

# Sustainable Design Throughout the Curriculum Using Case Studies\*

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*Case studies are presented as an option to integrate various thematic concepts such as sustainable design throughout a conventional engineering curriculum. This approach is best with the pervasive and consistent use of cases, which in turn requires a sustainable supply of good quality design cases covering a wide range of engineering topics. A new program at the University of Waterloo is described which is focused on the development and implementation of case studies. A key innovation of this program is that cases are developed primarily from student work term experience, through conversion of work term reports. Waterloo engineering students currently produce approximately 4000 of these work term reports every year, making them a rich source of design case material. The Waterloo Cases in Design Engineering program is presented and discussed, along with early results in the development and implementation of cases.*

**Keywords:** case studies; sustainable, design; co-op education; student experience; case writing

## 1. INTRODUCTION

ENGINEERING PROJECTS are increasingly complex. There is a greater need to work collaboratively in a team and to consider the impacts of engineering projects on society and the environment [1]. This has significant implications for engineering educators. In addition to a sound foundation of technical knowledge and skills, all students must have an appreciation for the complexity and interrelatedness of engineering projects. Some students must be able to take leadership in sustainable design, through minimizing processing inputs (energy and materials) and environmental impacts.

This changing academic environment is reflected in new requirements for the accreditation of Canadian engineering programs [2]. These new procedures are placing more emphasis on outcomes, as summarized in a list of 12 graduate attributes provided in Table 1, and many of these outcomes are directly related to an appreciation of complexity and working in teams.

Sustainable design is ‘a design philosophy that seeks to maximize the quality of the built environment, while minimizing or eliminating negative impact to the natural environment’ [3]. It is a design philosophy that represents an invaluable perspective for the training of engineers to meet the changing criteria. It takes an inclusive and holistic view of the design process, and offers experience in dealing with complexity. It is consistent with other approaches focused on the training of global engineers [4] or based primarily on projects [5], for example. These holistic approaches

represent a counterpoint to the traditional reductionist view of engineering and its focus on analysis. All have the same issues with implementation, since they require an inculcation of attitudes, methods and specialized skills which are qualitatively different from the analysis skills emphasized in the conventional engineering curriculum. All are difficult to achieve in a conventional academic environment.

Waterloo Cases in Design Engineering (WCDE) is a new initiative at the University of Waterloo, and is part of the Canada-wide NSERC Chairs in Design Engineering program [6]. The focus of the WCDE initiative is to develop and implement engineering design case studies throughout the Engineering curriculum. These case studies offer the potential to provide a rich context for the treatment of engineering science and design courses alike, and an ideal mechanism to convey different perspectives for complex engineering projects. This context allows students to make connections between concepts and subjects, and holds the promise of increasing both the depth and breadth of understanding. In order to take full advantage of this opportunity, the use of cases in the program must be pervasive; thus the target is to implement at least one case in every course. This requires a diverse and sustainable source of quality cases. The unique feature of the Waterloo program is that case studies are developed based primarily on student work term experience, which is currently documented in the form of work term reports. Waterloo students across the Engineering faculty write approximately 4000 of these reports each year across a wide range of disciplines. This provides an incredibly rich and sustainable source of case studies, which can be used to improve courses across the faculty.

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Table 1. Canadian Engineering Accreditation Board (CEAB) graduate attributes [2]

Criteria
1 A knowledge base for engineering
2 Problem analysis
3 Investigation
4 Design
5 Use of engineering tools
6 Individual and team work
7 Communication skills
8 Professionalism
9 Impact of engineering on society and the environment
10 Ethics and equity
11 Economics and project management
12 Life-long learning

Cases are also generated from student capstone projects and by working directly with industry partners. This latter approach is more time consuming, but is more powerful since there is more flexibility in choosing the topic and the depth of analysis, and one can focus on leading edge approaches to sustainability, for example.

In the present paper, the rationale for the program will be discussed, its structure and challenges presented, and preliminary results conveyed.

## 2. BACKGROUND

A case is a representation of a real situation that is used in learning [7]. Cases provide background context that motivates learning, and allows students to see the interconnections between concepts. Cases can be used in the application of a particular concept, the integration of several concepts, and/or as the basis for the design of a solution to a specific problem. Of particular interest is the way that a case can be used to provide students with an opportunity to see the application of engineering principles in a real context, be given the opportunity to identify the appropriate principles to use, and to see the interdisciplinary aspects of most engineering problems. Thus, sustainability can be identified as an important issue even if the focus of the use of a case is to investigate the application of heat transfer principles.

Cases have been successfully used in the teaching of law, medicine, science, business and engineering [8–10]. Cases can be used to improve understanding: breadth by illustrating connections between different subject areas, and depth by providing connections between facts, concepts and procedures in a particular application area. Learning with cases is an active process. Ideally, it starts with individual work to gain an initial understanding of the case, but is followed up with active discussions in small groups with fellow students and then in a larger class facilitated by the professor. This succession of discussion encourages students to take responsibility for their own learn-

ing, gives them some freedom to focus on areas of personal interest, while forcing them to make judgments regarding study time management.

There has been considerable research published on the advantage of case studies for problem-based learning in individual courses [11, 12]. The advantages of active and experiential learning techniques have also been well-documented in the literature on teaching and learning [13–15]. A study conducted at the Worcester Polytechnic Institute [16], for example, demonstrated that students enrolled in the Global Studies Program, a two-month work study program focused on technology and society, were more ready for self-directed learning than they had been before taking part in the program.

It is anticipated that this self-learning and motivation can only be improved when the cases are derived directly from students' own experiences. It is further expected that the potential that a case study will be developed from a student's work term report will increase their motivation to learn during the work term, and to properly document that learning in the form of a work term report, or directly as a case.

Available case histories of engineering failures [17, 18] or designs of ordinary things [19] can be used to provide an illustration of the engineering method and emphasize the responsibility of the engineer. Repositories of other cases for engineering [20, 21] are available, but are difficult to keep updated. A critical mass of engineering design cases has not yet been established, and insufficient cases are available to allow them to be used pervasively across the curriculum. A change in culture is required for all stakeholders—faculty, students, the university and industrial partners—to encourage the development and implementation of engineering design cases. Such a culture exists in certain business schools as a result of a long history of their use, and both academic and financial incentives for the development of cases.

A different approach is being tried at the University of Waterloo to develop this culture, based on leveraging our own student's co-op experience [22].

## 3. CASE STUDY PROGRAM AT WATERLOO

All engineering students at the University of Waterloo alternate co-op work terms with academic terms. They have a total of 6 work term opportunities, for a total of 2 years of engineering experience, before the completion of their 4-year engineering program. This requires one additional year compared with a conventional program. An engineering work term must be technical in nature, and at least 4 of their 6 work terms must be documented in the form of a work term report. Waterloo has one of the largest engineering faculties in Canada and currently

1.	Introduction
2.	Background (Context)
3.	Thermal Model
3.1.	Background Theory and Assumptions
3.2.	Model Verification
3.3.	Model Results for Renovated House
4.	Selection of Heating System
4.1.	Heating Systems Considered
4.2.	Cost Comparisons
4.3.	Selection of Best Option
5.	Conclusions
6.	Recommendations
7.	References



Fig. 1. Report outline for the Elora home heating project; house shown on right.

places approximately 2000 engineering students across all disciplines on work term every 4 months, resulting in about 4000 engineering work term reports each year. This represents an immeasurable and sustainable wealth of experience which could be used to enrich the academic experience of all engineering students, and an opportunity to strengthen university-industry partnerships at the working level during course development and delivery. In addition to improving the learning experience, this can generate spin-off opportunities for research partnerships.

The work term report must be related to a student's work term experience and have 'analytical content', which typically involves the application of engineering science to the analysis of a specific situation, or the design of component or system. A typical work term report is 15–20 pages in length. The expectation is that the work term reports will help to integrate academic and industrial experience for the student, but emphasis is on providing experience to improve the quality of written communication. There is renewed interest in emphasizing this integration role at the University of Waterloo through the practice of critical reflection [23], and the current program has been designed to help meet this objective.

Work term reports are accepted in a variety of formats. Figure 1 is an example work term report outline. This outline was provided to first year students in a first year concepts course for mechanical engineers in the fall of 2005. A key objective for this course is to introduce students to the profession and prepare them for their first work term placement, especially the writing of a work term report. In this case, students were required to use the design process and appropriate engineering analysis to recommend a heating system for Professor Lambert's house in Elora.

The work report starts with an introduction to the general problem area and background context. The specific approach to resolve the problem is indicated, and the subsequent sections document the solution. In this situation, students were provided with real data on monthly natural gas usage, and the knowledge that the home was being


renovated to provide for the addition of insulation. This implied that some kind of heat transfer analysis was required to identify the new heating load after the completion of the renovations. Once the new heating load was established, various choices for the new heating system could be evaluated, and a particular solution recommended. Students were asked to consider both qualitative factors, such as environmental performance, with quantitative factors, such as cost.

Figure 2 illustrates the corresponding case structure used to present the Elora home heating case. This structure has been selected to emphasize the similarities between a work term report and an engineering design case. The content is essentially the same. The case itself presents the problem and background context, and finishes with a general statement of the problem. The analyses used to examine the problem and to permit the choice of a solution are presented in separate modules to maximize flexibility in classroom use. Typically, only the case itself would be provided to the students. The solution modules would be available to the professor and they may choose to reveal parts of these after students have attempted their own solution. In this example, the thermal model and the selection of the heating type are placed in separate modules. Fig. 3 shows the front page of the completed case study.

This case illustrates an engineering problem with

Case: Problem Description
• Introduction
• Background Context
• General Problem Statement
Module 1: Thermal Model
• Background Theory for Model
• Model Verification
• Model Results
○ Heating Requirements
Module 2: Design Solution
• Heating Options Considered
• Cost Comparisons
○ Recommendations

Fig. 2. Case structure for Elora home heating project.



**WATERLOO CASES IN DESIGN ENGINEERING**

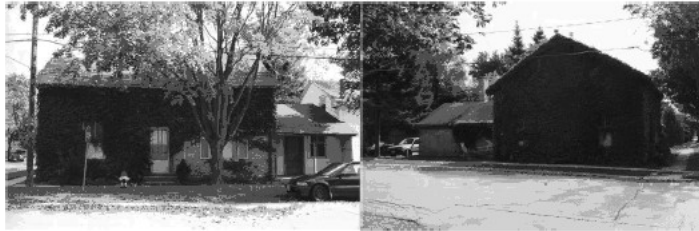
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## ELORA HOME HEATING

S. Lambert

**Introduction**

In August 1999, Steve Lambert, a Professor in the Department of Mechanical and Mechatronics Engineering at the University of Waterloo, purchased a stone house in Elora, Ontario, Canada. Figure 1 illustrates the front (west) and side (north) views of the house as it looked when it was purchased. The stone exterior is obscured by the ivy growing up the sides of the house. The house was not well insulated, and heated using a forced-air natural gas furnace. This furnace has a rating of *81,600 Btu/hr (102,000 Btu/hr natural gas input)*. The house was purchased with the intention of significantly updating the interior, especially the insulation and windows, to significantly improve both comfort levels and energy efficiency.



(a) Front (west) view of original house. (b) Side (north) view of original house.  
 Figure 1: Photos of the original house.

The main house consists of two floors approximately 30 ft long by 25 ft wide, for a total gross living area of about 1500 ft<sup>2</sup>. It has a rough basement under half of the main house and a crawl space under the remaining half. Figure 2 provides a schematic of the layout. Dimensions of each wall surface are provided in Appendix A.

S. Lambert of the University of Waterloo prepared this design case for classroom use. The authors do not intend to illustrate either effective or ineffective handling of an engineering situation. The authors may have disguised certain names and other identifying information to protect confidentiality.

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WATERLOO CASES IN DESIGN ENGINEERING

Fig. 3. Front page for the Elora home heating case.

a strong environmental context, to minimize energy usage for home heating. Students were able to appreciate the significant technological possibilities—the chosen levels of insulation upgrades were predicted to reduce home heating energy use by a factor of three—while the economic analysis of competing alternatives illustrated real-world financial challenges. In subsequent terms, students built on these results and investigated more aggressive environmental solutions including active solar thermal systems. This laid the foundation for the possibility of more dedicated sustainable design cases later in the curriculum, both in specialized and general engineering courses.

Cases are a simulation of reality, and will always represent a rough approximation to the real physical and social context. To engage and motivate students, the case must allow the student to put

themselves into the situation, as an active participant. This is made easier as the authenticity and relevance of the case increases. Authentic cases are based on real data and real situations. Cases written by co-op students based on their own experience are inherently authentic and relevant, and therefore motivating, but care must be exercised to ensure that the data, approach and analyses are correct. This is addressed as part of the release process, by requiring that the employer sign off on the use of the case, and that the technical analyses be presented clearly enough to be readily verified by a third person. This clear presentation reinforces the importance of communication to students.

A system has been developed to promote this program to students, and many have already submitted their work term reports for consideration for conversion to case studies. Submitted

work reports are reviewed for quality and alignment with current curriculum needs. These needs are identified by a committee of design champions associated with the WCDE group, with participants from each engineering department. Once a report has been identified for conversion, a short case plan is written, outlining the basic situation, the intended structure of the case and modules, and a list of data to be included and/or additional data required. This plan is reviewed by the student and their employer, to confirm that they would be comfortable releasing the completed case before any extra work required to convert the case has been expended. The case plan is also reviewed by an appropriate professor, to confirm that the final case would be suitable for use in their course. Once the provisional release has been obtained from all stakeholders, staff members from the WCDE group convert the report to a case. The final draft is again reviewed by the stakeholders, prior to final release and use in class. Measures are in place to address intellectual property issues. The student and case writer typically share the copyright for the completed case, and provide a royalty-free license to the University to distribute it for classroom use. The student and/or company retain all intellectual property described in the case.

#### 4. RESULTS TO DATE

A key advantage of the WCDE program is that it is faculty-wide, and centralized in the decentralized culture at the University of Waterloo. This provides an opportunity to use a consistent design language across all departments, forming a foundation for potential multi-disciplinary work in the future. It also forces the group to take a systems-level approach and place higher priority on cases that can be used throughout the faculty. An example is the Rainwater Harvesting case developed in collaboration with Engineers Without Borders (EWB—[www.ewb.ca](http://www.ewb.ca)), a not-for-profit organization founded in Canada by former University of Waterloo students in 2000. This case was developed to introduce students to a formal design process, and to illustrate the role of engineering calculations in design. It has been implemented in every first year concepts course across all engineering programs for the past 3 years.

In the EWB case, students are presented with a challenge of designing a rainwater harvesting system for a small village in India. The particular concept has already been selected based on practical and political issues, so students are focused on the implementation. This is quite realistic as engineers are often asked to follow through with someone else's design concept. However, as part of the design process, students were asked to question the assumptions that led to this concept. After some discussion, they are led through a simple Excel simulation to determine an appro-

appropriate reservoir size for an individual family. Due to the large number of students involved—over 1000 students per year, across 13 programs—this case was delivered over the web, and student volunteers from the local chapter of EWB were invited to lead some of the discussion in each class following completion of the case.

Students found this case engaging [24] and many were receptive to the more overtly social issues associated with this situation. Others emphasized the fact that this situation was real, and preferred it to other Excel examples they were asked to complete, which had no real context. The implementation of this case met the desired learning objectives: to introduce the students to the design process, to provide some training in the use of Excel for engineering calculations, and to introduce students to the importance of social issues in engineering practice. This provided a very positive experience of the integrating benefits of case studies.

In the upcoming term, fall 2009, this approach will be extended by having the first year mechanical engineering students design a rainwater harvesting system for the Elora house. This house was retrofitted with standing seam steel roofing in anticipation of this application. This will provide the students the opportunity to contrast water usage patterns in Canada and India.

A second case has been developed and implemented to demonstrate more details of the design process, especially conceptual design. The case was written based on a fourth year design project report. In this project, a student designed, built and tested a foot brace for himself, to be used to counteract a condition known as 'foot drop', wherein he had lost the ability to properly lift or *ever*t (twist outward) his foot due to damage to his *peroneal* nerve sustained as a result of a sports injury. Existing foot braces assist with this condition, but are not adequate to return the student to an active lifestyle, including running. The case objective is to design an alternate foot brace to permit long distance running. The case is structured in a series of modules beginning with the case itself, which describes the situation and the desired outcomes. Subsequent modules illustrate the student's solution and are structured to follow the design process: needs assessment, conceptual design, preliminary design, and detailed design and prototyping.

The *Foot Brace Design for Long Distance Running* case was implemented in three separate Mechanical Engineering courses in the fall 2008 term: a third year design project course, a fourth year machine design course, and a graduate level design methods course. Each used it to outline and reinforce the design process, although the last two classes tended to focus primarily on the early stages of design. In the third year project course, students worked through the foot brace design in stages throughout the term, and immediately completed the same stages for their term-long

design project: the design of a small-scale Trebuchet. This design case therefore provided excellent scaffolding for their project.

Students in all three courses were surveyed to provide feedback on the design and implementation of the foot brace case [25]. Students recognized the benefits of using the case, especially in the demonstration of the engineering design process. They consistently found the case engaging, able to improve their appreciation and understanding of the design process and related course topics. One specific comment on the appeal of the case was that it was generated by a student 'just like them'. This will apply to cases generated from design project reports, like this one, and also to those generated from work term experiences.

The advantage of this case was that it covered the entire design process, from needs assessment to working prototype. Initial experience with work term reports is that they are much narrower in their scope, and more focused in their analytic content. This may change as experience with design cases encourages more students to complete and submit more design-related work term reports, but for now these two sources for cases naturally complement one another. An added benefit of generating cases from fourth year projects is that it is more applicable to the vast majority of non-coop Universities.

## 5. CONCLUSIONS

A new program to develop and implement engineering design case studies, primarily from

students' work term experience, has been initiated at the University of Waterloo. A key feature of this approach is the sustainable nature of the program itself, taking advantage of an existing work term report requirement to provide a sustainable source of case study material. This program offers an exciting new mechanism to provide context and integration within a conventional engineering program. Early results have been promising, with cases implemented in courses across the curriculum. Students have welcomed the introduction of material in a wider context, including issues of social responsibility and sustainability. They are more engaged and motivated. Work must continue to develop more cases through a refinement of the report collection and conversion system, and to further promote the use of these cases across the faculty.

Focus to date has been on the generation of initial cases and a robust system for the development and conversion of work term reports to case studies. This is a very flexible program, with the potential to generate a large number of diverse cases. The success of this program in educating students in a sustainable mindset depends not only on generating sufficient high-quality cases, either from student work term experience or by working directly with leading environmentally-oriented companies, but also in tapping into the group of environmentally-oriented professors, who will use these cases in their courses. It is only this combination that will enable students to be exposed to a critical mass of cases addressing sustainability issues, and enable them to become sustainable engineering leaders of the future.

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