Bridging Research and Education through the Case Method

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Abstract – *Research is the foundation of modern higher education and the motivation behind the majority of work done by university faculty. Research results are a major metric used to rank universities worldwide. It is a major contributor to University reputation. There is a growing trend to focus on research, with little time left for educational improvements and little or no synergy between the two. Bridging the gap between research and education can enhance student experience by exposing them to applications which require fundamental knowledge. Currently at the undergraduate level, there are limited pedagogical tools employed to address this opportunity. Case methods can create synergy between research and education. Engineering cases sourced from postgraduate research are a teaching tool that can be used to help undergraduate students understand and appreciate the complexity of engineering research and gain insight into fundamental concepts. In this paper, a case-based framework to integrate academic research and teaching is explored. Detailed descriptions of the case method approach, case development, and the viability and reproducibility of these strategies are presented.*

Keywords: Research; Engineering Education; Case Method; Curriculum Innovation

1. INTRODUCTION

Research and teaching are the two most important activities in post-secondary education. Research can be defined as an intellectually controlled investigation to describe, explain, and predict the observed phenomenon that leads to advances in knowledge through discovery of new information or the development of further understanding about existing information and practice [1]. Engineering research often draws heavily from the practices of industry. Thus, there is also an opportunity to use research to demonstrate the practical aspects of academic subjects. Teaching is a multidimensional activity that seeks to promote quality of learning through a student-centred interaction between the teacher, student and the curriculum [2]. Creating synergy between undergraduate learning and research can be beneficial for faculty, students and other stakeholders.

In recent years university ranking has become increasingly important. The ranking compares post-secondary education using a number of metrics including research publications (volume and quality), global reputation survey results, and institutional variables such as university size and the staff-to-student ratio [3-5]. Generally, the ranking is focused on research output. For example Table 1 provides the major components of The Times Higher Education ranking formula [4].

Table 1: Times Higher Education ranking formula

Ranking metrics	Weight [%]
Citations: Research influence	30%
Research: Volume, income, reputation	30%
Teaching: The learning environment	30%
International outlook: People, Research	7.5%
Industry income: Innovation	2.5%

Other Similar ranking institutions, including the Shanghai Academic Rankings of World Universities use comparable metrics [5]. There is often limited time, energy, and commitment for faculty to do both teaching and research effectively, so opportunities to provide synergy are appealing. While it is possible for instructors to directly use relevant research in their teaching, there is limited impact with no mechanism to share resources.

Over the past eight years, Waterloo Cases in Design Engineering (WCDE) at the University of Waterloo (UW) has focused on the development and implementation of case studies from undergraduate student and industry experience. Recent efforts have focused on integrating engineering research and education by creating case studies and instructional activities sourced from postgraduate research. This paper discusses how WCDE integrates academic research into undergraduate teaching using a case method.

2. INTEGRATION OF RESEARCH AND EDUCATION

There is no shortage of literature on the topic of education and research synergy. Generally, it is believed that there is a positive synergy between faculty engagement in research and the quality of student learning. This is based on the fact that researchers aware of the newest perspectives in their field will be the first point of contact for students, and can share the latest developments [6]. Additionally, results from one's research can be used to clarify, update, and amend the teaching of a topic. However, a number of studies conducted on education and research synergy question the benefits of this link [7-10]. The link between these two activities has been called the Research-Teaching Nexus (RTN) [11], Research-Led Teaching (RLT) [12], research-based teaching [13], or research informed teaching [14].

Some investigations indicate that there is little or no positive connection between research activities and effective undergraduate teaching [7]. Other similar studies have shown negligible correlations between research productivity and teaching performance, suggesting that research and teaching have different goals and require different set of skills and personal attributes [8]. Excellent researchers must be observant, objective, skilled at drawing inferences, and tolerant of ambiguity. Excellent teachers must be skilled communicators, familiar with the conditions that promote learning, expert at establishing them, and approachable and empathetic [9]. While some professors excel in both areas, this is not universal.

Some studies found a negative correlation between a university's research orientation and a number of educational outcomes [10]. This suggests that faculty members may find that research and teaching activities are in competition or even in conflict, i.e. the time spent on research is time taken away from teaching, and vice versa.

2.1. Benefits of Research-Teaching Synergy

With a well-designed synergy between research and education, undergraduate student learning can be beneficial for all stakeholders involved in the process, Figure 1. There is an opportunity for research to demonstrate the practicalities of academic subjects taught in various courses. For students, integrating research into their learning experience can be stimulating and challenging, and help to develop them towards a future role as a researcher [6]. Moreover, students appreciate it when the academic identity of their teachers emerges through the teaching process; they respond well when teachers offer a first-hand perspective on their own experience. Active research faculty members may also find new stimulation and creativity from interacting with undergraduate students [15].

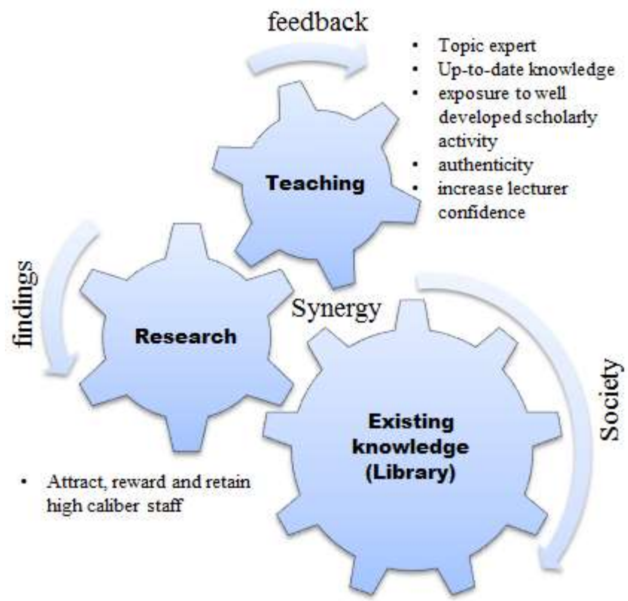

Fig. 1. Research-Teaching Synergy

2.2. Existing Synergies at UW

At the undergraduate level at Waterloo, student participation in research is limited and therefore the synergy is at a low level. Most universities, including UW, provide students with an opportunity to work as an Undergraduate Research Assistant (URA), which allows them to participate in engineering research during an academic term. They work on a research project under the supervision of a faculty member. However, a limited number of students work as URA, which limits the impact of this approach for the majority of students. Some Waterloo students are also hired as co-op students to work on research, but again this impact is limited to the participants.

3. EMBEDDING RESEARCH INTO THE CURRICULUM USING THE CASE METHOD

Case studies are a representation of an engineering challenge. The case method allows students to see the complexity of everyday practical challenges in context, appreciate this complexity and develop techniques and judgment to deal with it while raising their level of engagement in the learning process. Case studies have also been used as a teaching method and part of professional development, especially in business and legal education. The case method creates a classroom environment in which students must not only gain theoretical understanding, but also employ other skills including research to address real-world problems [16].

Case method have been shown by educational researchers to improve different aspects of teaching and learning [17], reasoning and problem-solving skills [18], the ability to make objective judgments [19], the ability to identify relevant issues and recognize multiple perspectives [20], motivation and interest in the subject [21], promote group learning and teamwork skills [22], and awareness of ethical issues [23].

Most case studies are derived directly from engineering practice, from engineers or co-op students working in industry. WCDE has also developed engineering case studies based on MSc and PhD research.

3.1. Research Based Case Development

Case development based on research work is effective when developed in collaboration with an instructor who wishes to use the case material in a course. A general WCDE case development and implementation cycle is illustrated in Figure 2. The initial case document, the case plan, is a vital communication tool between the case developers, researcher, academic supervisor and industry contacts (as appropriate). At this stage, the faculty member at the center of the research plays a critical role in identifying expected learning outcomes for the targeted audience and course(s). This requires defining a set of measurable indicators that describe the performance required to meet certain course learning objectives based on the source material.

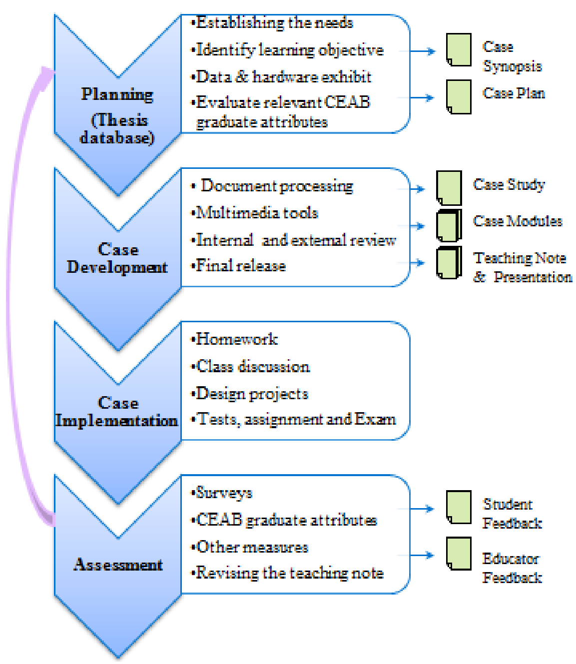

Fig. 2. Case study creation and implementation cycle

One of the key challenges with deriving cases from research work is appropriately limiting the scope to something that is appropriate for an undergraduate course. In most circumstances, only a portion of the original thesis is used to create the case problem.

The case plan is also used to obtain consent from involved parties, to ensure that case material can be ultimately released to the public. Once consent to proceed is obtained, the case is developed in the next phase, along with solution modules and a draft teaching note. A formal review process is used to ensure quality and accuracy. Internal reviewers include members of WCDE staff. External reviewers are the research author of the original thesis or dissertation and an appropriate company representative (if applicable), and the student's supervisor. In most cases, the student supervisor is assumed to be the prime user. They provide feedback including recommended activities for the case that would lead to effective implementation. The case is released for use only once these external reviewers have been satisfied.

The final cases are shared with other potential instructors as a mechanism to promote case use. Here is where the case study plays a key role sharing research material across faculty members and departments, allowing other instructors to obtain the newest perspectives from excellent researchers, maximizing research impact.

3.2. Example Research-Based WCDE Cases

3.2.1 Virtual Button® Development. A case study, entitled "Virtual Button® MEMS Accelerometer Design" was generated from MSc research at UW. This particular case provides an account of Virtual Button® development for consumer electronics devices and discusses related engineering design analysis. The research done by the MSc student, along with other inventors, led to a method to determine the location and intensity of physical impulses acting on the surface of a consumer electronics device, without the need for any direct interaction with an electro-mechanical switch or touch-screen. The technology is the based on accelerometers strategically placed inside the device. Virtual Button® technology can be applied to a wide array of device geometries and contours [24]. 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 3.

Fig. 3: Any location can be a button using virtual button.

The Virtual Button® interface technology also includes configurable software, allowing users to customize the button locations. This work led to a patent for the technology and the formation of VBT Innovations Inc [25]. The case has four modules to expose students to a wide range of engineering concepts, including Micro Electro Mechanical Systems (MEMS), MEMS accelerometer design and modeling, pattern recognition, and entrepreneurship, as shown in Table 2.

Table 2: Virtual Button® User Interface Design case modules

Module name	Description
Module 01	Case Study
Module 02	MEMS Accelerometer Models (Restricted to educators only)
Module 03	MEMS Accelerometer Performance Evaluation Models (Restricted to educators only)
Module 04	Pattern Recognition Analysis (Restricted to educators only)
Module TN (Teaching Note)	Teaching Note (Restricted to educators only)

Module 1 is the case study itself and consists of a description of the situation and context. It provides background information on the MEMS accelerometer at the heart of the system. It focuses on the design and modeling of the MEMS accelerometer for the Virtual Button® application. Subsequent modules have been developed to discuss the MEMS accelerometer design and fabrication process, with related engineering analyses. Generally, the solution modules provide a 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.

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.

3.2.2 Maximizing throughput: the value of dispatching rules. A second example is a case study for operations planning. An MASc student, from UW, was asked by an industry partner1 to analyze various dispatching rules and propose a method to improve throughput for a manufacturing jobs shop. In this particular case, the supervisor approached WCDE to develop the dissertation as a case study for his colleague. His colleague regularly taught the course MSCI 555 Scheduling: Theory and Practice. The supervisor acknowledged the connection between this course and the dissertation and approached WCDE to develop this work as a case study for his colleague. WCDE staff worked with the instructor of the course and the graduate student to develop this case and also develop an appropriate class activity for the intended course. During the case development process, the course instructor ensured the content of this case complemented the target course on scheduling theory.

The case study (Module 1) consists of a description of the situation and context as well as an Excel file containing necessary data. The solution module (dispatching rules analysis) discussed the dispatching methods that were tested and analyzed based on actual data by the researcher. The case study provides a real world scenario so that students can apply dispatching rules to operations within a real context using scaled and relevant data. The students will practice applying dispatching rules to job-shops and understand the benefits and disadvantages of selecting certain rules as well as analyze these options in order to make an appropriate selection.

3.2.3 Design of Sense and Drive Circuits for a Frequency Modulated Gyroscope. The last example is a case study developed from ongoing PhD research that involves the first and third authors of this paper. The research aims to develop a novel cantilever beam MEMS gyroscope with a frequency modulated (FM) readout. The gyroscope detects angular rotations as the difference between the natural frequencies of two closely spaced drive and sense modes rather than the magnitude of

[1] The identity of the company has been withheld at their request.

displacement in the sense direction. The gyroscope undergoes coupled flexural vibrations in two orthogonal directions when subjected to base rotation around the beam's longitudinal axis. In order to demonstrate the concept, a prototype MEMS gyroscope was designed and fabricated.

The case development process followed the same steps presented in the previous examples. However, since this is ongoing research, only the analog sense and actuation circuit design aspects are featured in the case study, along with background information on the gyroscope. The case teaching objective is to illustrate the effective use of circuit analysis and simulation for developing MEMS gyroscope feedback controlled sense and drive circuits. The case will give students the opportunity to evaluate commercially available components such as Automatic gain control (AGC), phase lock loop (PLL) and Variable Gain Amplifier (VGA).

4. CASE IMPLEMENTATION

The first two example 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. Figure 4 illustrates a typical example of case implementation outline.

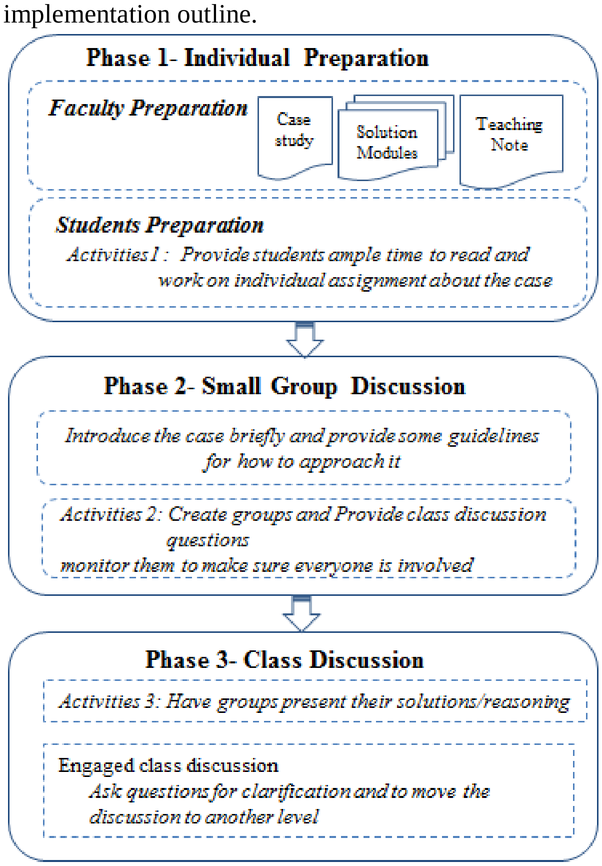

Fig. 4: Typical WCDE case implementation outline

A typical case implementation includes a sequence of suggested activities, with the estimated student time commitment. During individual assignment phases, students demonstrate their ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex real-world problems in order to reach comprehensive solutions and conclusions. They conduct investigations of these problems using methods based on analysis, interpretation of data, and synthesis of information in order to reach valid conclusions. They design solutions for open-ended engineering problems and they design systems, and subsystems that meet specified needs with attention to constraints, health and safety requirements and risks. To do so, they use proper engineering tools in the analysis and design phases to help them verify the validity and identify the weaknesses of their solutions.

4.1 Case Implementation in NE 343

Microfabrication and thin-film system (NE 343) is a third year core course on electronic device fabrication. The Virtual Button® MEMS Accelerometer Design was used in this course to provide an overview of MEMS fabrication, with special emphasis on lithography definition and assessment. The overall implementation approach was similar to the outline provided in Figure 4. The case and the individual preparation assignment were provided to the students one week in advance of the implementation date, after an introductory lecture on MEMS fabrication. For the individual assignment, students were asked to read the case and to answer questions related to fabrication selection for the MEMS accelerometer. This focused on their comprehension of the case material and prepared the students for subsequent small group and class discussions. During the class implementation, students were asked to form small groups of 3-4 people and discuss their answers, spending roughly 10 minutes on each question. Their answers were discussed in the class following each small group discussion.

4.2 Case Implementation in MSCI 555

Scheduling: Theory and Practice (MSCI 555) is an elective course for 4th year and graduate students. For this course, the value of dispatching rules case study was used to emphasize dispatching rules to operations and provide a real-world application of scheduling to scarce resources. The implementation focused on giving an overview of modeling and solving scheduling problems in real-world example which would be relevant to these students. Students were provided enough time to individually read over the case study material. During the individual assignment phase, questions were designed mainly to demonstrate students' ability to apply different dispatching rules to the production data analyzed trade-offs from observed difference between dispatching rules.

5. CONCLUSIONS

The Waterloo Cases in Design Engineering group at the University of Waterloo has created the processes necessary to generate research based case studies across engineering disciplines. The results to date with a variety of case studies have been shown to engage students in course material and simultaneously gain a broader perspective, integrating material from different courses. Cases derived from postgraduate and faculty research experiences can potentially be motivating for students to experience the cutting edge of a subject area. This is a relationship where the excitement of engaging with the development of the knowledge base of the discipline itself contributes to student learning. Hence, cases can create synergy between research and education at the undergraduate level and would be beneficial to all stakeholders, including other faculty members who are not active in research.

In this paper we have focused on a critical element of this approach: using the case as a bridge from research to teaching practice. Most of these cases are currently available only for use at Waterloo. However, the case development framework discussed could be a viable and reproducible method for other educational institutions. Further investigation on cases sourced from postgraduate research, their effectiveness and impact, is planned.

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