AC 2010-247: SCHOLARLY CREATIVE ENGINEERING DESIGN?

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Abstract

McMaster University has initiated a new Master of Engineering Design degree in engineering practice aimed at educating tomorrow's leaders in engineering design. Graduates of engineering schools are well versed in first-principles approaches to technology application and must acquire new skills and competencies in innovation and design in order to become global leaders in their field. The leading thinkers in engineering design must be prepared to innovate continuously in the global marketplace. This program has come to fruition through the collaboration of two schools: Ontario College of Art and Design and McMaster University offering Industrial Design and Engineering Design expertise, respectively. This paper presents the current efforts in defining creative engineering practice and couching it in terms that can be assessed by both creative/engineering professionals/academia. The paper will review the philosophy behind the current program, curricula, and an example of student work. For engineering students, learning to become creative individuals requires a considerable degree of learning outside their normal world view, which, by definition, expands the definition of the engineering design practice. To be creative, engineering students must borrow from established, scholarly, practices in art and design. In particular, the program borrows heavily from traditions in inquiry in the humanities, arts, and social sciences. The principles behind these practices directly challenge the positivist practices underlying the expectations of the scholarly work that underpin a graduate degree in engineering design. The paper outlines current efforts that bridge this divide and thus create a new kind of individual: one who is competent with the use and application of scientific and mathematical principles but has the capacity for finding new and creative means for delivering human benefits with this knowledge.

Introduction

McMaster University has initiated a new Master of Engineering Design degree in engineering practice aimed at educating tomorrow's leaders in engineering design. The particular vision of the founders of the program three years ago, was to develop a program which will build a community that finds, educates, and supports individual engineers to take on leading roles in terms of developing not only sound engineer designs but be capable of leading organizations in terms of generating new ideas, that is, being creative and innovative. To that end, the program has partnered with Ontario College of Art and Design, a university with strength in "right-brain" or creative thinking whereas engineers tend be stronger as "left-brain" or logical thinkers.

The vision to become a leading centre of creative engineering design for academia, business, and the engineering profession is a much greater challenge than was originally imagined by the founders. The ideal product of the program is an individual with traits that stretch beyond conventional engineering education norms to include commitment to creating value, creativity, risk-taking, strong communication and interpersonal skills, business acumen, ability to integrate ideas, capability to explore ideas, and a capability to collaborate with other professions, in addition to technical competence. This individual, in due course in their career, would show adeptness at creating higher-value and more innovative designs than his or her peers.

This has meant designing a sustainable program with these stakeholders in mind: leading and innovative local employers, engineering graduates, and academia. Each of these stakeholders requires a specially attenuated message aimed at their particular perspective as to the role of leading design engineers. In particular, to involve academia in this process means that they too must be able to evaluate not only the technical competence of design from within a positivist[1] paradigm but also the creative aspects of the work.

Herein lies the difficulty. Engineering faculties, such as ours in a research-intensive institution, has no experience or understanding of creative aspects of engineering design and tend to reject any inquiry that strays outside of a strictly positivist or perhaps post-positivist paradigm. This paper outlines our vision and understanding of engineering design and communicates the approach we have taken to defining a Master of Engineering Design degree that at the same time is acceptable to the scholarly sensibilities of engineering faculty and pushes the boundaries of the practice of engineering design. To develop the program, we believe that engineering scholarship must extend beyond problem-solving to include inquiry approaches from the arts and humanities[2].

The Nature of Engineering Design

Many of the early projects performed by students in the Master of Engineering Design degree resembled in every way a research Master's degree except in their depth and occasionally in the rigor of the application of the engineering and scientific knowledge. This represented a fundamental problem for the program. What value is the program if it is in no way unique compared to a research degree?

The original vision for the program was wrapped around traditional, and in many ways out-dated, understandings of engineering design. The Accreditation Board for Engineering and Technology's (ABET) definition of engineering design figures prominently as a normalized definition commonly understood by engineering schools. Engineering design is perceived first and foremost as problem-solving. That is, given a design space, find the best design point that best meets the criteria without violating the constraints. This decision-based view of engineering design[3] has been strongly supported by academic researchers systematizing the knowledge in the field of engineering design. In this context, creativity plays only one role: a more refined and deeper search of the design space. This notion of "creativity" is exemplified by such techniques as TRIZ and ARIZ[4].

> "Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation. The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems,

development and use of modern design theory and methodology, formulation of design problem statements and specification, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system description. Further it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact."

Figure 1. Navajo Bridge in the Grand Canyon National Park[7]

Implicit in this understanding of engineering design is that need is something that is established by non-engineers or engineers working outside of engineering practice and is communicated in an over-the-wall approach to the engineers. Non-engineering factors such economics, safety, reliability, aesthetics, ethics, and social impact are relegated to a plethora of systematized approaches often known as "Design for *X*". If engineering design is merely the application of already well defined knowledge then there indeed cannot be any possibility of granting the discipline and practice scholarly status. This perception of need suggests that the impact of engineering design is fixed at the beginning of the process and outside the setting of contraints has little impact on the design. Yet recent pedagogical practice belies this point. Textbooks such as Dym and Little's *Engineering Design: A Project-Based Introduction*[5] and Ulrich and Eppinger's *Product Design and Development*[6] begin to suggest that that interface between stakeholders, business, and technology is a great deal more complex and offers a bevy of opportunity for design engineers. Defining that interface in terms of objectives or affordances of the design is part of the design engineer's responsibility.

If one applies the above definition one may be lead to believe that excellence in engineering design is in fact determined by the highest level of competency and cleverness in meeting fixed engineering requirements. Curiously, the Navajo Bridge pictured in Figure 1 is not only an exemplary design in engineering terms but rather because it overcomes the conflicting interests including preservation of sacred Navajo land, endangered plant species in the Marble Canyon, the possibility of construction pollution entering the water, economic, financial and aesthetics considerations. The engineering was no doubt competent but the goodness of design was measured in terms of impact on the stakeholders.

Leadership in terms of innovation through engineering design is also increasingly being measured by the impact on the marketplace or society and not only in terms of new technologies developed. What if design engineers could begin a project asking themselves how can we maximize the impact of the design on our users or stakeholders? No longer could it be assumed that the design engineers knew or understood the need. No longer could it be assumed that design is strictly an engineering practice. In fact, design can only be interpreted as a means to deliver value to clients. The source of knowledge used to fulfill identified opportunities whether understanding of stakeholders, business, or technology is unimportant. In fact engineering design always is the intersection of those three key areas of knowledge: stakeholders, business, and technology (Figure 2). New understanding, discovery, in any or all three can lead to changes in any other two of the areas. Engineering design is then the engineers' contribution to that process and its result including participation in identifying opportunities. What would an engineer look like in an organization with this kind of an inter-disciplinary design focus?

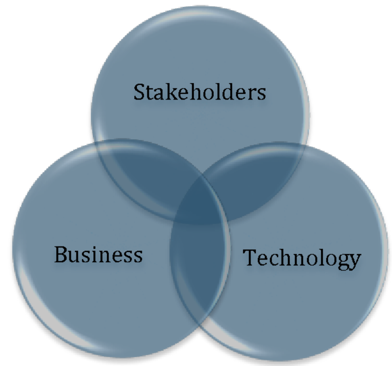

Figure 2. Engineering design lies at the intersection of stakeholders, business, and technology

A Model of Creative Engineering Design

All scholarly work is situated within a philosophical framework: a paradigm of inquiry. Engineering research and science are centered on a positivist philosophy. Positivism is founded upon the belief that reality is driven by immutable natural laws and mechanisms. Knowledge of these laws and mechanisms is acquired by the researcher in a distant, non-interactive posture. Questions are stated and then subjected to empirical tests (falsification) under carefully controlled conditions. From this perspective, it is quite natural to believe that the "need" in engineering design must be assumed since it cannot be objectively determined, at least not by the engineer. The need is cast as a set of binding criteria and constraints. The role of the design engineer must logically be to apply the existing systematized knowledge, in a problem-solving mindset, to find a solution. An open-ended design problem simply means that multiple disconnected design spaces must be searched. There cannot be inquiry from a practitioner's perspective in this model although researchers do find ample paths of inquiry in the field.

For most positivists and even post-positivists, the difficulty with inquiry with respect to stakeholders is that need cannot be considerable knowable. Yet, other disciplines in the arts, humanities, social sciences, etc. have a significant history of inquiry using methodologies such as ethnography. How can the needs of a small *n* of stakeholders be knowable in scholarly acceptable way? If a significant population were present then naturally surveys and statistically means could be conducted to understand what the stakeholders want. This is simply the role of the marketer. Yet methods like ethnography sacrifice a degree of certainty or rigor for the possibility of greater insight that surveys cannot achieve because the questions in the survey themselves are a confounding influence and themselves violate the principle of distant observer. In ethnography, the inquirer is no longer an objective observer but is, to a degree, a participant in the research and closer to the ideal of distant observer.

This notion of inter-disciplinary practice has increasingly become broadly accepted among design schools. It is well known as either design thinking[8] or integrative thinking[9]. Design thinking suggests the new ideas are best generated through the integration of multi-disciplinary knowledge. Design thinking is irreverent with respect to scholarly boundaries and inquiry paradigms. Designer thinkers are comfortable with qualitative and quantitative data collected with rigor or uncertainty and are able to integrate ideas from a broad range of perspectives. Generally, arts, industrial design, and business schools have adopted design thinking with only a few engineering schools beginning to consider its implications.

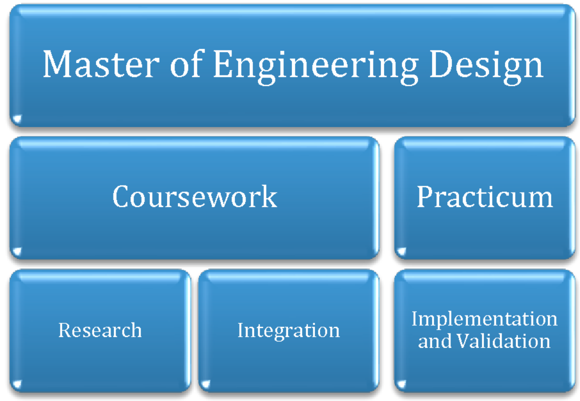

Figure 3. Composition of the Master of Engineering Design

Master of Engineering Design Program

The Master of Engineering Program is, like a research degree, composed of coursework followed by a project or practicum as shown in Figure 3. The goal[10], as stated earlier, is educate students to be broader thinkers, better communicators, risk-takers, and sensitive to human need. Part in parcel of being creative is the need to challenge students to think rationally and with some depth regarding their stakeholders. Students enter the program with a very limited model of the interface between technology and people. This model must be challenged through readings, discussions, and exercises that cause students to question their preconceptions of people with real world data. Essentially, in the research first half of the coursework, students are given assignments to go and speak to stakeholders and trained by an ethnographer on appropriate means for asking questions, interfacing with interviewees, and analyzing the results. Many of our students find this first step in the design process where their greatest “a-ha” moments come – where their discoveries are made. The goal of the first half of the coursework is the collection and research through ethnography, expert interviews, literature surveys, online surveys, etc.

The second half of the coursework puts the task of integrating the information into a coherent direction before the students. This is immensely challenging process for students who have been taught to solve problem using certain data and mathematical models. Although they will frequently to do some research, assessing the information organizing it and determining a new direction based on the research is taught as a collaborative, team process. As in any paradigm of inquiry, critical discussion and communication of one’s work plays a vital role. Whereas in most engineering research, sharing of one’s work follows the experimental stage, in design discussion and communication begin and continue from the outset of a project. Design inquiries must seek out opinions and criticism of their work by peers throughout the project.

The goal of the coursework is development of a new idea, thoughtfully supported by research, ready to be "designed". In other words, the conventional assumptions that frame a project are replaced by an inquiry approach that demands that its practitioners ask hard questions about the project, its stakeholders and the value proposition. This critical examination of the project and collection of data leads to a richer and deeper definition of the engineering work that is to be performed in the practicum – one that ostensibly results in a higher value design that may compete on a global level. Often new requirements derived from the inquiry lead to new designs. The project practicum is the engineering end of the program which can be evaluated, in part, by engineering faculty for its technical competence and by faculty invited from outside of engineering for its application of non-conventional (from an engineering perspective) inquiry.

Example Project

In the fall of 2008, two Master of Engineering Design students were tasked with finding a new direction for the Now House Project pictured in Figure 4.

Figure 4. The Now House Project[11]

The Now House Project is a demonstration project of a net-zero energy home. More than one million bungalows similar to the one picture in Figure 4 were built in Canada in the years following the Second World War. By today's standards these home are highly inefficient in the use of energy, particularly with respect to heating in the winter. These homes were built with no wall insulation. Converting the home into a net-zero energy home was a yearlong project contracted by the City of Toronto to a local firm. Had the owner performed the renovations at his own cost, he would have had to spend approximately $180,000 CAD in 2006[12] to achieve the goal of a net-zero energy home – a home which produces as much energy as it consumes in an average year.

The conventional engineering approach to this problem, that is finding a new direction or technology in the market of energy efficient homes and renovations would be look at inefficiencies in the new technology or implement new and emerging technological innovations in the home. For the purposes of the course the students followed the prescribed task of research first.

The two students held extensive interviews with the owner of the home, neighbors, contractors, city officials, project participants, etc. and they attended two charrettes related to similar projects over a period of months. Their conclusions were in many ways contrary to the understanding they had of the problem before they began. From the many observations and conclusions draw by the pair, the one that stood out was that the consumers, although they do care about energy efficiency, are much more likely to make renovation decisions in favor of changes that bring immediate and daily impact to their lives, such as a new kitchen. The thought of spending $20,000 on insulating the walls of their home was much less appealing even though they clearly understood the impact of the insulation. Similar conclusions were drawn by IDEO on the topic of energy efficiency in a 2009 study for the Department of Energy[13].

The upshot of their research efforts was that it led to a number of new ideas and directions for their design project. They now began asking how can practicing design engineers innovate in this field? Their goal became innovation, in the sense of searching for new ideas that lead to a significant impact on society. They concluded that investigating new energy efficiency technologies would be an unlikely path to innovation because of the lack of interest on the part of consumers.

Conclusions

The two students working on the Now House Project were able to find a new direction, entirely different from a conventional approach based on an evidence-based approach to examined the opportunity at a human need level.

This kind of work would unlikely find itself a home in traditional scholarly journals, at least not in engineering. Nevertheless, the results of the work are valuable to other design engineers leading to the question of why such results could not be published in an appropriate scholarly forum?

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