Design and Innovation in Western's Integrated Engineering Program

Ralph O. Buchal
Department of Mechanical & Materials Engineering
The University of Western Ontario
London, Ontario, Canada
rbuchal@eng.uwo.ca

Abstract

Society needs innovators to solve pressing design problems, and emerging technologies drive innovation. The Integrated Engineering Program offered at the University of Western Ontario develops engineering innovators by offering an interdisciplinary engineering education with emphasis on emerging technologies and engineering design. The program incorporates design in every year, and offers students the unique opportunity to participate in large multi-year design projects as part of their formal engineering education. A survey shows that students rate these features of the program important and valuable contributors toward their career goals.

1. Design and Innovation

A recent Conference Board of Canada study entitled “How Canada Performs: A Report Card on Canada [1]” benchmarks Canada’s socio-economic performance against 16 other developed countries, in six domains. The report concludes that Canada’s performance is mediocre, particularly in the innovation domain. The report states: “Most discouraging is Canada’s poor performance in innovation, where we earn a “D” and rank 14th—or fourth to last. Innovation is centrally important to Canada’s competitiveness and sustainable prosperity, and it underpins performance in the other domains.” The Conference Board of Canada defines innovation as “A process through which economic or social value is extracted from knowledge—through the **creation, diffusion** and **transformation** of knowledge to produce new or significantly improved products or processes that are put to **use** by society.” The creation and diffusion of knowledge results in new and emerging technologies, and the transformation of emerging technologies into new or improved products and processes is the essence of engineering design.

2. Emerging Technologies and Innovation

Many design courses and methodologies rely on ill-defined methods like brainstorming or flashes of inspiration to generate innovative design concepts. In

well-explored design domains, these methods are unlikely to produce innovative designs, especially for novice designers. To be clear, an innovative design is one that is better than existing designs, not one that is only different or creative. It is easy to invent original and imaginative but impractical “Rube Goldberg” solutions to design problems. It is much harder to generate innovations.

Design innovation requires awareness and knowledge of many technologies that could be applied to solving a design problem. Experienced engineers build up a storehouse of knowledge that allows them to generate many design concepts. Often, concepts are based on analogous situations the engineer has seen before.

Designers who rely only on past experience and personal knowledge tend to generate the same design concepts again and again. For example, mechanical engineers tend to consider only mechanical concepts, and do not consider solutions based on electrical or chemical principles. Innovative design requires a broad knowledge of existing and emerging technologies and principles from multiple disciplines.

Design innovation is driven by two forces:

1. Emergence of new technologies (technology push). Often products and services based on these technologies are “cool”, but fail in the

marketplace because they do not address a real need.

2. Understanding and meeting the needs of society (market pull). A goal of design is to develop new or improved products and processes to address real needs.

The challenge in innovative design is to match emerging technologies to the real needs of society. This requires knowledge of emerging technologies and the ability to recognize and identify needs. Often the developers of the technologies are unaware of the best applications, and designers facing real design problems are unaware of applicable emerging technologies.

An important trend in innovation is the emergence of Web-based “ideagoras” [2]. Ideagoras are on-line communities that attempt to find solutions to problems by engaging a global pool of experts. Companies post descriptions of design problems as well as descriptions of emerging technologies available for licensing. Two examples of ideagoras are yet2.com [3] and Innocentive [4].

3. The Integrated Engineering Program

The Integrated Engineering Program at the University of Western Ontario offers a broad-based, interdisciplinary engineering education. The curriculum incorporates fundamentals from several engineering disciplines, including civil engineering, chemical engineering, electrical engineering and mechanical engineering. The Integrated Engineering Program emphasizes interdisciplinary areas of emerging technology, particularly bioengineering, nanotechnology and mechatronics.

The Integrated Engineering Program offers flexible “streams” of introductory core courses and technical electives in these emerging technologies. Technical electives in mechatronics are drawn primarily from existing courses in mechanical engineering and electrical engineering. Bioengineering courses come mostly from mechanical engineering, electrical engineering and biochemical engineering. Courses relating to nanotechnology exist or are being developed in mechanical engineering, electrical engineering and chemical engineering. Students can choose several courses from the same stream to specialize in a particular area of emerging technology, or they can choose courses from different streams to broaden their education.

The program emphasizes engineering design and innovation based on emerging technology, and is the only engineering program at Western to offer design project courses in every year of the program.

4. Design and Innovation in the Integrated Engineering Program

The Integrated Engineering program offers a coordinated stream of design courses in every year of the program, starting in first year. A common design process is followed in all courses. Each course includes the elements of design including problem definition, background research, generation and evaluation of solutions, engineering validation, prototype testing, and design documentation. All courses develop skills in teamwork, project management, and technical communication.

Design in First Year

All first year engineering students at Western take a full-year design course, ES050 “Introductory Engineering Design and Innovation Studio” [5]. ES050 develops skills and knowledge in engineering graphics, CAD, design process and methodology, engineering validation, and technical communications. The course also introduces students to the various engineering disciplines, and to engineering as a profession.

The course involves many team-based and individual assignments and projects. Students complete a six-week project called a “creativity vignette” as a first introduction to the design process. This is followed by a major team design project. The problem domain is specified, but students are free to define their projects within this domain. For example, in 2006/2007 the major project was to “design a device that demonstrates a scientific, engineering or technological principle, with the objective of using this device as a teaching aid to support the Ontario Elementary and/or Secondary School curriculum in science and technology.”[6] The major design project culminates in a public Design Showcase during the last week of classes.

Design in Second Year

In second year, students from both Mechanical Engineering and Integrated Engineering take MME259a “Product Design and Development”. This course builds on ES050, with emphasis on mechanical product design. MME259a combines lectures and projects to introduce and reinforce the use of design tools and methodology in the completion of open-

ended team design projects. Further information about this course can be found in [7].

In the second term of year two, Integrated Engineering students take MME299b “Integrated Engineering Design I”. MME 299b fosters design innovation by emphasizing awareness of emerging technologies, and identification of needs. Students define and complete a design project after identifying many emerging technologies, and many possible design problems.

The approach of MME299b is based on the premise that real innovation is driven by the creative application of emerging technologies to new and existing design problems. To develop an awareness of promising emerging technologies that could lead to design innovations, students in MME299b are required to research at least five emerging technologies with potential application to innovative design. For each technology, students must:

1. Give a technical description of the engineering and scientific principles behind the technology.
2. Assess the useful properties and potential advantages of the new technology compared to current technologies.
3. Assess the risks and disadvantages of the new technology.
4. Assess the technological readiness and feasibility of the new technology. If the technology is still immature, give a prognosis of its potential in the future.
5. Identify several potential applications of the technology.

Student search many sources for suitable technologies, including websites, technology magazines, research literature, etc. The technologies found by each student are shared with the rest of the class, creating a dynamically growing pool of emerging technologies as potential solutions to design problems. Examples of emerging technologies found by students include: shear-thickening fluid, aerogel, quantum computing, light-transmitting concrete, bendable concrete, electronic ink, smart fabric, wireless battery charging, ultrasonic pens, shape memory metal, microbial fuel cells, pneumatic artificial muscles, nanomagnets, spray-on ceramics, thermionic energy conversion chips, electroactive polymers, stretchable silicon, and many more. The technologies range from very recent

scientific discoveries to commercially available materials and products.

A key aspect of design innovation is identifying problems and needs. Often the innovation lies in identifying and addressing a previously unrecognized need. For example, customers were not demanding a portable, high capacity, easy-to-use MP3 player with integrated music download service before Apple introduced the iPod. Apple designers recognized the latent need, and identified the necessary enabling technology (small, low cost, high capacity hard drives), to introduce a major innovation in portable music [8]. Now many people cannot imagine life without their iPod.

Once an unrecognized need is identified, an innovative solution is often obvious or straightforward. To promote innovative thinking, student teams in MME299b are required to identify at least ten market needs, and corresponding design problems to be solved. In some cases, the emerging technology research suggests directions to explore.

For each identified problem, students evaluate the following:

- Pervasiveness of the problem. Does it affect only a few people, or many?
- Impact of solving the problem. Will it result in only a minor improvement in convenience, or will it have a significant or even life-changing effect on standard of living?
- Technical complexity and engineering challenge. Is it a new hand tool, or a new type of aircraft?
- Potential market. Is it a niche market, or mass market?
- Solution feasibility.
 - Is it solvable using known technology?
 - Is it solvable using new and emerging technology?
 - Is it solvable using known but immature technology?

- Is it potentially solvable using future technology based on recent scientific discoveries?

Finally, each team is required to select one problem as the basis of a design project. The exposure to a range of emerging technologies, and the search for good design problems, promotes innovative design solutions.

Some of the projects from past years include:

- A wireless power transmitter.
- A device to increase the life of cut flowers.
- Design of driver display system for Sunstang solar car.
- A device to prevent burns from an electric stove.
- A magnetorheostatic fluid (MR) automotive differential.
- An improved ice dance skate.
- An improved alarm clock.
- A tricycle fertilizer spreader.
- Rapidly deployable housing.
- Design of electrical system for Sunstang solar car.

Design in Third Year

In third year, Integrated Engineering students take a full-year design project course, MME 399 “Integrated Engineering Design II”. Students work in teams on projects of their own choosing. The structure is very similar to the Mechanical Engineering capstone design course, MME419/499, with similar milestones and deliverables.

Example projects from past years include:

- An autonomous robot for searching and sorting applications.
- Heating system for proposed engineering green building.
- Design of a human-powered snow vehicle.

- Design of electrical system for Sunstang solar car.
- Design of an energy-efficient dishwasher using microwave drying.
- Design of SAE Aero radio controlled aircraft.

Design in Fourth Year

Engineering students in every program must complete a capstone design course. The capstone design courses are offered by the four engineering departments. The capstone design courses in Civil Engineering, Chemical Engineering and Software Engineering are very discipline-specific, and are not suitable for Integrated Engineering students. Integrated students select from either the Electrical Engineering capstone design course (ECE416) or Mechanical Engineering capstone design course (MME419/499). Almost all Integrated Engineering students choose MME419/499.

MME419/499 is a team-based capstone design course. Students select their own teams, and each team selects or proposes a design project. Students may choose from several types of projects:

- Faculty-defined projects, often associated with research. These projects often involve design and construction of research apparatus. These projects are attractive to students interested in pursuing graduate studies.
- Entrepreneurial projects. These are projects with entrepreneurial potential. The projects are proposed by the students.
- Major design competitions such as Formula SAE, SAE Baja, and solar car competitions. This option is chosen by students interested in or already working on these projects.
- Industry-sponsored design projects. These projects are defined by industry sponsors.

MME419/499 is described in more detail in [9].

Integrated Engineering students work in teams with other Integrated Engineering students, as well as with Mechanical Engineering students.

5. Multi-year Design Experience

A survey of 360 engineering departments by Dutson et al. [10] showed that 97% of student projects were of

one year duration or less. As a result, only relatively small projects are feasible if the entire design cycle of design, built and test is to be completed. There is not enough time to iterate, or to experience larger design projects. Prototype building and testing is usually limited by time and resource constraints.

One of the best design experiences available to students is participation in major student design competitions like solar car racing, Formula SAE, SAE Baja, etc. [11] These large-scale projects typically have a one or two year design cycle, with design iterations after every cycle. These projects involve the construction and testing of complex, fully functional prototypes. Students typically remain involved with these projects for several years, and experience more than one major design iteration. At most universities, this involvement is either entirely extracurricular, or at most it is part of a single design course of two semesters duration or less.

Western's Integrated Engineering program includes design project courses in every year. Furthermore, the design stream of courses, MME299b, MME399 and MME419/499, are all currently coordinated by the Director of Integrated Engineering. The continuity of the design stream in Integrated Engineering provides a unique opportunity for students to participate in ongoing, multi-year projects as part of their formal engineering education.

Of 52 students registered in the 2006/2007 academic year, seven students participated in the same project for more than one year. Another seven participated in large projects for one year, with possibility of continuing participation in subsequent years. Two students participated in ongoing projects for one year only.

6. Multi-year Design Project Case Studies

Sunstang Solar Car

The Western Sunstang Solar Car team has been in existence since 1991. The project is interdisciplinary, involving primarily mechanical and electrical engineering. The team has about 50 members from all years and engineering programs. Some members are from non-engineering faculties as well.

Over the past three years, nine Integrated Engineering students have participated in Sunstang-related design projects in at least one design course. Three students have been involved for two or more years, and several others are expected to continue on the project next year.

Several Integrated Engineering students will miss a substantial amount of their first semester of fourth year in order to compete in the World Solar Challenge in Australia in October 2007. These students have been working on the project since second year, and this race is the culmination of the project. They will be able to count this experience as part of their capstone design project, since the race is essentially a grueling test of their prototype design. Their capstone project will start with prototype testing, and culminate in a report documenting the test results and making recommendations for design improvements for the next iteration of the car.

Formula SAE

Western's Formula SAE student design team has been active since 1996. The team is composed primarily of Mechanical Engineering students, but several Integrated Engineering students are involved as well. Three Integrated Engineering students completed an MME299b design project related to Formula SAE, and these students may continue to work on Formula SAE for their subsequent design projects in coming years. Several other Integrated Engineering students are involved in an extracurricular capacity.

Western Engineering Green Building

The Faculty of Engineering plans to construct a new, environmentally friendly "green building" [12]. For the past three years, students from all engineering programs at Western have been engaged in undergraduate design projects related to the green building. Four Integrated Engineering students have been involved for at least one year, and two students have been involved for two or more years.

7. Student Survey

A survey of Integrated Engineering students was conducted in June 2007. The survey questionnaire was sent a total of 52 students registered in the Integrated Engineering program during the 2006/2007 academic year. A total of 25 students responded to the survey. Relevant survey questions and responses are summarized and discussed below.

Career Goals

Students were asked to indicate their career goals from a list of options. They were permitted to select more than one goal. The Integrated Engineering program is designed to prepare students for all of these goals. The results are shown in Table 1.

Table 1. Career goals of Integrated Engineering students

Career goal	Number of responses	Percentage of respondents
Become an entrepreneur	16	64
Manage interdisciplinary design projects	12	48
Pursue a career in management	11	44
Work on interdisciplinary design projects	9	36
Pursue graduate studies in emerging technologies	4	16
Work as an engineer in a small company	3	12
Other	4	22

Over half of the students indicated an interest in pursuing an entrepreneurial career. Management of interdisciplinary design projects was also a strong theme. Integrated Engineering attracts students with a wide range of career options.

Curriculum

The survey collected feedback on several aspects of the Integrated Engineering program and curriculum. One of the objectives of the program is to offer a broad-based engineering education. Figure 1 shows the response to the question:

“Considering your career goals, please rate the importance to you of a broad-based engineering education. The answers use a 5-point scale from Not Important to Very Important.”

Figure 1. Importance of a broad-based engineering education.

The broad-based education offered by the program was considered important by all survey respondents, with nearly half considering it to be very important.

The Integrated Engineering program emphasizes emerging interdisciplinary areas including bioengineering, mechatronics and nanotechnology. Figure 2 shows the response to the question:

“Considering your career goals, please rate the importance to you of the emphasis on emerging interdisciplinary technologies. The answers use a 5-point scale from Not Important to Very Important.”

Figure 2. Importance of emphasis on emerging, interdisciplinary technologies.

Most students consider emerging interdisciplinary technologies to be an important focus, regardless of their career goals.

Design in Integrated Engineering

The survey contained several questions relating to design in the Integrated Engineering curriculum. Figure 3 shows the response to the following question:

“Considering your career goals, please rate the importance to you of the emphasis on engineering design in the Integrated Engineering Program. The answers use a 5-point scale from Not Important to Very Important.”

Figure 3. Importance of emphasis on engineering design.

The majority of students felt that the emphasis on engineering design was important, with more than half rating it as “very important”. Emphasis on engineering design was considered important regardless of career goals.

Figure 4 shows the response to the question “Please rate the value of research on emerging technologies in MME299b, on a 5-point scale.”

Figure 4. Educational value of research on emerging technologies.

Response was mixed on the educational value of research on emerging technologies in MME299b. In some cases, students surveyed technologies that are still at the fundamental research stage. While

promising and interesting, these technologies are still too immature for practical applications. As a result, some students may have felt this to be a waste of time.

Figure 5 shows the response to the question “Please rate the value of identifying and defining multiple design problems in MME299b, on a 5-point scale.”

Figure 5. Educational value of identifying and defining multiple design problems.

The majority of students felt that identifying and defining many possible design problems in MME299b was a valuable educational experience.

Figure 6 shows the response to the question “Please rate the value of design projects in every year in the Integrated Engineering program, on a 5-point scale.”

Figure 6. Educational value of design projects in every year of the program.

Almost all students agreed that having design projects in every year was valuable, regardless of their career goals. This correlates with the response regarding the importance of the program’s emphasis on engineering design. This suggests that the emphasis on design

plays an important role in attracting students into the program.

Figure 7 shows the response to the following detailed question:

“A unique feature of the Integrated Engineering program is that students can work on major design projects that can last more than one year (e.g. Sunstang, Formula SAE, etc.). How valuable do you think this is? (1-not valuable, 5-extremely valuable)”

Figure 7. Educational value of multi-year design projects.

Most students felt that being able to work on large design projects for more than one year was moderately to extremely valuable. This is an opportunity that is of great interest to some students, while others prefer to work on different projects. The number of students rating this as extremely valuable is about the same as the number who are working on multi-year projects. Very few students did not consider multi-year projects to be of value, even if they did not participate in them.

Of the 52 Integrated Engineering students surveyed, 14 students participated in the same project for more than one year.

8. Conclusions

Western's Integrated Engineering Program promotes engineering innovation by offering a broad-based engineering education, with emphasis on design and emerging interdisciplinary technologies. Design is offered in every year of the program, and students have the unique opportunity to participate in large, multi-year design projects. A survey shows that the majority of Integrated Engineering students rate these features of the program to be important and valuable.

9. References

- [1] *How Canada Performs: A Report Card on Canada*, The Conference Board of Canada, June 2007.
- [2] Tapscott, D.; Williams, A. D.; *Wikinomics: How Mass Collaboration Changes Everything*, Portfolio Hardcover, 2006.
- [3] Yet2.com, Inc., www.yet2.com, accessed June 8, 2007
- [4] Innocentive, www.innocentive.com, accessed June 15, 2007.
- [5] Buchal, R. O.; Gibb, E.; Bartlett, F. M.; Hinchberger, S.; Barghi, S.; Bassi, A.; McIsaac, K.; Sabarinathan, J.; Samani, A.; Sun, X.; "A New First Year Design Course at the University of Western Ontario", *Proceedings of the Second CDEN International Conference on Design Education, Innovation, and Practice*, Kananaskis, Alberta, July 2005
- [6] ES050 Course Website, www.eng.uwo.ca/es050, accessed June 8, 2007
- [7] Kurowski, Paul M., Knopf, George K., "Education Engineers about Product Design Methodology", *Proceedings of the 3rd CDEN/RCCI International Design Conference*, Toronto, Canada, July 24-26, 2006.
- [8] Levy, Steven, "The Perfect Thing", *Wired*, Issue 14.11, November 2006.
- [9] Buchal, R. O., "Capstone design in Mechanical Engineering at the University of Western Ontario", *Proceedings of the CDEN/C2E2 2007 Conference*, Winnipeg, Canada, July 22-24, 2007.
- [10] Dutson, A. J.; R. H. Todd; S. P. Magleby; C. D. Sorensen, "A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses", *Journal of Engineering Education*, January 1999, pp.17-28.
- [11] Buchal, R. O., "The Educational Value of Student Design Competitions", *Proceedings of The Inaugural CDEN Design Conference*, Montreal, July 2004.
- [12] O'Carroll, D. M., Yanful, E. K., Berruti, F., Buchal, R. O., Design of a Western Engineering "Green" Building, *Proceedings of the 3rd CDEN/RCCI International Design Conference*, Kananaskis, Alberta, July 24-26, 2006