

TITLE:

Transdisciplinary Design Education for Engineering Undergraduates

Abstract

Today's engineers work in a complex design space and are called upon to work in transdisciplinary teams in order to develop efficient solutions to interdisciplinary problems. Despite this new reality, engineering design curriculum remains focused on teaching subject specific problem resolution approach of various engineering disciplines. As a result, engineers graduating from different disciplines have no common basis from which to think about engineering design processes. We propose developing curriculum using educational tools such as Bloom's taxonomy to ensure that fundamental aspects of design processes are addressed in engineering design curriculum. This will be done by benchmarking current practices with contemporary design methodologies while considering Canadian Engineering Accreditation Board standards and regulations to develop a design curriculum to be taught across the Faculty of Engineering, which will provide students with a common set of fundamental cognitive and creative skills to rely upon as they create our world anew.

Keywords

Design education, design learning, design cognition, design methodology, systematic design approach, transdisciplinary design

Introduction

Our project will draw upon recent innovative and successful engineering design education projects to develop a curriculum, based on Bloom's taxonomy, to teach first year students in the Faculty of Engineering the fundamental cognitive, creative and logical processes, systems and tools of engineering design. Engineering design problems and processes exhibit a common core of cognitive, logical and creative iterative processes (Visser 2009; Visser 2006) and contemporary engineering design professionals work in a complex design space and are called upon to work in interdisciplinary teams in order to develop efficient solutions to multidisciplinary problems.

Despite this, across the Faculty of Engineering at the University of Alberta, the design curriculum consists of discipline-specific design courses. These classes retain strong disciplinary and applied emphasis without exposing students to fundamental cognitive and logical processes of design. However, these students, after their graduation, are expected to become team-members of highly transdisciplinary design teams where they are expected to collaborate and communicate with colleagues from other disciplines. This poses a major challenge to early stage professionals and causes design delays and iteration due to mutual understanding and communication of problem at hand. Some of the fundamental issues faced by them are: complex interfaces between collaborating development teams (ElMaraghy et al. 2012); error-prone communication (Maier et al. 2009); differing goals and a lacking awareness of other stakeholder's needs (Fong 2003); differing views on the product lifecycle (Qureshi et al. 2014); differing modelling approaches (data representation) (Gericke, Qureshi, et al. 2013; Dong 2009). A recent faculty of engineering design retreat attended by cross faculty design instructors identified the need of sequential and early introduction of design skills education and need for improved teaching support for undergraduate students.

Recent research by principal applicant (Gericke, Adolphy, et al. 2013; Qureshi et al. 2014) has concluded that engineering design processes have similarities across disciplines and that there exists a core of common design stages. Howard et al. analyzed 23 design process models and identified a set of 6 stages common to all (Howard et al. 2008). The stages are as follows: establishing a need, analysis of task, conceptual design, embodiment design, detailed design, and implementation. (Gericke & Blessing 2012) compared 64 design process models from 9 disciplines. They identified two further stages in at the end of the engineering design process: use, and closeout. (Gericke & Blessing 2012). Both studies conclude that design processes have a stepwise, iterative process.

Eisenbart et al. (Eisenbart et al. 2012) performed a transdisciplinary analysis of the processes of documenting information and storing knowledge, which are known as 'design states' in engineering design processes. They produced the following list of design states common to all engineering design processes: problem statement, context analysis, need, product idea, product proposal, design object specification, requirements specification, product functionality, working structure, conceptualization, preliminary layout, layout, and production documents.

The principal applicant has carried out a transdisciplinary industry study comprising 17 organizations from 14 different countries on 4 continents (Gericke, Qureshi, et al. 2013; Qureshi et al. 2013; Qureshi et al. 2014). Our study showed that experienced design professionals also recognized and worked with a fundamental core of cognitive, creative and logical processes in engineering design and design states that are similar across discipline.

Following this research, a number of leading engineering design schools, in Canada and internationally, are developing integrated early-stage design education curricula to allow

undergraduate students to understand and grasp the complexities of contemporary design challenges. These programs provide teaching and learning support for technical challenges as well as the more profound underlying cognitive, collaborative and logical challenges of design.

Objectives

Our project will review the current design education at the University of Alberta and compare it to existing national and international best-practice design education programs to develop a design curriculum for a first-year engineering design course. This will be supported by a workshop of international experts on engineering design education practices to support us in defining our challenges and solutions.

Methodology

The research project will follow the four stages of Blessing and Chakrabarti's Design Research Methodology (DRM): research clarification; descriptive study I; prescriptive study; and descriptive study II. (Blessing & Chakrabarti 2009). Our project is divided into 5 major work packages, over two years beginning in July 2016. From our research we will produce two peer-reviewed journal articles and two conference presentations as well as an international workshop described below. For detailed activities, please see budget justification and schedule of timeline section.

WP-1, Research Clarification (RC), July 2016 – December 2016

- Obtain ethics approval and hire necessary resources.
- Compile all courses in design education at the Faculty of Engineering.
- Develop a semi-structured interview questionnaire for academics and students involved in the design education for current practice.
- Develop a semi-structured interview questionnaire for members of Canadian industry to establish their needs and requirements.
- External benchmarking for design curriculum of 2-3 leading institutes WP-2, Descriptive Study-I (DS-I), September 2016 – June 2017

WP-2 Descriptive Study-I (DS-I) September 2016 – June 2017

- Perform domain and competency mapping of discipline specific coursework.
- Data analyses of the external benchmarks to determine which approaches have the potential to be adapted for the U of A, including the evaluation of internal and external stakeholder requirements, teaching support development and evaluation of facilities and infrastructure.
- Identification of the gaps and requirements for the the coursework.
- Host a workshop with leading education experts from the U of A, Canada and abroad to establish a consensual understanding of the projects challenges and goals.

WP-3, Prescriptive Study (PS), April 2017 – December 2017

- Develop a transdisciplinary design curriculum for practice and education based on a four dimensional framework: gaps between internal and external benchmarks; education experts' input; industry needs and requirements; and CAEB and regulatory body needs.
- Develop all necessary course materials including learning objectives and outcomes, course content, assessment tools, and teaching and learning methods.

WP-4, Descriptive Study-II (DS-II), October 2017 – June 2018

- Solicit feedback from education experts to assess the potential for the newly-developed curriculum to improve the engineering design education in the faculty via Delphi study.

- Integrate feedback to improve the course curriculum.
- Implement a course trial with a test group and control group of undergraduate students.
- Collect student feedback through surveys.
- Analyze data from surveys to implement final improvements to the course and make it ready for uptake in the Faculty of Engineering.

WP-5, Workshop and Final Support Development, October 2017 – June 2018

- Host an international workshop/conference on engineering design education to disseminate findings and to provide the newly-developed curriculum to interested members of the engineering design education community.
- Offer the curriculum to the Faculty of Engineering for initial implementation, either as a module within an existing course or as a stand-alone course.

Originality, Novelty and Innovation

The project aims to revitalize design education in the Faculty of Engineering in order to provide students fundamental cognitive, creative, and logical design skills. This will allow the students to appreciate the integrated broader nature of contemporary engineering design. Our multi-step comparison of design education methods cover multiple domains and takes into account the latest developments in practice as well as in research. To date, most of the few existing comparisons are mono-disciplinary and mainly based on engineering design literature, not on discussions with educational experts. Our approach of including the views and experiences of academic and industrial experts from multiple domains through interviews, discussions and workshops will provide us with a sound interpretation of the educational methods and should be a starting point for an increased interest in design methodology across the engineering disciplines.

Collaboration

Transdisciplinarity is a core element of this research project. The comparison of design methodologies and methods from multiple domains requires extensive collaboration between academics from different departments in the faculty. The PI and the applicants represent all the departments in the faculty. The applicants will actively solicit input and feedback in RC, DS-I, and DS-II phases of project from design instructors in the faculty including the participants of faculty design retreat 2014. Contacts within the University of Alberta will not be limited to researchers in the Faculty of Engineering, but also include researchers in other departments such as education and cognitive psychology to design the course for maximum attention retention and psychomotor, cognitive, and experiential learning. International collaboration will also be established with known experts and institutions including: Prof. Dr.-Ing. Lucienne Blessing, Engineering design and methodology product development, University of Luxembourg; Prof. Thomas J. Howard, Engineering Design and Product Development, Denmark Technical University; and Prof.dr. P.G. Badke-Schaub, Design Theory and Methodology, TU Delft, Netherlands. Other international experts from a design education will also be involved during the interviews and the workshop. The aim is to achieve bidirectional collaboration – in order to encourage knowledge on Design education to be transferred in both directions.

Evaluation

The project is designed and implemented with a systematic design research methodology, which provides systematic stages of development, assessment and improvement. The RC phase will set the baseline reference system for ongoing benchmarking and evaluation of the development work.

This will be evaluated by a panel of collaborators and inter-departmental stakeholders for relevance to the academic deliverables of the course. An international benchmarking exercise is also built in the project to provide an external benchmark for the project. Furthermore, after the PS stage, the approach will be tested with a double blind Delphi method with field experts to ensure an arm's length evaluation without bias or fixation. Lastly an international workshop is envisaged to bring internal stakeholder and external experts from collaborating institutes to evaluate the final approach, provide recommendations, and disseminate the results of the project. Peers review of the research work undertaken as a part of the project will be provided through publishing in high quality conferences and journals.

Sustainability

The project deliverables intend to include full course material including notes, lecture slides, Eclass documents and support. A number of workshops as described above will be used to disseminate the results as well as pedagogic support in collaboration with CTL. Periodic review of the coursework will be undertaken by a panel composed of cross faculty academics of design education to ensure taking into account the design priorities of the departments. One of the main tasks of the study would be to identify the existing resources available at the faculty for teaching of design education and recommendations to design the curriculum to utilize these facilities while minimizing any extra unnecessary expenditures.

Impact on Students

Around **1,000 students** are enrolled in first year undergraduate engineering program every year. Design Engineering is one of the most critical skills that they are expected to learn throughout their enrollment at the University. The main key learning outcome of the project is to empower these students to have a transdisciplinary overview of the design processes. This will allow them to appreciate the integrated broader nature of contemporary engineering design and develop early cognitive, psychomotor, and experiential experience to tackle these problems. It is also expected that by participating in a transdisciplinary design immersive work, the students will be better guided towards their disciplinary inclinations, allowing them to make informed decision making towards choosing their specific disciplines for the subsequent years of study.

Having a common understanding at an earlier step of their engineering studies will setup a common baseline design education metric. This can be used as a prerequisite for developing further, advanced interdisciplinary design courses at the intersection of two or more disciplines e.g. Mechatronics Design which can be taken by the students at an advanced level.

Dissemination

Information will be disseminated via peer reviewed publications and a conference and workshops. 4 peer reviewed publications are planned (2 journal papers in the journals related to engineering design education journals (2017, 2018), 2 conference papers (ASME International Conference on Design Education 2017, and the Design Conference 2018)). In addition to above, two workshops will be held. The first workshop will be held at the end of DS-I with an aim to form a consensual approach with the participation of academics, regulatory and industrial representatives, and students. A second international workshop/conference will be held at the end of DS-II to disseminate the research and developed curriculum to all the stake holders for its implementation and uptake. The curriculum and support for the transdisciplinary approach will be developed with the aim for an easy adoption of the approach to be implemented as a Massive Open Online Course (MOOCs) in the future.

Budget Justification and Project Plan

A total amount of \$134,240 is being requested for the project. Due to extensive research scope of the project a large amount of the requested budget (78.4%) is allocated to hiring a part time research assistant (RA) (grade 7) and a graduate student for MSc for the duration of the research project. The RA will support the applicants in the development and execution of the questionnaires, surveys, and planning and administration of workshops as well as managing the international workshop. The RA will also support the applicants in development of the teaching curriculum, and collection and compilation of interdepartmental documentation. The graduate student will carry out research on the topic of transdisciplinary engineering design education framework development. The student will carry out research based on the needs, elements and structure of design research methodology, including data analyses of questionnaires and design or prescribed approach as a part of his research project. The student will also participate in benchmarking exercises as well as needs analysis for CEAB.

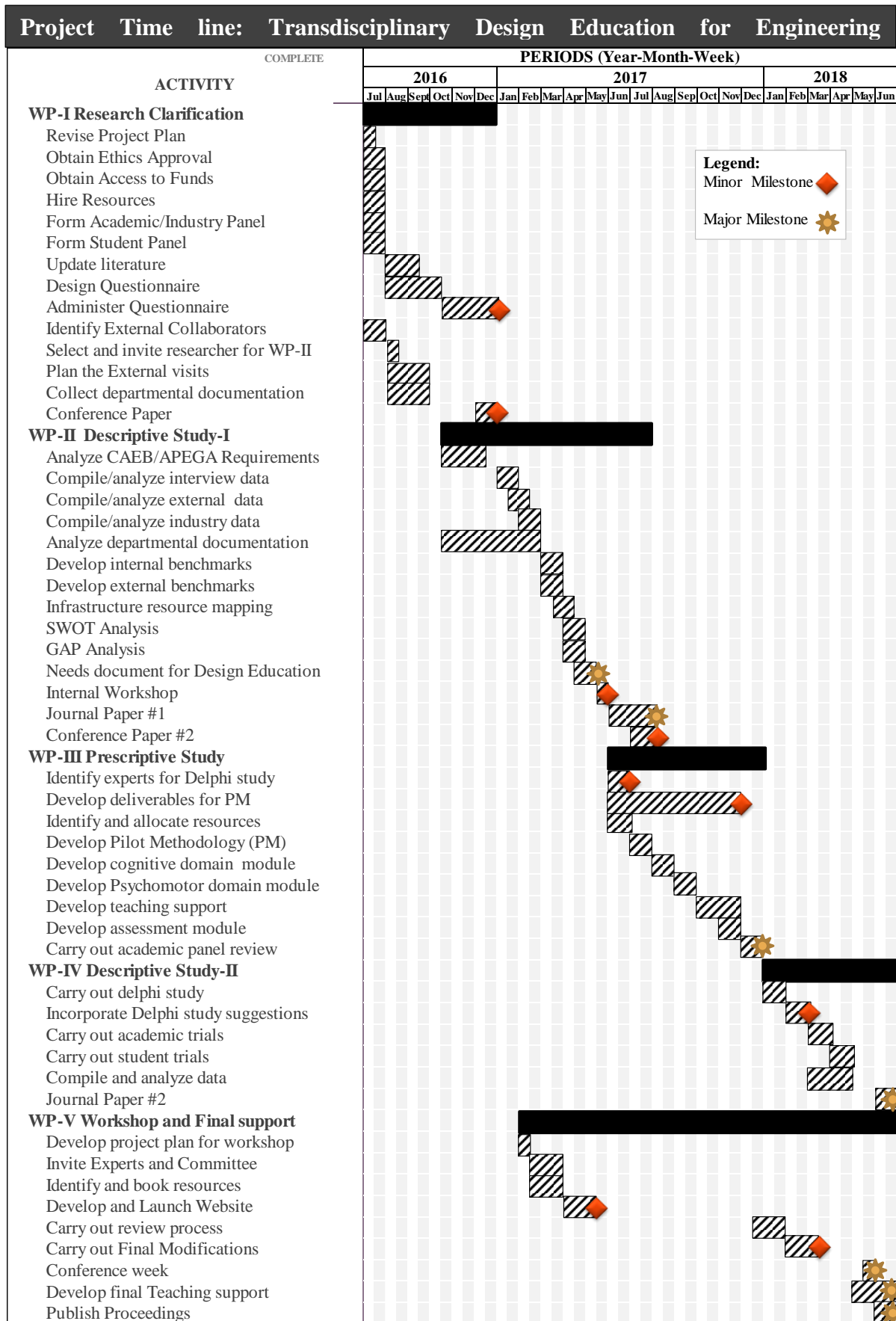
The supplies requested comprise the cost of stationary and general office supplies associated to the project. Two computers will be procured ($\$1,500 \text{ Ea} \times 2 = \$3,000$) for the incoming graduate student and RA to enable them to carry out the assigned tasks.

The travel cost (excluding the dissemination cost) includes costs (\$5,000) of visiting three universities in Canada ($3 \times (\$500 \text{ air ticket} + \$100 \times 3 \text{ days boarding}) = \$2,400$) and one international university ($\$2000 \text{ air ticket} + \$100 \times 6 \text{ days boarding} = \$2,600$) for establishment of external benchmarks in first year. For second year \$5,000 is requested to cover the cost of inviting 3 internationally recognized experts in design education in second year for Delphi process.

The dissemination costs are intended to cover the costs of graduate student for 2 conferences as well as partially covering the cost of hosting an international workshop in conjunction with the department of mechanical engineering. The graduate student is expected to present his work at two renowned conferences in design education for which an amount of $\$5,000 = 2 \times (\$1,200 \text{ tickets} + \$100 \times 5 \text{ days of boarding} + \$800 \text{ registration})$ is requested. An amount of \$7,000 is requested to partially support hosting an international conference on engineering design education. The outstanding amount of conference will be supported by the Mechanical Engineering department for an amount up to \$20,000. Additional funds support will also be requested through NSERC connect grant for holding workshop and conference as planned in the project. The breakdown of the costs is shown in Table 1.

Table 1. Budget breakdown in general heads

Description	Total amount for 24 months
Graduate student Support	\$ 46,200
Research Assistant	\$ 59,040
Supplies	\$2,000
Computer Hardware	\$3,000
Software	\$2,000
Travel (excluding dissemination)	\$10,000
Travel (dissemination)	\$12,000
Total	\$134,240



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