# PATHWAYS BETWEEN ENGINEERING AND EDUCATION FACULTIES: EFFORTS TO ESTABLISH AN ENGINEERING EDUCATION GRADUATE PROGRAM AT THE UNIVERSITY OF MANITOBA

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***Abstract -*** *Engineering education is a recognized field of research and inquiry that draws on a number of established disciplines to enhance the practice and teaching of engineering. Within the last ten years, some universities in the U.S. and abroad have developed engineering education graduate programs with an emphasis on drawing from the education discipline in particular. These programs range in scope from those in which graduate students maintain a technical area of expertise alongside a focus on pedagogy to more interdisciplinary collaborations with education faculties. In Canada, such programs are still in development and the more recent movement towards outcomes-based assessment in engineering schools to satisfy changing accreditation requirements, has further mobilized an institutional interest in teaching and learning processes. This paper reports on the evolution of such a program, combining the expertise of both engineering and education faculties at the University of Manitoba to achieve this synergy.*

***Keywords:*** engineering education; graduate studies; pedagogy.

## 1. INTRODUCTION

Engineering and education faculties are seldom mentioned in the same sentence; the conventional understanding is that one school develops prospective engineers while the other prepares future teachers. Often overlooked is the common element that links these two fields: their attention to pedagogy – the teaching, learning and assessment processes in which both instructors and students invest considerable time and effort, shaping career outcomes. Engineering education in a formal capacity is a relatively new discipline, emerging within the last 15 - 20 years and drawing from a number of other fields, including the social sciences, educational research, and the cognitive and learning sciences to create a unique synthesis with its own expanding scholarly base [1][2][3][4][5][6][7][8][9][10][11][12].

Much of the thinking behind this enhanced view of scholarship can be attributed to Boyer [13], who argued that the intellectual rigor of scholarly activities should extend beyond conducting original research and publishing, and rather be connected to four inter-related activities: discovery, integration, application and teaching [5][14][15]. The scholarship of discovery is the act of creating new knowledge within a given discipline, while the scholarship of integration connects information between different disciplines and areas of knowledge. The scholarship of application builds on the prior two forms of scholarship to ask 'how can this knowledge be used?' For example, engineering course revisions can be informed by the findings from the research on cognitive psychology and learning theory, and similarly, K-12 teachers can be helped to understand how to best teach engineering and scientific concepts by familiarizing themselves with the research in engineering education. Finally, the scholarship of teaching puts the results of research into action, whereby teachers make active efforts to incorporate their new knowledge into their courses, thereby integrating teaching and scholarship [16]. For example, borrowing from the field of education, the 'pedagogies of engagement,' which have been shown to promote academic learning and integration and which encourages active learning, including cooperative, problem-based, project-based, case-based and service learning, have been incorporated by growing numbers of engineering faculty [17][18]. Boyer's four forms of scholarship are not seen as independent, but rather each overlaps the other and exerts influence on the other domains [19].

## 2. ENGINEERING EDUCATION PROGRAMS – GLOBAL OVERVIEW

Recognizing the need and benefits of focusing on the pedagogy of engineering, more formalized programs in engineering education have been recently established, such as Ph.D. graduate degree programs and university departments in several prestigious American universities [2][4][20]. In fact, there are about 20 centers involving Engineering Education research, most established within the last decade [3]. Such programs vary in structure and

scope. They range from those open exclusively to engineering graduate students who, alongside their own technical area of expertise, take courses in areas such as principles of curriculum development and educational research methods, or they may take the form of cross-disciplinary approaches in which graduates from other disciplines have the ability to develop, implement, and assess engineering curricula at high school and university levels.

American institutions that offer graduate programs in engineering/STEM education include: Arizona State University, University of California – Berkeley, University of Cincinnati, Clemson University, University of Kentucky, Louisiana Tech University, University of Maryland, The College of New Jersey, Niagara University, North Carolina State University, Old Dominion University, The Ohio State University, Purdue University, University of Texas, Tufts University, Utah State University, Virginia Tech [21]. The obtainable degrees are diverse, with programs offered through Departments, Schools and Colleges of Education, as well as through Departments and Schools of Engineering and STEM Education. Additionally, there are a number of American institutions that provide engineering education-related certificate programs [21]. The article, "Engineering Education: Departments, Degrees and Directions," published in the *International Journal of Engineering Education* in 2010, details the formation of four American engineering education academic units: the School of Engineering Education at Purdue University, the Department of Engineering Education at Virginia Tech, the Department of Engineering and Technology Education at Utah State University, and the Department of Engineering and Science Education at Clemson University, exemplifying typical characteristics of the programs. The authors also discuss atypical and amalgam engineering education cultivation [22].

Along with the critical infrastructure of centers and departments now established predominantly in the U.S., there is also an increasingly enlarging global community of engineering education researchers [1][2][3][23] and established international institutions that offer engineering education research programs. Graduate programs in engineering/STEM education are found at Aalborg University in Denmark, Chalmers University of Technology, Linkoping University and Uppsala University in Sweden, Universiti Kebangsaan Malaysia and Universiti Teknologi Malaysia in Malaysia, and Universidad de las Americas, Puebla in Mexico [21]. As well, several international and American institutions house innovative engineering and interdisciplinary programs. (For a comprehensive list of engineering education programs and degrees awarded, see Appendices A–C, and the Engineering Education Community Resource wiki [21].) All of these engineering education initiatives, as well as the numerous journals, associations and conferences devoted exclusively to the intellectual growth of engineering education research are fundamental to the expansion of the discipline of engineering education.

## 3. ENGINEERING EDUCATION PROGRAMS AND INITIATIVES IN CANADA

To date, there is one degree program in Canada that offers a formal certificate in engineering education, although arguably studies in engineering education are not novel. The University of Toronto, through the Faculty of Applied Science and Engineering, has a Collaborative Program in Engineering Education. It is described as an interdisciplinary opportunity designed for students in engineering or education who are interested in taking courses and conducting research in engineering education. Students receive the notation "Completed Collaborative Program in Engineering Education" on their transcript when they successfully complete requirements of both their home department and the program [24].

While developments have been slower to take hold in Canada, there have nonetheless been significant initiatives within the last few years. In 2009, the Canadian Engineering Accreditation Board (CEAB) began an outcomes-based approach for engineering curriculum development and assessment [25][26][27]. Similar to events that took place in the U.S. in the 1990s due to their changing accreditation requirements through ABET [28][29][30], Canadian engineering schools are now seeking and embracing educational expertise in order to engage in rigorous, scholarly, and scientifically driven research in engineering education [1][3][8].

At the crux of the movement, is the formation of the Canadian Engineering Education Association (CEEA), a relatively new organization whose mission is to 'enhance the competence and relevance of graduates from Canadian engineering schools through continuous improvement in engineering education and design education.' Additional Canadian engineering education initiatives include the DuPont Canada Chair of Engineering Education Research and Development that is held by a faculty member at Queen's University [32], and the STEM Teaching and Learning Community that has recently been established at the University of Calgary between the Werklund School of Education, the Faculty of Science, and the Schulich School of Engineering [33], and now the Centre for Professional Practice and Engineering Education at the University of Manitoba. CEEA, changing accreditation requirements, global influences, and the impact of the learning sciences on engineering education [31] have thus fueled a growing interest among Canadian engineering academics and practitioners in the field of engineering education.

## 4. ENGINEERING EDUCATION AT THE UNIVERSITY OF MANITOBA – HISTORY

Interest in engineering education at the University of Manitoba has grown steadily over the last 15 years. Initiated by individual professors who wished to explore innovative classroom methods or motivated by the need to document such activities as our Engineering Access Program and the Internationally Educated Engineering Qualifications Program, engineering education has gradually become a component of our scholarship.

This focus has been sharpened by two developments. The first development was that Dr. Ron Britton, the faculty's former NSERC Design Chair, was a major proponent in the formation of the Canadian Engineering Education Association (CEEA). Strong support for this organization has come from three successive Deans of Engineering at the University of Manitoba. This support extends to housing the Secretariat for CEEA in Manitoba.

The second development was the strong encouragement provided by the visiting team in 2011 for the third term of the NSERC Design Chair at the University of Manitoba, where Dr. Douglas Ruth is the current chair holder. Two of the visiting team members were from engineering education programs in the United States. A recommendation in their review was that a formal recognition of engineering education should be a necessary component of the program. The new chair program has wholly incorporated this suggestion. As one demonstration of this, the Chair has committed to provide support for any researcher at the University of Manitoba who is presenting research findings at the annual CEEA conference or any other engineering education or educational forum. This support has grown to include annual provision for over 20 individuals conducting engineering education research from the University of Manitoba.

Over the last 15 years, the Faculty of Engineering has built a strong engineering education group around the NSERC Design Chair. First called the "Design Group," this organization has now been formally constituted as the "Centre for Engineering Professional Practice and Engineering Education" (CE2P2E). The University Senate confirmed its status as an 'Academic Centre,' the first such Centre at the University of Manitoba, in May 2014. The Centre highlights our commitment to support engineering education as a field of rigorous, scientific and creative scholarship.

## 5. WHY AN ENGINEERING EDUCATION GRADUATE DEGREE?

In the past, there have been a number of graduate students completing degrees at the University of Manitoba who could claim that they were doing "engineering education" research. These students came from two distinct academic backgrounds, and had to be treated very differently from an administrative perspective. The first group was those with undergraduate degrees in Engineering. These degrees allowed them to register for graduate degrees in the Faculty of Engineering. With the cooperation of particular Engineering Departments (most notably the Department of Biosystems Engineering), these students were allowed to pursue engineering education research for their graduate programs. Generally, these students had members of the Faculty of Education on their committees, but committee members from Education functioned under Faculty of Engineering rules. The second group were students who did not have a first degree in Engineering. These students pursued what are termed "Interdisciplinary" degrees that function under very different rules from those in the Faculty of Engineering. In particular, it is required that students embarking on an Interdisciplinary degree take at least one course from the home departments of each of their committee members. Students would typically have at least one committee member from the Faculty of Education, which is synergetic, because these students would expect to take education courses to fulfill a degree in engineering education. However, students would also be required to take graduate level engineering courses from every engineering committee member's department, which could require taking more than one graduate level engineering course, thus making it problematic for students without an engineering degree.

One of the initial reasons for establishing the newly formed Centre for Engineering Professional Practice and Engineering Education in the Faculty of Engineering was to facilitate the Interdisciplinary Degree program. However, executing this plan encountered a major roadblock. Due to the structure of the Faculty of Graduate Studies at the University of Manitoba, CE2P2E is not considered a "unit" in the faculty of Graduate Studies. This means that any person who is a member of CE2P2E and supervises a graduate student must hold an adjunct appointment in an engineering department. In other words, their appointment in CE2P2E does not qualify them to supervise graduate students. Of principal importance here is that the academics with the most interest in engineering education are naturally appointed to CE2P2E; most of them do not hold adjunct status in an engineering department. The natural solution would be for interested academics to seek adjunct appointments in one of the four engineering departments within the Faculty; however, this adjunct appointment would then trigger the need for potential engineering education students to take a graduate level course in the particular engineering department as part of the Interdisciplinary Degree Program.

The establishment of an Engineering Education Postgraduate Degree program will fulfill a long-standing aspiration to facilitate non-engineering students and academics (largely but not exclusively from Education) involvement in the Faculty of Engineering. But this is only the "functional" reason for the degree. The fundamental motivation for this initiative is that engineering education is an important and rapidly expanding area of scientific and creative scholarship and the University of Manitoba is committed to providing leadership in this area.

## 6. PROGRAM DEVELOPMENT AT THE UNIVERSITY OF MANITOBA

Early in 2015, two coordinators were appointed, one each from the Faculties of Education and Engineering, to recommend a course plan for the postgraduate degree program in engineering education to the Design Chair and the Dean of Education. Combining a literature review of existing globally located Engineering Education programs with other resources, the coordinators have amalgamated salient aspects of historical approaches on, and modern perspectives of, engineering education to create a new graduate program. The first iteration of the proposed program, which at this time is being conceived as a Master's degree, will be executed in five phases. It begins with a parallel, but independent dual-entry process. One entry stream is dedicated to students with an education background, while the other is for students entering with an engineering background. It is envisioned that these groups will begin the program as a unified cohort, enrolling in collective courses that provide a background in the historical and social context of engineering as well as an introduction to educational research methods: Phase 1. Following these introductory courses, each entry stream will dissociate to participate in specialized courses for their group for which they require expertise. Here, the Education entry students will engage in engineering-based courses focused on the design process (either alone or in combination with engineering graduate students who currently take the course), and the Engineering students will be introduced to an in-depth study of teaching and learning at the post-secondary level: Phase 2. Once this phase is complete, both entry streams will re-unite for collective courses on the views of teaching, paradigms and methodologies for carrying out inquiries into teaching as well as a more focused approach to research in engineering education: Phase 3. From here, Education entry students will have an opportunity to learn about Engineering Education in the K-12 curriculum and how they can be prepared to instill an understanding and appreciation of the subject matter to students, while the Engineering entry students will engage in courses focused on pedagogical theory and practice, curriculum development, and innovative practices centered around Engineering Education at the post-secondary level: Phase 4. Once this phase is complete, both entry streams will embark on their capstone final project/thesis: Phase 5. Figure 1 shows the proposed curriculum. Courses with the designation EDUA, EDUB and ENG refer to those that already exist within the faculties. The courses without designations will need to be designed. This program plan has already been proposed to both the Faculties of Engineering and Education, and is currently under review.

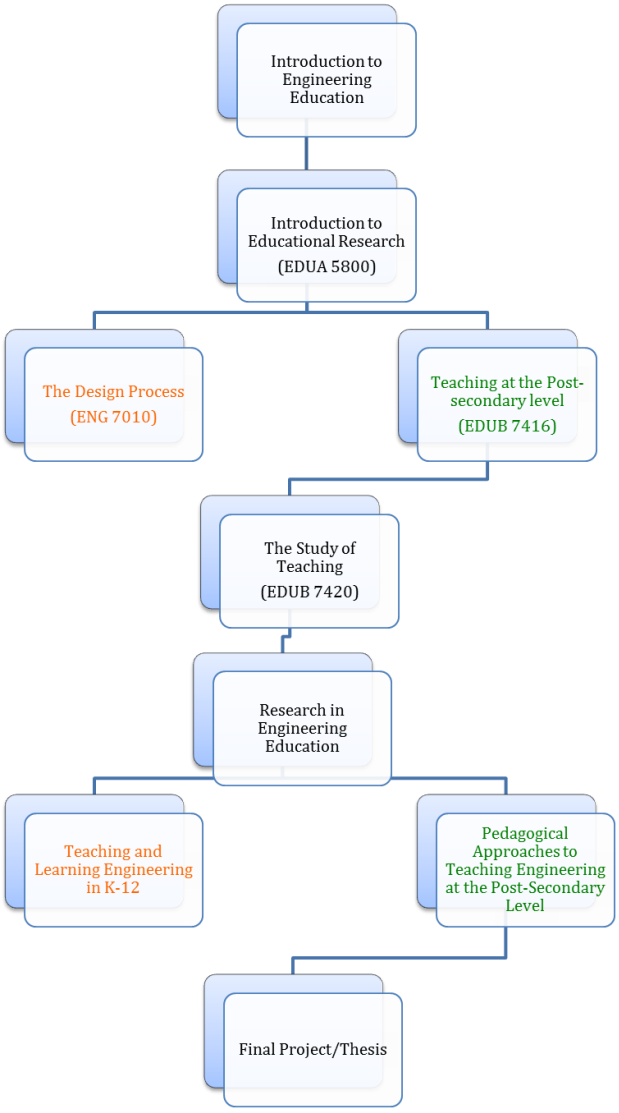


Fig. 1. Proposed curriculum for the Engineering Education Masters Degree Program at the University of Manitoba.

## 7. CONCLUSION

While the engineering education landscape within universities continues to evolve, the University of Manitoba is breaking new ground with its proposed Engineering Education Graduate Program. Several developments within the last few years, including the formation of CEEA, changing CEAB accreditation requirements, and global influences have spurred a growing interest among Canadian engineering academics and practitioners in the field of engineering education. The University of Manitoba is poised to capitalize on these trends and develop a program of study that will benefit graduate students in the fields of both engineering and education to better understand and tackle the challenges that lie ahead. Increasingly, these two fields will no longer be seen as disparate from one another, but rather through their combined focus and scholarship on pedagogy, inextricably linked.

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## APPENDIX A: ENGINEERING EDUCATION DEPARTMENTS & PROGRAMS (GRADUATE) [21]

| Engineering/STEM Education Graduate Programs | | | |
|---|---|---|---|
| **Institution** | **Country** | **Program** | **Degrees Awarded** |
| Aalborg University | Denmark | UNESCO Chair in Problem Based Learning in Engineering | Ph.D. in Engineering Education (joint with UTM (Malaysia))<br>Ph.D. in PBL in Engineering Education<br>Master in PBL in Engineering and Science |
| Arizona State University | USA | Mary Lou Fulton Teachers College | Ph.D. and M.Ed. in Educational Technology<br>Ph.D. in Learning, Literacies and Technologies<br>Ph.D. in Curriculum and Instruction with concentration in Engineering Education (more info) |
| | | Ira A. Fulton School of Engineering | Ph.D. Engineering Education Systems and Design (coming soon)<br>Ph.D. Aerospace Engineering with concentration in Engineering Education<br>Ph.D. Mechanical Engineering with concentration in Engineering Education |
| University of California - Berkeley | USA | Graduate School of Education | Ph.D. in Studies in Engineering, Science, and Mathematics (SESAME) Education |
| Chalmers University of Technology | Sweden | Department of Applied Information Technology | Ph.D. Engineering Education Research |
| University of Cincinnati | USA | School of Engineering Education (SEE) | |
| Clemson University | USA | Department of Engineering and | Ph.D. Engineering or Science |

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|---|---|---|---|
| | | Science Education | Education |
| Universiti Kebangsaan Malaysia | Malaysia | Centre for Engineering Education Research (CEER) | Ph.D. Engineering Education |
| University of Kentucky | USA | College of Education - Department of STEM Education | Ph.D. in Education Sciences |
| Linköping University | Sweden | Department of Science & Technology - Division of Physics and Electronics | Engineering Education Engineering Education Research Group |
| Louisiana Tech University | USA | College of Engineering and Science | Ph.D. in Engineering with Engineering Education concentration |
| University of Maryland | USA | College of Education | Ph.D. in STEM Education |
| The College of New Jersey | USA | School of Engineering - Department of Technological Studies | M.A.T. in Secondary Education - Technology Education |
| Niagara University | USA | College of Education | M.S. Ed. Math, Science, and Technology Education |
| North Carolina State University | USA | College of Education - Department of Science, Technology, Engineering, and Mathematics Education | M.S. and M.Ed. Program in Technology Education Ed.D. Program in Technology Education |
| Old Dominion University | USA | Darden College of Education - Department of STEM Education & Professional Studies | Ph.D. Concentration in Occupational and Technical Studies |
| The Ohio State University | USA | Science, Technology, Engineering, & Mathematics Education | Ph.D. Technology & Engineering Education |
| Purdue University | USA | School of Engineering Education | Ph.D. Engineering Education |
| University of Texas at Austin | USA | College of Education | Ph.D. STEM Education M.A. or M.Ed. STEM Education |
| Tufts University | USA | Department of Education | M.S. Science, Technology, Engineering Education or Math (STEM) Ph.D Science, Technology, Engineering Education, or Math (STEM) Master of Arts in Teaching - Engineering Masters of Arts in Teaching - Elementary STEM Education |
| Universidad de las Americas, Puebla | Mexico | EDEI - The School of Engineering | Ph.D. in Education of Sciences, Engineering and Technologies |
| Universiti Teknologi Malaysia | Malaysia | Department of Technical and Engineering Education Training and Research in Engineering Education (TREE) | Ph.D. in Engineering Education Ph.D. in Engineering Education (joint with AAU (Denmark)) |
| Uppsala University | Sweden | Uppsala Computing Education Research Group (UpCERG) | Ph.D. in Computer Science with specialization in Computer Science Education Research |
| Utah State University | USA | Department of Engineering | M.S. Engineering and Technology Education, Ph.D. Engineering Education |

## APPENDIX B: ENGINEERING EDUCATION-RELATED CERTIFICATE PROGRAMS [21]

| Engineering Education-Related Certificate Programs | | | |
|---|---|---|---|
| **Institution** | **Country** | **School, College, Department** | **Certificate Awarded** |
| Arizona State University | USA | Mary Lou Fulton Teachers College | Educational Technology Certificate Technology for Teaching and Learning Certificate |
| Boise State University | USA | College of Engineering | Certificate in Secondary Teaching for Engineers |
| Clemson University | USA | Department of Engineering and Science Education | Certificate in Engineering and Science Education |
| Michigan State University | USA | College of Engineering | College Teaching Certificate |
| University of Michigan | USA | Center for Research on Learning and Teaching (CRLT) | Certificate in Engineering Education Research |
| North Dakota State University | USA | Center for Science & Mathematics Education (CSME) | Graduate Certificate Program in College Teaching |
| University of St. Thomas | USA | Center for Engineering Education | Graduate Certificate in Engineering Education |
| Virginia Tech | USA | Department of Engineering Education | Engineering Education Graduate Certificate |
| | | School of Education | Integrative STEM Education Graduate Certificate Program |

## APPENDIX C: INNOVATIVE ENGINEERING AND INTER/CROSS-DISCIPLINARY PROGRAMS [21]

| Innovative Engineering and Inter/Cross-Disciplinary Programs | | | |
|---|---|---|---|
| **Institution** | **Country** | **Program** | |
| Aalborg University | Denmark | Department of Development and Planning | M.S. Problem Based Learning in Engineering and Science |
| Carnegie Mellon University | USA | Program in Interdisciplinary Educational Research (PIER) | Ph.D. in Interdisciplinary Educational Research via Mechanical Engineering program |
| King Abdullah University of Science and Technology (KAUST) | Saudi Arabia | | Ph.D. Program |
| National Institutes of Technical Teachers' Training & Research | India | | Ph.D. Programme in Engineering Education (Inter-disciplinary Research) Master of Technology Human Resource Development Master of Technical Education |

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|---|---|---|---|
| North Dakota State University | USA | College of Engineering & Architecture, College of Mathematics & Sciences, and College of Human Development & Education | Ph.D. in STEM Education |
| Stony Brook University | USA | Department of Technology and Society | Ph.D. in Technology, Policy, and Innovation (TPI) |
| Texas A&M University | USA | College of Engineering | Ph.D in Interdisciplinary Engineering |
| University of Georgia | USA | Faculty of Engineering (more information at:: Engineering Education Research CLUSTER) | M.S. and PhD in Engineering with Area of Emphasis in Engineering Education Research |
| University of Washington | USA | Human Centered Design & Engineering | Ph.D. in Human Centered Design & Engineering (HCDE) |
| University of Florida | USA | College of Engineering | Ph.D in Materials Science and Engineering with research emphasis in Engineering Education |