging their ratings over all their teammate's responses and over all the assessment categories. This is a gross overall average that does not take into account specific features that might correlate better with performance on the final exam. Although the correlation coefficient of the grade versus rating relationship is low, 0.63, the F statistic is large, 156, because of the large amount of data. The F value indicates a high probability that the data are correlated and not random. Two important features can be seen in Figure 2. The A students (>80% on the final) are the satisfactory or above satisfactory performers in the group, where a satisfactory ranking is arbitrarily set at a student rating of 2.8; all the rest were above 3.0. Only 5 students scoring above 80% on their final exam received group rankings between 2.94 and 3.0. Although high student ratings were not a guarantee of good final exam performance, good exam performance was associated with a high student assessment[2]. However, it is also apparent that most students were satisfied with the performance of the team as a whole, as shown by the striking density of points along the vertical line at the student rating of approximately 3.0. It is also apparent on the left of Figure 2 that students deemed to have unsatisfactory performance, student rating <2.5, scored poorly on the final exam (< 60%).

New Challenges

The large group sizes encountered in 2012 resulted in an overall poorer performance by the students. The students did not succeed in working less to produce better quality work, a complaint of teams in previous years. Instead, the groups tended to lose focus. The team leadership was as strong as in any other year, but the students themselves seemed to lose track of the grading requirements for the project – conformance to the EA guideline. This may be because each individual looked at producing less than in the past, and did not feel they needed to be responsible for the goals of the project. A large class is anticipated for 2013, and the project management may need to be examined. One suggestion has been to use deadlines as part of the marking scheme, and any team members who do not submit work on time are immediately penalized and their work excluded from the marking scheme. The issue of deadlines was significant in 2012 since one group submitted unacceptable work because of missed deadlines, and did not receive feedback that was pointed to produce an acceptable quality final report. Another possible adjustment may be to emphasize sub-groups with greater responsibility for the sub-groups to produce the final product. In previous years the teams were too small to effectively split into sub-groups. However, this year the groups were nearly double the size of the groups in past years (a constraint placed because of the class time available to complete the project hearings component). This sub-grouping may be a far more effective distribution of work and responsibility. Convincing the students that they are responsible for all aspects of the project will remain a challenge.

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[2] Note that this is only the final examination result, not the final grade for the course. Students with < 80% on the final exam have and do achieve A's in this course.

The inclusion of BASc students in the course introduced a new variable: deliver the same course material to two different groups of students. While this had been accomplished for graduate students enrolled in this course (the project component was different and their role in the undergraduate project was significantly different), the objectives of the BASc and BEng(Nuc) students were sufficiently different that a similar solution may not be appropriate. The significant difference between the BEng(Nuc) and the BASc course objective is that the engineers should develop skills to develop innovative design solutions to radioactive waste management whilst the BASc students need to develop skills for managing and understanding the processes for managing the waste on a power plant or waste management site.

The lecture material was the same for the two classes, the message to be delivered to the two classes was slightly different. The BASc students had difficulty identifying the non-design messages from the material. The assignments for the two groups were different, with more emphasis on assignments given to the BASc students because their group project was not so demanding. The different career paths for the two students dictated the different projects and groups since operations staff are unlikely to be grouped into such large, problem solving groups, even though their work-group may be large. This leads to a more conventional teaching format for the BASc students, with more traditional tutorials and work assignments and adds to the challenge of managing the joint class. However, they did benefit from participation in the hearings sessions. Understanding the rules, that is, the policies and procedures for managing waste is important for the BASc students, but the public hearings process instilled a realization that the public and social politics can have a significant impact on the work processes.

CONCLUSION

Through the design of a waste disposal facility and the subsequent justification of the safety of the facility via an environmental assessment, the final year BEng(Nuc) students gain an appreciation for the role of facility design on environmental impacts. They learn through individual research, and develop supplemental knowledge necessary to complete an interdisciplinary report on the environmental effects of their facility. Through a mock public consultation process, they develop an appreciation for the role of the public on the success of a waste management project. The success of the student is closely tied to their investment in the project. Those students content to perform minimal research in a small area of the waste management scheme tend to have a weaker understanding of the overall waste management design process and achieve lower grades. In contrast, those students willing to perform work in many areas and drive the success of the project tend to show a better understanding of the requirements to design a waste management facility and achieve higher grades.

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