INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
8 & 9 SEPTEMBER 2011, CITY UNIVERSITY, LONDON, UK

INTEGRATING BUSINESS CONCEPTS AND ENTREPRENEURSHIP INTO AN UNDERGRADUATE ENGINEERING CURRICULUM USING CASE STUDIES

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ABSTRACT
The University of Waterloo has one of the largest undergraduate co-operative education programs in the world, with 100% of the engineering students in the co-op program. Most engineering departments have a strong but conventional engineering curriculum, focused on engineering science with a sprinkling of engineering design. All engineering programs require at least one course in engineering economics, and several innovative programs are available to support students who have an entrepreneurial vision. However, more can be done to provide a solid business foundation for all students; to promote creativity, motivate development of an entrepreneurial vision, and provide the necessary skills to realize that vision.
Engineering design cases are a teaching tool used to help students understand and fully appreciate the complexity of engineering practice, gain experience and develop the skills necessary to deal with this complexity, and make connections between various topics in their undergraduate curriculum. They are also an ideal mechanism to emphasize the importance of business issues in engineering design, and to promote creativity and innovation in solving real-world problems. To be effective, students must be exposed to a wide range of cases, covering a wide range of concepts, in a wide range of contexts. This requires a sustainable supply of diverse cases.
The Waterloo Cases in Design Engineering (WCDE) group was established to generate engineering design case studies, and is currently producing cases at a target rate of 30 per year. Case content is primarily derived from experiences described in co-op work term reports generated by our own students, offering a unique opportunity to pervasively implement a broad range of inherently motivating case material throughout the curriculum. Results to date are summarized, with a focus on promoting both creativity in engineering design and building an appreciation of the business context for engineering practice using cases which demonstrate engineering science concepts.

Keywords: Business cases, design case studies, promoting creativity, design education, entrepreneurship

1 INTRODUCTION

It is widely recognized that engineering students require deeper knowledge about business practices, entrepreneurship, and the global economy to gain crucial competitive advantages and a higher degree of industry-readiness. Many startup companies and new business ventures are formed based on technological innovations. This makes it essential for engineering students to be introduced to the processes of business practice and technical entrepreneurship in addition to the physical design of a product or system. Furthermore, recent changes in the global economic climate present both challenges and opportunities to engineers, and engineering education should foster a vision of individual entrepreneurship to prepare students to address these new opportunities and challenges when they enter the workforce. To that end, engineering programs increasingly strive to include entrepreneurship and innovation in the curriculum. An ideal configuration would provide a general background level of understanding for all students and enrichment programs for those students who desire it.

The University of Waterloo (UW) has a number of enrichment platforms to foster business concepts, innovation and engineering entrepreneurship. These include VeloCity, a residence for students wishing to pursue entrepreneurial ideas in the area of mobile communications and digital media; and the Enterprise Co-op program, which allows students to spend a work term developing their own business, under the mentorship of experienced professionals, including lawyers, accountants and advisors. The Conrad Business, Entrepreneurship and Technology (CBET) Centre is a part of UW's Faculty of Engineering, developed to support, build on, and expand UW's culture of entrepreneurship. Its Master of Business, Entrepreneurship and Technology business (MBET) program challenges students with a practical and modern curriculum; it offers professional development that extends both the entrepreneurial and intrapreneurial skills of business professionals.

To help establish a stronger foundation for all students, a method is needed to integrate business concepts and entrepreneurship in engineering courses throughout the engineering curriculum. Several integration strategies are available to feasibly achieve this, in the same way that there are different ways to integrate other concepts such as design, manufacturing, or sustainability across the curriculum. Separate courses can be created and inserted into the curriculum. For example, most engineering programs require students to take a course in engineering economics, and business and entrepreneurship concepts could effectively complement the material taught in such a course. Or, business and entrepreneurship could be introduced as part of an engineering project, which could be used to integrate several engineering (and non-engineering) concepts for the students. This could be done in a single project, but ideally would be reinforced, from a different perspective, in different projects in consecutive academic terms. The challenge with both of these approaches is the need to introduce new material into an already packed curriculum, and to ensure that the material is presented effectively and consistently.

An alternate approach is being developed at Waterloo. The Waterloo Cases in Design Engineering (WCDE) group has been formed to generate a sustainable supply of realistic case studies to illustrate various engineering and non-engineering concepts in a real-world context. The intention is to implement these cases in courses throughout the curriculum. This is an ideal mechanism to introduce business and entrepreneurship concepts to students in engineering science courses, allowing them to fully understand the relevance of these concepts to engineering practice. Cases which have more emphasis on these concepts can then be used in engineering economics courses or in separate enrichment programs, such as those outlined above.

This paper summarizes the methods by which business concepts and entrepreneurship can be integrated into the undergraduate curriculum. A review of the WCDE program is presented first, followed by a discussion of current and potential methods of integrating entrepreneurship concepts in the engineering curriculum. This includes an overview of the WCDE method of teaching business concepts and entrepreneurship to engineers through engineering case studies, as well as an outline of our experience in introducing entrepreneurship into engineering education. An example engineering case study that was specifically developed to teach engineering design as well as business concepts and entrepreneurship is provided to illustrate the potential of the WCDE teaching method.

2 WATERLOO CASES IN DESIGN ENGINEERING (WCDE) PROGRAM

Engineering programs must change to respond to the needs of modern engineering practice. A balance between theory and practice, and between academic rigor and the best practices of industry, is needed. WCDE provides a means to bridge this gap through the engineering case method. The program was established with support from the Natural Sciences and Engineering Research Council (NSERC), General Motors of Canada Limited (GMCL) and UW, to enhance the teaching and learning of engineering design. The initial development period focused on laying the groundwork for case development and implementation. Now at the start of its second 5-year term, WCDE will focus on producing a sustainable supply of 30-50 cases per year, and implementing these cases pervasively throughout the curriculum.

WCDE obtains case study material from a wide range of sources, including personal experience in the subject area, co-op work term reports, 4th year design project reports, graduate theses, Professional Master of Engineering (MEng) design project reports, and directly from engineering practice. However, the majority of case material is developed directly from the experiences of UW students experiences, as described in their co-op work term reports and in their final year design project papers. The University of Waterloo is a co-operative engineering school where all students are required to

gain practical experience between each academic term. Every student obtains up to 2 years of real engineering practice before completion of their degree. As part of this process, they must submit a number of work term reports. Over 3000 work term reports are generated and submitted for academic credit across all disciplines each year. In addition, most students are required to complete a final year engineering design project to earn an accredited engineering degree. Both represent sustainable sources of engineering design experience for the development of design cases that can be published for future educational use at UW or at other educational institutions. Reports which are submitted are scanned for quality and alignment with course needs, and then industry participants are contacted to gain preliminary approval for conversion to a case study. Once approval has been obtained, the case is developed, edited based on feedback from all stakeholders (student author, industry supervisor, and professor intending to use the case in a course), and the final version is prepared for final approval and release.

WCDE cases have been used in various forms to add new dimensions to the learning process. Where and how cases are used depends on the course objectives, the nature of the class, and the instructor.For example, in a recent implementation of a design case study in the final year mechanical design course [1], students were asked to design a brake system for a large, off-road truck. While notionally a straight-forward application of engineering analysis as discussed in class, the real context made the application more engaging and posed several challenges for students. They were required to interpret and assess the role of potentially conflicting company and international standards for brake design. The application challenged their assumptions about the final configuration: a single caliper would not provide sufficient braking torque, and a dual-caliper system was required instead. This forced them to think outside their comfort zone. In general, students found this an engaging application of the course material, and appreciated the real-world context. Some also appreciated the system-level thinking that was required.

Similar results were obtained through the introduction of a different case study presented to a first year computer engineering class. Students were led through the design of an alternate battery configuration for a hybrid-electric fuel cell vehicle, based on the University of Waterloo's entry into the EcoCAR challenge student competition. While the focus of this case study was to illustrate the role of engineering analysis and modeling in design, students were exposed to a realistic context. They were exposed to the importance of working in multidisciplinary teams – seeing how mechanical and electrical engineers would interact in a real-world problem – and gained an appreciation for the importance of addressing physical constraints. However, some students were also disappointed that this case was not more closely aligned with their interests as computer engineers. It is expected that exposure to more cases will help even these students to broaden their perspective. This should naturally complement their own individual work term experience, where they will be exposed to real work environments with a diverse range of projects.

While most WCDE cases are focused on engineering design practice and other engineering concepts, many provide information related to the business context. In fact, some WCDE cases are specifically developed to emphasize technical entrepreneurship, business concepts and innovation.

3 BUSINESS CONCEPTS AND ENTREPRENEURSHIP IN ENGINEERING CURRICULA

Entrepreneurial thinking and leadership are fundamental factors in the creation of new enterprises and the sustained competitive advantage of both large and small businesses. The Merriam-Webster Dictionary defines an entrepreneur as "one who organizes, manages, and assumes the risks of a business or enterprise" [2]. Entrepreneurship links vision, commitment, passion and people to a common cause. Entrepreneurs usually set high goals for their enterprise, and have a desire for their innovations to impact a large number of people. The ability to foster an entrepreneurial mindset across generations is a major element of business continuity and longevity. This ability is instrumental for effective strategic execution, innovation and growth. The integration of entrepreneurship and innovation into the undergraduate engineering education has been found to enhance student performance and improve their competitive advantage [4]. It also prepares graduating engineers for work in rapidly changing environments defined by a competitive global marketplace. This educational approach aims to satisfy industry demands for engineers with better communication and teamwork skills, and most importantly, a broader understanding of how to solve real-world problems and create value in the marketplace.

4 FOSTERING AN ENTREPRENEURIAL MINDSET THROUGH CASE STUDIES

It is widely accepted that many aspects of entrepreneurship can be taught [5]. An engineering-based entrepreneurial program would focus on innovation, intelligent risk taking, technology planning and development processes, requirement assessments, and intellectual property. Most engineering schools have incorporated engineering entrepreneurship into their curriculum using a design project approach. Often these projects are driven by theoretical text book problems and may not properly address the actual needs of current industries or reflect the challenges posed by the real-world business environment. Case studies can be used to introduce realistic problems into this process, and cases derived from students own experiences can be particularly motivating.

The objective is to teach business concepts and entrepreneurship where engineering students work together on teams, with the course being team-taught by professors who can collectively provide the diverse engineering and entrepreneurial background necessary. A case can be used to present open-ended engineering problems (design, analysis, selection, planning), entrepreneurship, and business decision situations, and in this way introduce a measure of both technical and commercial uncertainty and complexity (as opposed to just technical uncertainty and complexity) to the learning experience. The case method can be used to foster students' core entrepreneurship attitude, guide interested entrepreneurs in fostering entrepreneurship spirit, and to improve their ability to identify business opportunities. The case method imparts necessary entrepreneurship knowledge and skills by means of a systematic simulation-type process.

Cases promote active learning, team-based activities, and the ability to deal with uncertainty. Thus, cases are a natural way to introduce engineering design, business and entrepreneurship concepts. The case method also fosters the development of higher-level cognitive skills by forcing students to go beyond rote learning. Cases address problems that require analysis, assumption development, judgment, decision-making, perspective taking, role-playing, independent thought, and critical thinking. Cases are designed to force students to think about particular issues, and face the ambiguities and uncertainty associated with real-world decision-making.

Cases can be used for individual or group learning through various methods including class discussion, design project, and homework. Students study the case material, seek to understand the problem or situation, and then answer the questions given by the instructor related to the subject matter at hand. This may be done individually or in teams. Often, individual study and preparation are followed by small group discussions. The students aim to understand the perspective of each of the participants in the case. They may be asked to commit to a role and position, and to present and defend that perspective. This is usually done via classroom discussion, with the teacher acting as facilitator. Eventually the team and the whole class provide a possible solution of the case problem which may lead to further class discussion. By comparison with traditional teaching methods, case studies provide a broader perspective on engineering and business issues, have greater focus on decision-making processes, reveal the system level analysis of the engineering concept, and highlight both technological and commercial uncertainty, ambiguity, and risk. Therefore, cases extend the learning experience beyond the typical classroom or laboratory.

5 EXAMPLE WCDE CASE STUDY - VIRTUAL BUTTON® USER INTERFACE

WCDE currently has a wide range of engineering case studies in its collection; several can be used to teach engineering and business concepts. An example case, entitled "Virtual Button® MEMS Accelerometer Design" was generated from a UW student course project report. This particular case provides an account of how three UW students invented the Virtual Button® application for consumer electronics devices, and discusses the related engineering design analysis. The initial inventors came up with a method to determine the location and intensity of physical impulse acting on a consumer electronics device, without the need for any direct interaction with an electro-mechanical switch or touch-screen. Virtual Button® technology can be applied to a wide array of device geometries and contours. This innovation can allow buttons to be ‘placed’ on flat and curved surfaces, edges, and locations where a mechanical button is not feasible, as shown in Figure 1. The Virtual Button® technology can be used in environments with high levels of shock, vibration, humidity, among other rugged environmental conditions, or which require exceptional levels of hygiene [6]. The Virtual

Button® interface technology also includes configurable software, allowing users to customize the button locations.
The invention of this application has led to a patent for the technology and the formation of VBT Innovations Inc. Currently, the company is developing this technology for a wide range of applications including medical, military and consumer electronics devices (http://www.virtualbutton.com). The company is investing in cutting edge technical development and IP protection to introduce Virtual Button® technology with the right mix of licensing and manufacturing capabilities. VBT is working to expand its market presence with a world-class workforce, investment in proprietary technology, and continued idea-to-market process innovation.

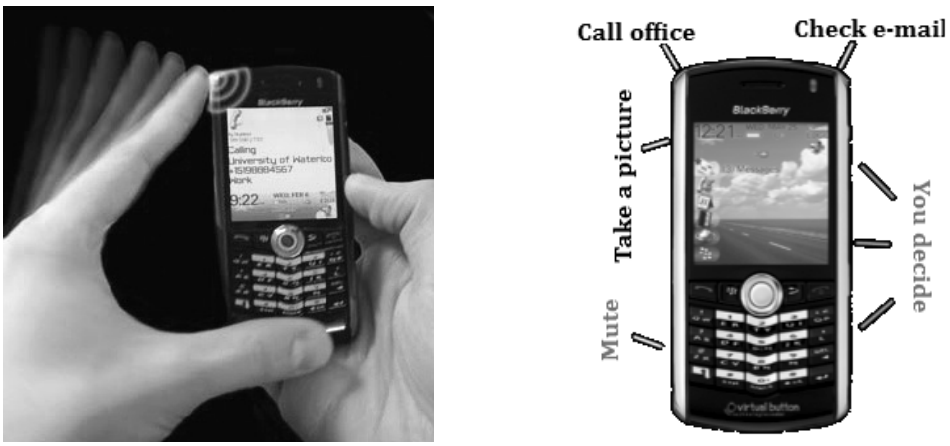

Figure 1. Any location can be a button using virtual button technology

The case has four modules to expose students to a wide range of engineering concepts, including: Micro Electro Mechanical Systems (MEMS) accelerometer design and modeling, pattern recognition, entrepreneurship, and business concepts.
Module 1 is the Case Study itself and consists of a description of the situation and context. The Virtual Buttons® Case Study provides background information on the MEMS accelerometer at the heart of the system and the innovation of using the new device. It also focuses on the design and modeling of the MEMS accelerometer for the Virtual Button® application. Subsequent modules have been developed to provide a solution method to the MEMS accelerometer design and fabrication process, with related engineering analyses. Generally, the solution modules provide the solution developed for the problem, including simulation or other analysis results available with the case, so that students can verify their calculations, adapt them to other applications, or examine 'what-if' scenarios. These modules are typically not released directly to students, but professors have this information to help guide class discussion, and they can release specific information to the students to support their calculations or provide closure. For cases such as this, additional modules provide information on the specific business context, including the issues and processes of intellectual property protection, and financing. These can be used directly in courses which have a greater focus on business and entrepreneurship, or be used by professors in other courses as background context, and enable them to answer students' questions relating to the business context.
An important supplemental component is the Case Teaching Note, which contains information regarding the educational objectives of the case. It recommends potential implementation methods to instructors intending to use the case. The teaching note also includes an introduction describing the case, teaching objectives and intended learning outcomes.

6 DISCUSSION

This particular case study will be used to teach MEMS concepts, pattern recognition, and analysis of mechanisms, as well as business concepts and entrepreneurship. It provides a concrete, real-world example of how engineering students invented a new enterprise based on engineering concepts, which serves to illustrate the critical need for innovation and creativity in developing engineering solutions with commercial potential. This case can be used in a variety of contexts to help students see the 'big

picture': how engineering science concepts are used in practice and the importance of taking a holistic approach to engineering problem solving. This is a foundational skill for entrepreneurship.
The results to date with a variety of case studies, such as the brake design or EcoCAR Challenge cases discussed above, illustrate the value and effectiveness of using case studies to broaden a students' perspective and make them see the bigger picture. This should provide an excellent foundation of knowledge, skills and attitudes, which will allow them to more effectively apply their experience in a business context, and allow some of them to excel as entrepreneurs.

7 CONCLUSIONS

The Waterloo Cases in Design Engineering group at the University of Waterloo has created the processes necessary to generate a sustainable supply of real-world case studies across all engineering disciplines. These cases have been shown to engage students in course material and simultaneously gain a broader perspective, integrating material from different courses. These can be used to give students a better grasp of the importance of and a feeling for the application of business principles in real engineering problems. In combination with their own work term experience, and the extracurricular programs already available to interested students, cases are expected to improve on the already strong entrepreneurial opportunities for our students. Most of these cases are currently available only for use at Waterloo. However, once a critical mass of cases has been produced, and more experience has been gained on their most effective use, it is anticipated that some of these will be made available to other institutions.

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