Waterloo Engineering Design Case Studies Group

Colin Campbell, Steve Lambert, Oscar Nespoli

University of Waterloo, Ontario, Canada

(http://design.uwaterloo.ca)

1. Abstract

In this paper we provide an overview of the *Waterloo Engineering Design Case Studies Group* in the Faculty of Engineering at the University of Waterloo. The mission of the three member group (growing to five) is: ***to develop a culture of learning excellence based on the philosophy of design and the mechanism of cases***.

The group's essential goals are to: give engineering students necessary design skills and experience to design innovative products, foster teamwork and multi-disciplinary partnerships, and generate increased awareness and appreciation of design engineering.

Ideally design case studies involve a real situation and real data, require judgment as well as analysis, require problem formulation and refinement, are motivating, and integrate material from other courses in the same or earlier years.

Several cases will be discussed from various disciplines in engineering. For example: *Hydro Quebec Photovoltaics*; *Indian Rooftop Rainwater Harvesting*; *Nanticoke Power Station (coal)*; *Ladle Tipping in Foundry*; *Fluid Power Control Systems*; *Soil Contamination (FEA model and physical model),* etc. Plans to release the case studies free of charge to other institutions will also be discussed.

2. Introduction

The University of Waterloo faculty of engineering is a 100% co-op school. Every engineering student is required to participate in the co-op program, alternating 4 month terms at school and in industry. This provides invaluable engineering experience to the students as they progress in their academic studies. During their academic career, each student will have 6 such industrial opportunities, which can provide a rich and diverse experience. This experience provides individual students with an excellent opportunity to mature, to appreciate the relevance of material covered in class, and to have the opportunity to apply some of this material in specific situations. Collectively, however, the diversity and depth of experience is vast. Unfortunately, there is no clear mechanism to capture this experience and package it for use by other students.

As part of their program, students are required to document part of this experience during 4 of their 6 opportunities in the form of a work term report. Collectively, more than 1000 of these reports are produced every 4 months throughout the engineering program, in the various disciplines including Chemical Engineering, Civil Engineering, Electrical and Computer Engineering, Mechanical and Mechatronics Engineering, Software Engineering, Systems Design Engineering, and now Nano-Technology Engineering and Management Engineering. This represents an enormous reservoir of engineering experience, but it remains untapped, since work term reports are produced by individual students working at specific companies, and are not generally made available to others.

Recently a new group has been formed at the University of Waterloo to look into developing engineering case studies from this experience, and directly with industry. This is a small group, led by Professor Steve Lambert, which consists of up to 4 full time staff focused on the development and delivery of case studies. This represents a significant innovation since there is the potential in the long term that a significant fraction of Waterloo co-op students could develop case studies based on their experience. This can be used to enrich the in-class experience of all students, at Waterloo and elsewhere, by providing context and examples of design and engineering science analysis across a broad spectrum of applications. The development of such a program is difficult, and this paper will present the approach and some results to date. Emphasis in the development stages has focused on pilot cases and the development of suitable processes.

3. Design Case Studies

Cases in their most general sense represent realistic situations used for learning. Actual definitions vary. According to the Ivey School of Business at the University of Western Ontario, a case can be defined as:

> "… a description of an actual situation, commonly involving a decision, a challenge or an opportunity, a problem or an issue faced by a person or persons within an organization. A case requires the reader to step figuratively into the position of a particular decision-maker (Ivey School of Business)" [1].

Clyde Herreid at the National Center for Case Study Teaching in Science has a more general definition:

> "Cases are stories with a message. They are not simply narratives for entertainment. They are stories to educate." [2]

A case is a depiction of a real situation which has educational value. The essential features of a case include a realistic situation with real data. For engineering, this means an example of actual engineering practice and design. It represents an appropriate application of engineering principles, and as such will typically require engineering judgment and evaluation as well as analysis. A case may have incomplete or extraneous data. Like typical engineering problems, a case will typically have no single solution and require problem formulation and refinement. Typically, the chosen solution will be available.

A case can be used in various classroom situations. It may be used purely for motivation and context; to demonstrate why a particular engineering science principle is needed, and where it would be used. A case may be used as the focus of discussion to reinforce a particular topic discussed in class, or as the basis for a problem to be solved. Students' exposure to a case can be short, over 1 or 2 days, or it could represent a major effort, from 1 to 10 weeks during the term. A case could be used in a single course, or it may be used to integrate material across courses, and help to illustrate the connection between disparate topics. It may also be used in subsequent teaching terms, with the introduction of increasingly sophisticated engineering analyses and principles, to emphasize the iterative nature of engineering analyses.

A case may be structured in a variety of ways. The structure used at Waterloo is evolving as experience is gained in the development and delivery of cases. A modular structure is being pursued to maximize flexibility in use. The main section of the case itself consists of a description of the situation and context. This may also include a concise description of the problem. Other modules are set out separately as appendices, and may include background theory, experimental or simulation data, the solution method chosen, and a solution. It is anticipated that a key aspect of most cases developed and used at Waterloo will be the inclusion of simulation or other analysis results, available with the case so that students can verify the calculations, adapt it to other applications, or examine 'what-if' scenarios. The modular approach means that all of this data can be readily made available to the professor, but they can decide which data to provide to the students depending on the pedagogical objectives. An important supplemental component is the case teaching notes, which contain information regarding the educational objectives of the case, and guidance on how best to use the case.

Much effort has been devoted to the case development process used at Waterloo, modeled after the design process and taking advantage of the experience at the Ivey School of Business. This process is used to maximize the effectiveness of the resources used to develop the case, to ensure the integrity and authenticity of the case, and to maintain quality. Figure 1 illustrates the case development process used at Waterloo. Participants can be characterized as a ***source***, a ***receptor***, and the case writer. The case writer may be a separate individual, but may also be the source or receptor. The source may be a student or an industry representative. The receptor is a professor who will use the case in a particular course.

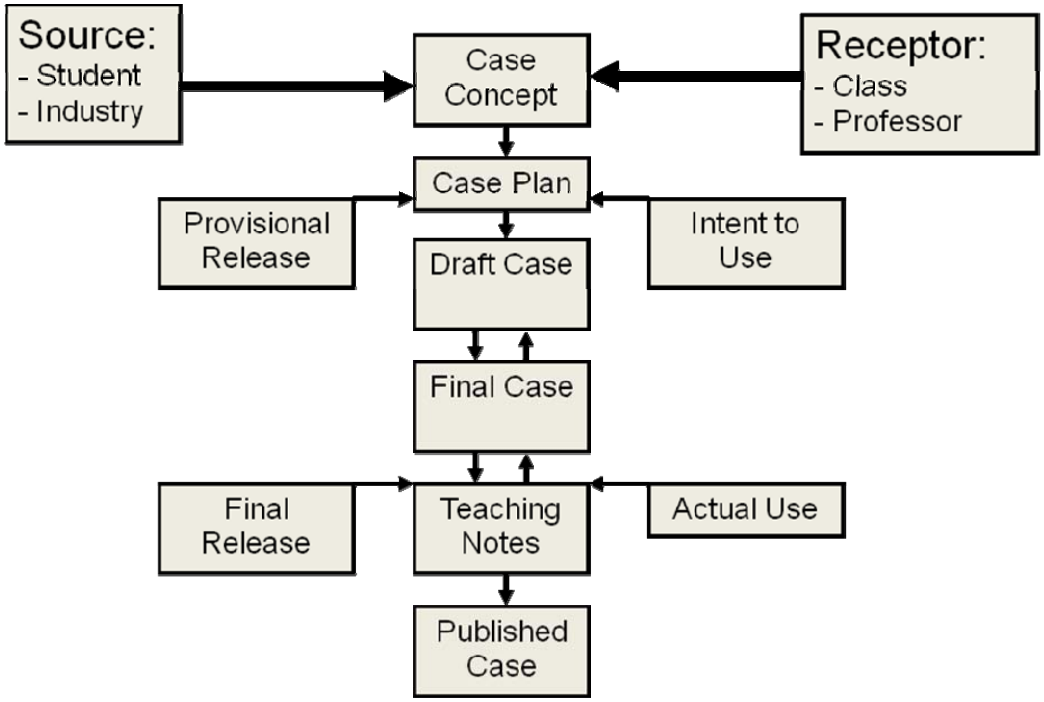

Figure 1: Case Development Stages

The source and receptor are matched using the case concept, the core idea characterized by the case. This may arise from a student through their choice of work term report, by an industry representative based on what they are most familiar with and what they feel today's students should be exposed to, or a professor, based on what they would like to achieve in a particular course or courses. The case writer then prepares a case plan, outlining the core concepts covered and teaching objectives, the type and quality of data required, and the type of analyses to be performed in achieving a solution. The case plan must receive approval from all of the participants to proceed. This acceptance is required to ensure that there is agreement on the content of the final case, that the student is willing to have their experience used, that the company is willing to provide the data and have it made public, and that it meets the needs of the professor, so that it will actually be used. The source then provides the agreed-on material for the case and the case is written and reviewed. Prior to actual use, a formal release is signed based on a review of the completed case. This staged process is necessary to safeguard the important relationships between the students, industry, and the University, and to guarantee the authenticity of the resulting case.

The centralized nature of the case development group at Waterloo, with a mandate to develop and deliver cases throughout the program, provides an ideal opportunity to integrate material across the curriculum and to provide a common language for engineering design. For example, a common terminology for the design process is evolving, based on the principle of a sequence of stages with design loops during each stage, as illustrated in Figure 2.

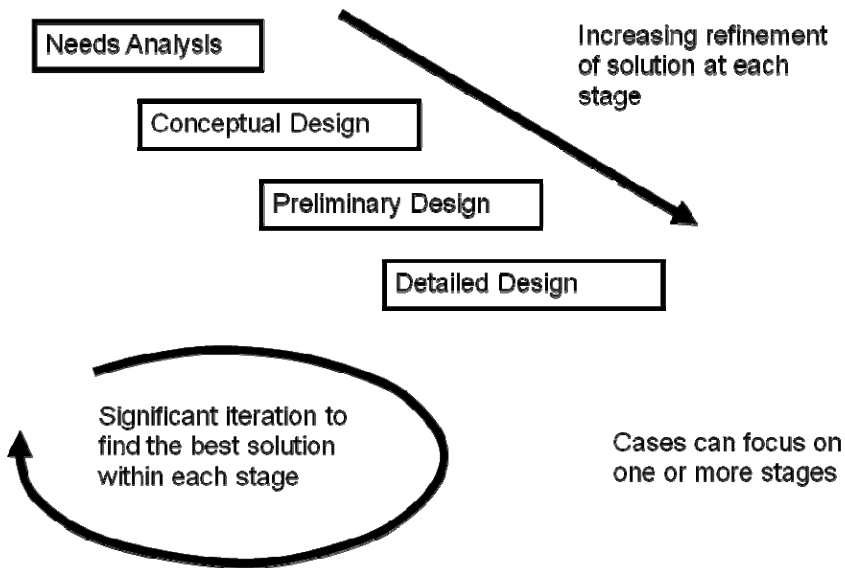

Figure 2: Design Process entwined with Design Case Studies

4. Results to Date

The first two case studies were developed to introduce the **Engineering Design Process** to first year engineering students. These cases were developed in consultation with instructors using material made available by the Government of Canada and Engineers Without Borders. The target audience consisted of students in all engineering programs, and consisted of over 1000 students commencing in the Fall of 2006. Therefore, efforts were made to present the case on-line in a multimedia format. This multimedia format was preferred to text for imparting background information, but the multimedia had to be of the highest quality [3]. These cases are currently being used again for the present group of first year students.

The cases were administered in the freshmen “Concept Courses” and were used to reinforce the Engineering Design Process for the students. The teaching objectives were to develop a common terminology and experience for students, and to provide a preparedness for the use of design cases in other courses.

The first case was used to introduce the Engineering Design Process. The case concerned the selection of an alternative power source on an island in the St. Lawrence that was prone to power outages whenever the power cable to the island was downed by ice storms. It presented the situation in narrative form with the information in no particular order. This was delivered in video form with some photographs. In the next video the students were shown a structured way to present the information based on the Engineering Design Process, and summarized using a standard worksheet. [3]

The second case was based on field work in India by a grad student affiliated with ***Engineers Without Borders (Canada)***. The problem was first to select the “best” water source for a village in India. They then went on to further specify the chosen solution: a rooftop rainwater harvesting system. Several videos were used to impart background information, on Engineers Without Borders, and the Engineering Design Process. These were generally well received, but more effort is required on providing uniform audio quality. [3]

A key objective of this case was to emphasize the important role of engineering calculations in design, and the effectiveness of common programs such as Excel to perform these calculation. For rainwater harvesting, water is collected from the roofs of houses through gutters into storage tanks. The larger the storage tanks, to a certain point, the greater security that a household will have enough water in the dry seasons. Students are led through the different stages of the design process using increasingly sophisticated calculations. The students are given household needs and 20 years of rainfall data. They use this data to establish the feasibility of rainwater harvesting, make simple estimates of the reservoir size, and then perform a simulation to perform what-if scenarios to refine their estimate. Figure 3 illustrates a plot from one of these intermediate calculations.

The online case took students through the engineering design process stages, asking questions and giving students immediate feedback. In addition to the calculations, students were asked to consider all aspects of the system life cycle, including manufacturing, environmental impacts and retirement. The case study was used in various ways by the different departments in Engineering. In general, it was treated as an extension of the lecture. The students generally only got marks for their Excel simulation work, but nonetheless a very high percentage completed the case study, seemingly due to interest in the subject matter, and the fact that (as many commented) it was their first real engineering problem. Many students also commented that the reason they went into Engineering was to help people; the case reinforced this desire.

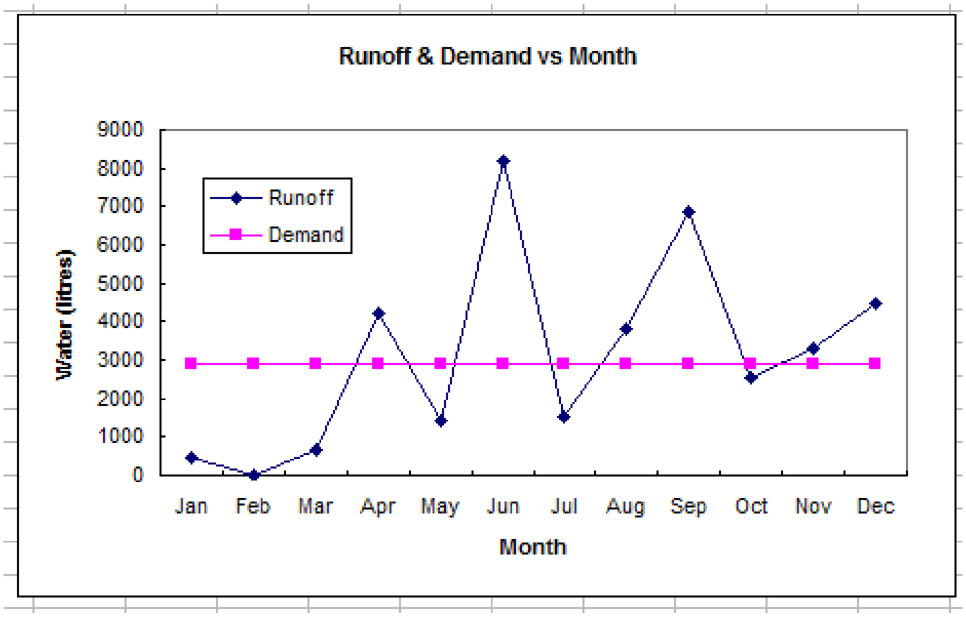

Figure 3: Runoff from roof to storage tank, and monthly demand.

Further cases are being developed through discussions with various companies in the telecommunications, chemical process, transportation, and automotive sectors. This initial set of companies was selected primarily based on personal contacts of the case development team, and will be expanded once the students are more fully engaged in recommending topics for case studies. At the same time, individual courses and professors have been targeted based on their receptivity to the use of cases. These have a wide distribution across the faculty, with initial interest focused in Mechanical and Chemical Engineering. An important strategy for maximizing the impact of cases is the targeting of courses which are taught across the faculty, especially mathematics courses. Cases currently under development cover concepts in energy balance, airbag sizing, distillation processes, chemical reactor sizing, process safety, soil contamination, home heating, area and volume integrations, control systems, assembly line automation, engineering economics, and mechanism design. Table 1 provides a summary of cases currently available or under development.

Most of the cases in this table are still being developed. They are all targeted for use in specific courses. The intention is to make these cases available to other Universities once more experience is gained in their development and use at Waterloo.

Table 1: Cases that are Available or under Development

Case	Case Course
Heat Exchanger	Heat Exchanger Design
Airbags	Airbag sizing Ideal Gas Law Energy Conservation
Stage distillation	Distillation processes
Chemical reactor sizing	Systems engineering
Soil contamination	FEM modeling
Alternative Energy Sources	Engineering Design Process
Alternative Drinking Water Sources	Engineering Design Process
Elora Home Heating Case	Engineering Design Process
Molten Steel Ladle	Volume and C.M. calculations Verification of computer calculations
Process management and simulation	Process management [4]
Hood hinge design	Kinematics and Dynamics
PLC controller design	PLC programming

5. References

1. Erskine, J.A. and Leenders, M.R., “**Learning with Cases**”, 1997, *Richard Ivey School of Business.* (www.ivey.uwo.ca/cases)

2. Herreid, C. “**What is a case?**”, National Center for Case Study Teaching in Science, (http://ublib.buffalo.edu/libraries/projects/cases/teaching/whatis.html)

3. Campbell, C. and Lambert, S., “**Using Case Studies to Teach Introductory Design Concepts to First Year Engineers**”, *Proceedings of the 2007 American Society for Engineering Education Annual Conference and Exposition*. (www.asee.org.)

4. McClain,S. “**A MathCAD Function Set for Solving Thermodynamics Problems**”. *Proceedings of the 2006 American Society for Engineering Education Annual Conference and Exposition*. (On-line at www.asee.org.)

6. Biographical Information

COLIN CAMPBELL

Colin Campbell, BMath is the Assistant Director of the Waterloo Engineering Design Case Studies Group in the Faculty of Engineering at the University of Waterloo. His particular case study interests are in courses that cross all departments, such as Engineering Mathematics, Engineering Economics, Chemistry, Finite Elements, etc. (http://design.uwaterloo.ca.)

STEVE LAMBERT

Steve Lambert, PhD, PEng is the Director of the Waterloo Engineering Design Case Studies Group. His other research interests include: Automotive Design, Design Education, and Fatigue and Fracture.

OSCAR NESPOLI

Oscar Nespoli, MASc, PEng is Design Lecturer in the Waterloo Engineering Design Case Studies Group. His research interests include: Engineering and Product Design, Engineering Design Education, and Advanced Composite Materials System and Process Design.