AC 2010-228: THE CHALLENGE OF TEACHING SUSTAINABLE DEVELOPMENT USING A MULTIDISCIPLINARY PROJECT WITH INTEGRATED PROCESS DESIGN

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Louise Millette is, since 2002, the first (and only) woman to hold the position of Department Director at Ecole Polytechnique de Montreal. After graduating in civil engineering at Ecole Polytechnique, she obtained a Master's of Applied Science from UBC and then a Doctorate from Ecole Polytechnique. An experienced environmental manager, she worked at Bell Canada for 12 years before joining Ecole Polytechnique as Director of the Department of Civil, Geological and Mining Engineering. Very involved on the municipal scene, Dr. Millette chairs two committees of "la Conférence régionale des élus de Montréal": the Environment and Sustainable Development committee and the Urban Landscape Committee. She is a founding member and a major contributor to Montréal's First Strategic Plan for Sustainable Development.

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Erik Bélanger has worked on the development of the course Sustainable Development Capstone Project. Since then, he has contributed to the evolution and the teaching of the course. He obtained his engineering bachelor's degree in mechanical engineering from University of Sherbrooke in 1999. After graduating he worked in industry as a design engineer before completing a Master's of Applied Science Montreal at Ecole Polytechnique de Montreal. Since 2004 he has worked at Ecole Polytechnique as research assistant for sustainable development projects and as a lecturer.

The Challenge of Teaching Sustainable Development Using a Multidisciplinary Project with Integrated Process Design

Introduction

The Sustainable Development Capstone Project is a course designed to demonstrate that every engineer, regardless of his or her specialty, must be concerned with sustainable development. It is a final year undergraduate technical project offered to students from all engineering disciplines, which is almost unheard of at the École Polytechnique de Montréal (Polytechnique). The course started in the 2008 winter term and was being given for a third time as this paper was being written. Students work in multidisciplinary teams on a sustainable development project in a context very similar to the real engineering working environment.

A multidisciplinary course provides major challenges for both teachers and students. These include the acceptance of a multidisciplinary technical course when it is a departure from current practice, the process of making students from various disciplines work together using an integrated process design, and the guidance and evaluation of multidisciplinary teams despite limited teaching resources.

This paper will present the course context, the challenges faced to get the course approved, the course description, the main difficulties related to the course organization, and the activities planned to ensure effective student guidance and evaluation. The paper will conclude with lessons learned from both the student's and teacher's point of view.

Context

In 2005, Polytechnique completely reorganized all of its undergraduate engineering programs[1] The bachelor's degree in engineering at Polytechnique is a four-year program of 120 credits, 108 of which are for compulsory courses. One of the major changes to all programs was the addition of a project course to each year so that students could integrate technical learning and apply oral and written communication skills developed in complementary studies.

During this program overhaul process, each department suggested the improvements needed to address the desired competencies and to meet the requirements of the Canadian Engineering Accreditation Board (CEAB)[2]. To propose such changes, the civil engineering professors compared the competencies achieved in each program course with the desired competencies using a matrix, as suggested in Civil Engineering, Body of Knowledge for the 21st Century[3]. This examination showed that the civil engineering program should better integrate environmental management and sustainable development into its courses to ensure that students develop the desired competencies.

The idea of "contaminating" the civil engineering program with sustainable development crystallized in the mind of Professor Louise Millette (Associate Professor and Director of the Department of Civil, Geological and Mining Engineering) following an analysis of the competencies matrix. Initially, she sought and obtained two teaching support subsidies in 2006 and 2007 to finance a pilot project that produced a series of "capsules." These capsules are

examples of the application of sustainable development to a variety of civil engineering courses. They demonstrated that the material for each course could be taught from a sustainable development perspective.

A sustainable development capsule is material developed for a course and adapted to its pedagogy. It can involve a one-hour lecture, practicum or case study. A capsule has been prepared for sixty-five percent of the courses in civil engineering. A capsule was also developed for a computer engineering course in response to a request from a professor in that department. This capsule has demonstrated that a course from any discipline can be given from a sustainable development viewpoint.

In 2008, Professor Millette obtained a five-year grant from the Desjardins Foundation, which has a special interest in sustainable development projects. To obtain the Desjardins Foundation grant, Professor Millette proposed the creation of the Sustainable Development Capstone Project, a course that combines a multidisciplinary group project and individual projects in the form of sustainable development capsules. The Desjardins Foundation grant has provided a unique opportunity to create the Sustainable Development Capstone Project course, to allow the sustainable development capsule project to be completed, and to address the need for the institution to offer project courses. The Sustainable Development Capstone Project also provided an opportunity to address several graduate attributes desired by the CEAB[2]. These attributes include :

1) Design :

"An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, economic, environmental, cultural and societal considerations."

2) Team work and multidisciplinary work :

"An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting. "

3) The impact of engineering on society and the environment :

"An ability to analyse social and environmental aspects of engineering activities. Such abilities include an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society; and the concepts of sustainable design and development and environmental stewardship."

Although the Sustainable Development Capstone Project satisfied competencies development desired by Polytechnique and the CEAB, it was not readily accepted at first, and the Sustainable Development Capstone Project developers had multiple challenges getting it approved by all programs and department directors. This acceptance was difficult for two main reasons :

1) Multidisciplinary technical projects were not part of the Polytechnique culture. At the time, they simply did not exist.
2) To be viable, the course had to be offered to fourth-year students from all programs as a replacement for the fourth-year capstone project in their disciplinary program. The loss of students who would take the fourth-year capstone project in another department made some program and department directors reluctant to accept the course.

A lesson learned : the course would have been more easily accepted if its content had derived from a consultation process, but the time-frame was short, and the foundation supporting the project wanted immediate concrete results. At present, the course is accepted by all programs, and some inter-departmental cooperation has begun.

Course description

The first two times the course was given, the students worked on the design of a sustainable multi-use community building in an urban setting with the collaboration of a non-profit support organization, Montréal Urban Community Sustainment (MUCS). The third time the project changed, and another sustainable multi-use building was designed. It was set in an eco-village in collaboration with the developer Terravie, also a non-profit organization. It also included design for local energy production, water and wastewater treatments, and local transportation infrastructure. Since the beginning, the work has been based on a real project with as much client involvement as possible.

The course outcomes are:
1) Have students understand the role of engineers in sustainable development design.
2) Have students master the multidisciplinary context of design.

Students are encouraged to work together and develop design skills using an integrated process, which is a common practice for the design of green buildings. This process requires involving all project stakeholders from the beginning so that the design is initiated on a sound basis and takes into account the constraints and goals of all disciplines involved[4]. With this process, projects may start slowly, but problems are avoided later in the design. The main goals for the teachers are to make the students work together and guide them in addressing all fields of sustainable development in the project (the environment, economic, and social issues). Teachers have to remind the students that engineers design for a community and must address its needs. This might mean a compromise on energy efficiency to address social aspects, which are especially important in this project.

Teaching

In project courses at Polytechnique, students apply knowledge acquired in previous courses to an engineering project. Little new material is provided to students, the goal being to have them integrate already mastered concepts. Special attention is paid to the design process, multidisciplinary work and the integration of sustainable development. Two teachers, a mechanical engineer and a civil engineer, supervise the students. The main challenges for the teachers : provide support and evaluate students despite the wide diversity of engineering

specialties involved. Activities implemented to address these issues are described later in this paper.

Group project

The main part of the course is the group project. Students work in multidisciplinary teams established by the teachers and based on the balance of student disciplines, specialties and academic results. The first time the course was offered, only one team of five students was involved. The second time, the course had twenty-two students in four teams and the third time, twenty-six students in six teams. The second and third times, students from civil, mechanical, chemical, electrical, geological, industrial and material engineering enrolled in the course. The third time, twelve architecture students from Université de Montréal joined the engineering students, but the integration of this type of expertise will be the subject of a separate paper.

Work method

To address integrated process design, students must not work in silo. The teachers emphasize the design process and refer to the problem solving method proposed by Wankat and Oreovicz [5]. The development of competencies such as problem definition, hypothesis generation, problem planning and resolution, and verification of results are especially important for this course. The skill levels desired are the higher levels of Bloom's taxonomy[6].

In the course of the four-month term, students must hand in four reports intended to :
1) Show an understanding of their task and plan the team's work and project schedule.
2) Make and justify the design choices.
3) Design the project and present it to an expert panel.
4) Reply in writing to the panel's questions and present the project to a wide public audience.

Individual project

In addition to the multidisciplinary group project, each student completes an individual project that involves the re-examination, from a sustainable development viewpoint, of material from an engineering course already completed. The student must then develop a sustainable development capsule for that course. The student develops material for this course in collaboration with the teacher of the chosen course. Collaboration with the professor involves a one-hour meeting at the start of the project to define the project orientations and the type of material that will be developed. The material (oral presentation, practicum or case studies) can then be used by the teacher if he or she wishes to include sustainable development aspects in the course. The goal is to assist all teachers in adding the sustainable development viewpoint to their courses.

The individual projects are evaluated by the teachers of the Sustainable Development Capstone Project course. First, the students submit a detailed plan for their individual reports to the teachers. The teachers perform a formative assessment of the plan to allow students to improve their individual reports. Students submit a final written report half-way through the term. The following components are evaluated:
1) Relationship of the individual project with the chosen course and the field of engineering.

2) Integration of sustainable development.
3) Explanation of the individual project (context for practicum and case studies, accompanying text for the oral presentation).
4) Structure and visual quality of the material developed.

Difficulties related to the group project

Difficulties: *teacher's* viewpoint

One of the challenges of the course is to find real projects that involve client collaboration and offer an equivalent work load and complexity for all disciplines. This is not an easy task, especially since the class composition (in terms of disciplines) is known just a few weeks before the beginning of the term. However, some trends have been observed : the course is popular mostly with civil, mechanical and chemical engineering students. Students from other disciplines also enrol in the course, but in smaller numbers. A major part of the project has thus to address civil, mechanical and chemical engineering topics. Another challenge: ensure effective student guidance and evaluation despite discipline variety.

Difficulties : *student's* viewpoint

For most students, the Sustainable Development Capstone Project is their first multidisciplinary experience. Although they know this is an enriching experience, they often face challenges. One of the possible difficulties is that no one else on the team speaks the same technical language or has similar skills to face and solve problems. Despite the fact that the course is designed to represent the real engineering working environment, this context is not really established : junior engineers are usually guided by senior engineers and, in real life, an engineering project is not entrusted to a team composed entirely of junior engineers. The teachers alleviate this problem by providing support to students for the design process and guiding them to technical resources if needed. Finally, students have to make sure they work as a team and resist the temptation to work alone.

Logistical aspects

Logistics comprise a large part of the organization of the course. There is a nominal course choice grid for each year of every undergraduate program, but not all students are willing or able to follow it. This flexibility generates timetable conflicts within programs and becomes a real puzzle when trying to schedule a multidisciplinary course. Timetable conflicts are thus inevitable for the Sustainable Development Capstone Project, even with the full cooperation of the registrar. Coordinating the professionals involved in the course also requires much time and energy.

Course activities

To address some of the difficulties and develop specific skills, activities have been created to help teacher's guidance and offer technical support to students from all disciplines.

Conference

During the first six weeks of the term, engineers with practical experience give conferences in various disciplines related to the project. Their goal: upgrade students' technical knowledge and establish a basis to initiate the design. A workshop follows each conference; students are helped by the guest engineer to apply learned concepts to their project.

Design studio

Twice during the term, professionals from various disciplines (engineers and architects) participate in a design studio. During this activity, students work with their team in collaboration with one professional for a period of forty minutes. After that time, the professional moves to another group so that each team eventually receives support from each professional. To benefit from the design studio, students have to be well prepared and their project has to be sufficiently advanced. The objective of this activity is to simulate collaboration between junior and senior engineers and to give students technical support. It also helps that teachers offer adequate technical guidance during the project. Students appreciate this activity because they work in collaboration with a professional with experience in their discipline.

Expert panel presentation

One of the objectives of capstone projects at Polytechnique is for students to apply the communication skills developed in complementary studies courses. They meet this objective through the team project presentation to an expert panel. The panel's task is to challenge students about their design and give constructive feedback. Students have to answer the panel's questions in their final report.

Public presentation

At the end of the term, students also present their project to a wider public audience. The objective for the students is to make technical content accessible to a wide general audience.

Lessons learned

Student's point of view

At the end of the term, students must trace their progress, both technical and social, during the course. They submit a team report that synthesizes their observations. They must also answer the question, "What would you do differently if you had to do the project again?" An answer is required for each of the following areas : work organization, design process, technical aspects, teamwork and crisis management. The purpose of this reflection is to show students that they have not just gained technical knowledge but also learned skills in adjacent fields, such as teamwork, multidisciplinary work, team dynamics and crisis management, which are all important for their future careers as practicing engineers.

Several interesting results emerged from this exercise. The students found that it was better to work as a team than individually and that team management was easier if they closely followed the project schedule from the beginning. The teachers made these suggestions throughout the entire term, but the students only truly integrated them at the end of the process. The students also found that it would have been useful to hold design review meetings in order to monitor work progress as a complement to meetings about the work yet to be done.

Teacher's point of view

This course is very enriching for the teachers. After each term, improvements have been made to better guide the students. The improvements listed below will be implemented in the next term :

1) Explain the importance of holding design review meetings and find ways to get students to hold them.
2) Encourage students from the same engineering discipline but from different teams to work together at specific times during the term. The goal is to get the students to discuss their design difficulties and to initiate collaboration among students from the same discipline. To encourage this, the second design studio will be modified so that students from the same discipline will work with a professional for two hours. They will then return to their team and report what they have learned to the other team members. The advantages of this approach : increased collaboration between members of the class, consistent messages sent to all teams, and an enhanced design thanks to help from the professional.

Conclusion

Offering a multidisciplinary course such as the Sustainable Development Capstone Project presents several challenges. The first was a key aspect : getting Polytechnique to accept a multidisciplinary technical project course for the first time. It is interesting to note that another multidisciplinary course has since started, but it involves only one team of five students. Despite several difficulties and initial resistance, the course is now accepted and functioning. Each term, the teachers face the problem of timetable conflicts. They also have to ensure the multidisciplinarity of the student teams without knowing the class makeup in advance. They therefore have to adjust course content according to class composition. Activities to ensure good technical guidance and proper evaluation of students have been put in place; these activities have made the course a success and continue to be improved each term to ensure student's competencies development. Emphasis is put on the design process, multidisciplinary work and the integration of sustainable development into the work of an engineer.

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