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An Approach for Improving Design and Innovation Skills in Engineering Education: The Multidisciplinary Design Stream*

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Engineering practice is multidisciplinary by nature. While some engineering projects may require discipline-specific specialists, the vast majority of engineering practice is carried out either by an engineering team of mixed disciplines, or by individual engineers who are competent across multiple fields. In both Canada and the US, engineering accreditation boards have recognized the need for students to develop at least a modest level of competency to function in multidisciplinary teams prior to graduation. Recognizing the growing need for enhanced design education and multidisciplinary competency for undergraduate students, in 2005 Queen's University introduced an elective series of courses known as the Multidisciplinary Design Stream (MDS), available to students from all engineering disciplines. The first course in the stream is offered over one term at the third year level and incorporates a broad range of lecture topics and interactive learning activities that are further reinforced with a concurrent design project in multidisciplinary teams of four students. The continuing course spans the final two terms at the fourth year level and enhances students' design, professional, and problem solving skills through their application in multidisciplinary teams on funded, industry-sponsored projects. Every team is supervised by one or more faculty members or 'engineers in residence', all of whom have significant engineering professional practice experience. The MDS has been filled to capacity since its second year of operation. Student feedback after graduation is very positive, and client response has typically been outstanding, reinforced with a very high rate of year over year client return. Student surveys and a design skills assessment provide significant evidence of increased design competency.

Keywords: multidisciplinary; design; engineering education; industry project; design education; professional practice; capstone; integrated learning; team design project

1. Introduction

The Canadian Academy of Engineers, an assembly of highly respected senior engineering practitioners and educators, has stated 'The essence of engineering is design, a multidisciplinary approach to meeting economic, social and environmental needs' [1]. The message in this statement has been offered by countless sources for decades, yet many engineering degree programs are still heavily science based, with true engineering design teaching and practice opportunities found only in the form of a final year capstone course. All too often, these are limited to a 'paper design' without prototyping, testing, or societal considerations.

It has been suggested that the 'modern, science based engineering curriculum' [2] was influenced by the Grinter report [3], which argued for more investment in science as a result of the need for further technological advances such as radar developed in World War II. However, engineering education literature has for several decades described the need for both improving engineering graduates' design skills, as well as the professional skills that round out a practicing engineer's 'tool kit'. Sound ability in engineering science and mathematics, while critical elements of any engineer's training, are only two of the many core competencies required by practicing engineers.

Todd [4] suggests 'it is sometimes forgotten that industry is an important customer of engineering education'. The results of their survey of industry published in 1993 describe industrial perceptions of weaknesses in engineering graduates such as 'technical arrogance . . . a desire for complicated and high-tech solutions . . . lack of design capability or creativity . . . all wanting to be analysts . . . a narrow view of engineering and related disciplines . . . weak communication skills . . . little skill or experience working in teams . . . being taught to work as individuals', amongst many others.

More recent industry surveys indicate that there may now be more alignment between industry and academe with respect to what topics are important. A 2002 publication by Eggert [5] surveyed both international industry and academic representatives, and had them rank perceived importance of topics and activities in undergraduate engineering education. These were then compared in terms of 'supply (academe) and demand (industry)'. Teamwork, engineering design specifications, and overall design process topics were ranked similarly. How-

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ever there were noted gaps in specific design related skills such as creativity, project management, design for manufacture, and product testing. It was also reported that industry topics in highest 'demand' were interdisciplinary design projects and industry based design projects.

Although there may be some improvement in alignment of learning priorities according to the Eggert survey, another 2002 survey by Frise et al [6] suggests that industry continues to be satisfied with the technical and scientific abilities of graduate engineers, but have a 'marked lack of satisfaction' with their non-technical capabilities and general knowledge of engineering practices. Design and 'complementary' skills (communication, project management, economics, etc.) are again considered deficient. This is reinforced in a 2006 survey by May et al [7] where students and engineering practitioners were asked to rank competencies in a wide range of capabilities. Some of the most notable gaps between students' self-ratings versus practitioners' assessments of new graduates were in teamwork and communication—both of which are key elements of multidisciplinary competence.

Engineering accreditation boards have been evolving to require demonstrated skills in key areas of engineering competency. In the United States, the Accreditation Board for Engineering and Technology (ABET) [8] has specified for over a decade that 'an ability to design a system, component, or process to meet desired needs within realistic constraints . . .' and 'an ability to function on multidisciplinary teams' are two of the eleven outcomes which engineering programs must demonstrate are present in their graduates.

Although the Canadian Engineering Accreditation Board (CEAB) has required engineering design for many years as part of the accreditation requirements, it has until recently been assessed by course credits or units, rather than by demonstrated proficiencies. As of 2009, the CEAB Accreditation Criteria and Procedures has introduced more stringent 'outcomes' requirements in the form of graduate attributes [9], similar to those required by ABET. However, the requirement for multidisciplinary capability is arguably weak, falling under the graduate attribute 'individual and team work', which requires 'an ability to work effectively as a member and leader in teams, preferably in a multidisciplinary setting.' The term 'preferable' is not a mandate, but is rather an option for engineering programs, open to interpretation.

Regardless of the strength of accreditation requirements, the data from engineering practitioners, organizations, and industry is clear. This paper will discuss one approach to achieving design competence and multidisciplinary capabilities in the engineering program at Queen's University. This approach, first introduced in 2005, is called the Multidisciplinary Design Stream.

2. Presentation

2.1 Engineering education at Queen's

Queen's is a medium-sized Canadian university with 16,000 full time undergraduate students. The Faculty of Engineering and Applied Science, with 2,600 undergraduate and 500 graduate students, offers ten four-year programs in engineering, six of which are traditional programs (Chemical, Civil, Computing, Electrical, Mechanical and Mining) and four of which are engineering science programs (Engineering Chemistry, Engineering Physics, Geological Engineering and Mathematics and Engineering). The first year class of approximately 650 students takes a common curriculum in year one and does not select from among the ten programs until the end of that year. The quality of students entering Queen's is very high and failure rates are correspondingly low.

In the mid 1990's, Queen's began a thorough evaluation of its engineering education program, which included a broad investigation of other engineering programs and institutions around the world. The result of that effort was an educational initiative that is referred to as Integrated Learning. Integrated Learning seeks to develop professional skills and to achieve deeper learning through an increased emphasis on how technical material relates to other ideas and subjects. It endeavors to link material between courses and amongst engineering disciplines, and integrates engineering with business, environmental and social contexts. Moreover, it emphasizes how to elevate theory to practice.

A critical outcome that evolved from the Integrated Learning approach was a new building to support and facilitate teaching and learning objectives. Following an extensive planning and design effort with the involvement of all stakeholders, Beamish-Munro Hall, home of the Integrated Learning Centre (ILC), was opened in 2004 [10,11]. Combining 42 student 'group rooms' (for undergraduate team meetings), interactive and flexible teaching facilities, a design studio, prototyping centre, dedicated competitive student team facilities (for projects such as solar decathlon, concrete canoe, fuel cell, and aircraft), dedicated first year studio, 'live' building instrumentation, as well as housing the Engineering Society (student government) and faculty administration offices. The ILC has become an integrated 'home' for engineering students and has been a critical element in the evolution of engineering education at Queen's.

In the common first year, Queen's engineering students take a full year course that lays the foundation for design, multidisciplinary, and professional skills. APSC 100 'Engineering Practice', first introduced in 1997, consists of three main elements: an introduction to communication, teamwork, and basic design methodology, as well as practical laboratory and analysis techniques; laboratory sessions wherein students are encouraged to design their own experiments; and an engineering design project in 4 person teams working on a variety of real engineering topics, often in the form of service learning in the community [12]. Professional skills including societal and environmental issues and ethics are incorporated, and students are encouraged to 'think like an engineer'. The team structure encourages the development of communication, negotiation, time management, and team skills throughout the project.

In the second through fourth years of engineering studies, design content varies according to the choice of discipline, and multidisciplinary opportunities are very limited. In the second and third year, while some courses attribute fractions of course content as design and may assign design problems, very few actually teach supporting design methodology, tools, or techniques. One exception to this is a second year 'Design Techniques' course in Mechanical & Materials Engineering, which has been offered for 15 years, and a new and rigorous Faculty-wide second year design/professional practice course is planned for the near future. All disciplines incorporate a final year capstone design project and/or an independent research thesis. The majority of Mechanical & Materials and Civil Engineering capstone projects are industry-based, with other disciplines opting mainly for faculty or student driven projects. All of the core capstone courses/projects are discipline-specific.

2.2 The multidisciplinary design stream

In late 1999, the Natural Sciences and Engineering Research Council of Canada (NSERC) introduced a new program— the Chairs in Design Engineering/ Chairs in Environmental Design Engineering Program (CDE/CEDE) [13]. Stating in the prospectus that 'design engineers are the enablers of innovation', one of the objectives of this program was to encourage education research and development, leading to the enhancement of design skills in Canadian engineering graduates. In preparing what became a successful application for design chair funding at Queen's, a significant review of the existing engineering program was carried out. It was determined that there were significant opportunities for enhancing students' engineering design and complimentary professional skills, consistent with industry surveys and engineering education literature. It was further determined that the ideal setting in which to teach these elements would be in a multidisciplinary environment where students can learn and practice engineering design in a manner that best simulates the engineering workplace. Although programs at Queen's were providing design project opportunities in first year and in most capstone courses, it was noted that with only one exception, there was no rigorous teaching of methodology and 'tools' for engineering design. These were the driving elements for the creation of the Multidisciplinary Design Stream (MDS).

The MDS has been structured over three consecutive terms. In the first term, following successful completion of the first two years of engineering study, students from any discipline may elect to take the first MDS course, APSC 381 'Fundamentals of Design Engineering'. Students may then elect to enroll in the continuing MDS two-term course, APSC 480 Multidisciplinary Design Project (MDP), typically in the fourth and final year of their engineering program.

2.2.1 APSC 381—Fundamentals of design engineering

The objective of the first MDS course is to provide the student with a sound background in engineering design methodology and 'tools', as well as related professional and project management skills, in a manner that simulates engineering practice wherever possible. The pilot offering of this elective course was in 2005, with enrollment consisting of 33 students representing 9 of the 10 engineering disciplines at Queen's. Twenty-five students were in third year, and the remaining 8 were in the fourth and final year of their engineering program. Enrollment increased to 48 in the second year which was the capacity of the classroom. In the third year the class was moved to a larger room and yet again it filled to capacity of 96. By this point the class was still a mix of third and fourth year students with approximately two thirds being in third year. Since the objective of this course was intended to be a prerequisite for the following course in the MDS, it was decided at this point that only third-year students would be eligible to register for the third year course. From that point on the course has continued to be full to capacity with only exceptional cases of fourth-year student enrollment, indicative of the high student demand.

The course incorporates classroom instruction as well as a concurrent multidisciplinary design project. Because there are no available daytime slots commonly available to all 10 disciplines of engineering students, the course is run at night once a week, with three hours of formal instruction and a tutorial period thereafter. From an instructional perspective, this has become much preferred to typical 50 min. slots as it allows much more flexibility in the style of instruction and classroom activity. Rooms without fixed seating areas are more suitable in order to accommodate team grouping or other class reconfiguration for specific activities. Active learning opportunities are incorporated wherever possible in order to instill deeper learning and keep the three-hour session lively for the students.

The core instruction team typically consists of one instructor/coordinator and 3 teaching assistants (TA). The TA's have been all graduate students, or a combination of graduate and senior undergraduate students. The latter must have previously taken the course and/or demonstrated thorough understanding of the material.

Projects are specifically developed in order to enhance the classroom learning. Although it results in a higher load for the instruction team, each team of four students has an individual project. This requires the creation of at least 24 projects for the class of 96 students—not a simple task, but one that summer students can greatly assist with. Projects are posted at the first class and students are asked to submit their top 10 project preferences. The instruction team then assembles the project groups according to preference and multidisciplinary mix. It is typical for at least 90% of the class to be placed in one of the top three project preferences, and no student has ever dropped the course because of their project placement.

The course material, both instructional and practical, was drawn from a combination of the instructors' professional experience and engineering design education literature. Course topics include:

- Design process methodology.
- Client statements and problem identification.
- Needs analysis.
- Information research (technical and market).
- User preferences (surveys, focus groups, QFD).
- Functional analysis.
- Intellectual property.
- Creativity techniques.
- Idea selection processes.
- Reliability and quality (including Failure Modes and Effects Analysis).
- Hazard assessment (HAZOP process).
- Design for 'x'.
- Engineering economics/cost estimation.
- Project management techniques.
- Risk analysis.
- Regulatory and Safety considerations.
- Detailed design techniques.
- Developing test plans.
- Assessing technical and economic feasibility.
- Social and environmental considerations.
- Communication skills (oral, report writing, and presentation skills).
- Team skills.

These topics are reinforced with many examples drawn from engineering practice. Guest speakers with expertise on topics such as information research and intellectual property support the instruction team. A number of past students have also been guest speakers, typically drawing significant interest and extensive Q&A sessions.

Students are placed in their project teams in week two based on a combination of preference and multidisciplinary mix. Wherever possible, lecture material is provided in 15–30 minute bursts, and student teams are frequently tasked with short in-class exercises to apply topics just discussed. If time allows, a few teams are invited to briefly discuss their application of the technique, thus illustrating variable interpretations of the process. Each team submits weekly memos related to team activities, as well as progress reports addressing project status. Just past the mid-point of the course, students make formal project presentations and submit a detailed interim report, formatted as a professional engineering report. The presentations and reports are assessed and student teams received formative detailed feedback on design methodology, techniques, and on their presentation and report writing skills. At the end of term, final project presentations are made to the class and invited guests, and final reports are submitted. Occasional unscheduled presentations, in the form of a short 'elevator pitch', are also incorporated. Although the course expectations are very high and it has been argued that not all topics can be captured within one 12 week term, the outcomes of the concurrent project indicate that the students are able to learn and apply the majority of the course content.

2.2.2 APSC 480—Multidisciplinary design project

The main objective of the multidisciplinary design project (MDP) is to deepen and broaden students' competence in engineering design, project management, and professional skills, by tackling a real engineering project with an industry partner. Teams of 3–4 students, comprising two or more disciplines, engage in an industry-based project, typically covering all facets of engineering design from product definition through to physical or 'virtual' prototyping, while continuing to receive timely relevant design instruction and guidance either in class or in weekly meetings with project advisors. All of the current course advisors have extensive experience in engineering practice (18 to 35 years), but students are also strongly encouraged to seek project guidance from others, including faculty members who have expertise in areas related to their particular project, as well as their industry contacts.

The first offering of the MDP began in September 2005, wrapping up in April 2006. That first year, due to limited departmental acceptance, the elective enrollment was 18 students—sufficient for five projects. Since that time, with the growth of the prerequisite course to the cap of 96 third year students, the MDP has grown substantially, with typical enrollments of 45 to 65 students, and 15 to 20 projects. All 10 engineering programs have been represented in the course over the five years it has been offered and typically students from at least eight disciplines are involved.

It was decided at the outset that a $5000 fee would be levied for each project, regardless of company size, in order to fund adequate support and opportunities for the student teams. Initially, there was concern that it would be difficult to find partners. However, given a reasonable effort and sound explanation of the program, engaging good quality project partners has not been an issue. In fact, a number of new partners have been established through word-of-mouth recommendations from companies who have participated in the program, and many companies have requested multiple projects in subsequent years. The return rate for at least a second year of project sponsorship is currently about 90%.

The vast majority of corporate partners have been excellent. To date, only three have not been asked to engage in further projects. In one case, the owner of a small company was essentially looking for what could be best described as 'cheap labour'. In the other two cases, the companies simply failed to pay their project fees (without explanation) and were therefore not asked to return.

The structure of the course has evolved somewhat since its inception, but for the most part the core activities and structure are much the same. Similar to the third-year course, students provide a list of their top project preferences in the first week of the course. At that point they are also provided with a complete overview of the expected deliverables, assessment criteria, client communication options and arrangements, and policies and procedures for travel and purchasing. At the beginning of week two, the students are organized into teams (3–4 per project), which have been built based on a combination of student preference and project requirements. Teams are encouraged to meet with their corporate client as quickly as possible. As with the third year course, the vast majority of students achieve one of their top 3 choices, and no student has ever dropped the course due to their project placement

Students are provided with an initial budget of $200 to allow a degree of creativity with early exploration. Receipts are required to satisfy University reimbursement policy, but as long as the spending is project related, no other justification is required. Further spending is approved via a process not unlike a corporate capital appropriation request, albeit much less onerous. Due to the variable nature of the projects, some teams spend modest amounts only covering items such as the cost of travel for meetings, while others spend thousands of dollars on prototyping. Students are made aware that while $5,000 is a maximum spending guideline, there is no set budget limit so long as the course funding 'pool' can accommodate justifiable expenses. The maximum single year project spending to date was $18,000 to construct a vertical axis wind turbine prototype.

The general expectation is that by the end of the first term, students will have achieved a first pass design solution. During this term, in addition to weekly memos and progress reports, a series of 'briefs' are submitted approximately every two weeks in order to encourage phase-wise progression of the projects. These briefs, which are essentially summaries of steps in the design process, were initiated into the third offering of the course after realizing that teams were reluctant to move in a timely way into later phases of the project. This was, in most cases, not a lack of effort, but rather a sense of needing to do more research and generate more ideas before moving on. At the end of the first term, teams submit an interim report discussing their progress to date.

At the beginning of the second term, teams are required to carry out a design review with their client and determine next steps. In some cases students can move into a physical or virtual prototyping stage, while others are required to iterate their design using feedback from the client. Due to the variety of projects, there is a significant degree of variation as to what level of prototyping and testing can be done. Wherever possible, physical prototyping is encouraged, however in some cases, teams are limited to computer design simulations and analysis. At the end of the second term, student teams again meet with the client to make a formal presentation of the overall project, and final reports are submitted.

Through both terms every project team meets with their internal project advisor at least once weekly. Classes are held most weeks with activities including discussions on advanced elements of design techniques, guest speakers, often with extensive practical engineering experience or specific expertise, or meetings between teams and their advisors. In addition to visiting clients at their facilities or vice versa, most teams engage in conference calls with their industry representative on a regular basis (typically every 2 weeks). It is worthy of note that this activity does not come easy to some students; rather, there is a very strong tendency to resort to keystrokes of some form. However, over the course of the project, with some encouragement, most students become quite comfortable with conference telephone conversations.

The Integrated Learning Centre is a critical element in facilitating these projects. The group rooms, bookable only by undergraduate students, provide a common meeting location with 24/7 access for upper year students. The design studio is equipped with state of the art workstations, loaded with extensive design, analysis, and modeling software. Across the hall, the prototyping shop is complete with hand and machine tools, and rapid prototyping equipment to allow students to build much or all of their designs. The open and accessible nature of the ILC fosters interest from other students, often in earlier years of study, thus reinforcing the 'theory to practice' objective across all levels and disciplines of the engineering program.

Working in small teams with frequent industry partner interaction allows students to experience the realities of the engineering profession in the competitive and bustling business climate. It is virtually impossible to frame internal student projects in a manner that provides a sense of urgency and the demand for value that is found in industry. In addition to applying sound technical skills, they become immersed in a situation where project management, effective communication, appropriate economic considerations, and serious consideration of social, environmental, safety, and regulatory factors become a reality.

3. Discussion

3.1 Assessment and feedback

Formal and anecdotal feedback on the MDS courses has been very positive since their inception. Standard university student feedback questionnaires provide overall course satisfaction and learning value ratings ranging from 4.3 to 4.8 out of 5, which is on the very high end of the scale for elective courses in the category. Entry and exit surveys, discussed below, have been carried out every year to provide student self-assessment of a variety of knowledge, skills, and attitudes related to course learning objectives. In addition, over the last 3 years, a further 'design skills assessment' instrument that has been developed to relatively quickly measure design process competence has also been applied on the third year course [14]. Fig. 1 is an amalgamation of the resulting entry and exit scores, illustrating a statistically significant increase for design process competency over the duration of the course. The details of this instrument and the full set of results, including statistical data, can be found in the aforementioned reference.

Example results of the entry/exit surveys from the 2010 class (95 students) are presented in Fig. 2. These results are typical of previous years' data. All data suggest that students believed they were much more prepared to cope with engineering design problems at the end of the course, including related elements such as communication and information research. All open-ended comments received with regard to the multidisciplinary teams and projects were very favorable, other than indications that it was difficult to find common times for teams to meet, given the substantially different schedules across disciplines.

In these same exit/entry surveys, students are also asked to rate their design capability on a scale of 1 to 5 (higher being better). Over the first two years, a number of students provided rather remarkable and unsolicited comments in the exit survey, indicating that should have given themselves lower ratings on their design capability in the entry survey. In following years, an additional question was posed in the exit surveys, asking students to re-rate their capability at the entry level. In the 2010 class, the students' average entrance rating on self-assessed design capability was 3.11, and the exit rating was 3.96. However, when asked to re-assess their design capability at the entry level, the average dropped to 2.68. The detailed design capability rating distribution is presented in Fig. 3. Such individual reflection is a positive indication that students have grasped the reality of engineering design as a topic to be learned over time and experience.

Students in the APSC 480 Multidisciplinary Design Project also perform entry and exit surveys, although they are somewhat different from the surveys at the third-year level. The questions are much more open ended in order to gather a thorough understanding of student knowledge, skills and attitudes relating to the course, the project and their overall perspectives related to engineering

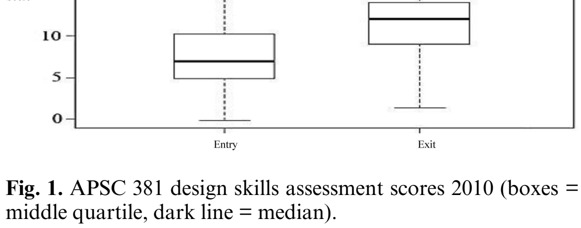

Fig. 1. APSC 381 design skills assessment scores 2010 (boxes = middle quartile, dark line = median).

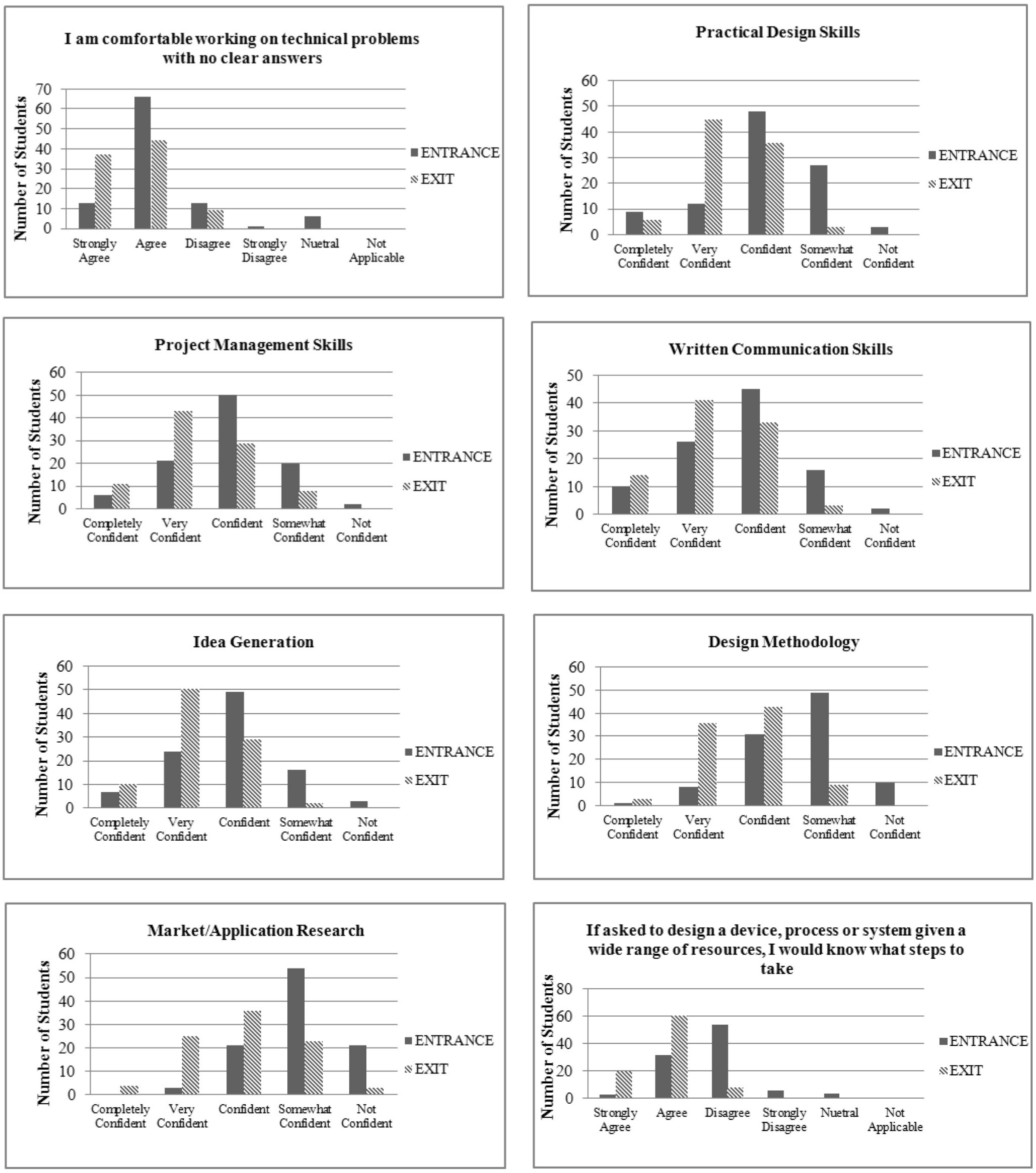

Fig. 2. Student entry/exit survey results from APSC 381 2010 (η = 95).

design. A thorough qualitative analysis has not been performed on the rather extensive data, however there are some consistent themes in the feedback. Three of the most positive themes the students report on are the value of client interaction, having the chance to do a real world project, and learning to overcome obstacles. It is also both interesting and satisfying to note that many students comment on the improvement in their writing skills, and more specifically, appropriate writing for a given audience. A sample of feedback quotes touching on a variety of areas follow:

- 'I learned a lot about dealing with people and clients. How to interact in a good way and ask the right questions'.
- 'Learned a lot about dealing with and overcoming setbacks and obstacles facing a project'.
- 'I think my project pushed me out of my comfort zone and provided a challenging project'.
- 'Successfully designing and implementing simple ideas is actually quite difficult'.
- 'Real world applications, importance of not overlooking problems'.
- 'The ability to work in fields outside my area of

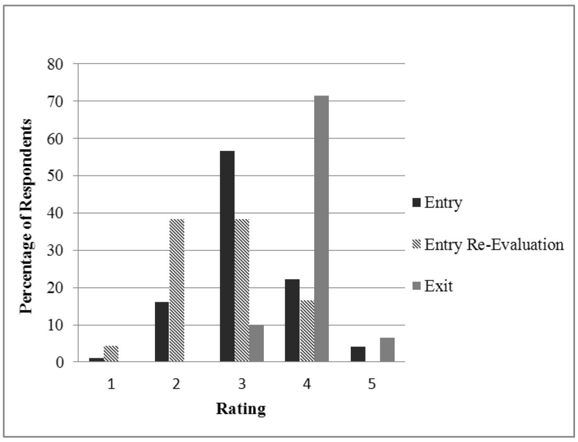

Fig. 3. Distribution of pre/post self-assessed design skills ratings from APSC 381 2010 (η = 95).

study. The ability to create an effective team from an ineffective one'.

- 'The experience has helped me figure out what I know and what I don't and has helped show me what I need to improve on'.
- 'Amazing course. Taught me more than any other course at Queen's, in terms of useful information'.
- 'The best part of this course was learning the non-technical skills'.
- 'I really enjoyed this class, and think it's really great that it's multi-disciplinary'.

Many students have commented that they speak extensively to their experience in the MDP during job interviews. For many, it is the only practical engineering experience they have had prior to graduation.

Continued contact with students after graduation is relatively frequent. Many have made return visits, sent emails, or called to give an update on their progress. Those that do stay in touch commonly express their thoughts on the value of the MDS. Although structured longitudinal research has not yet been done to study the progress of MDS graduates, it is perceived to be of significant value to the vast majority of students who have experienced it. It is not uncommon for students to suggest that it was the most useful course or experience they had in their engineering program and many have indicated that they still commonly apply many of the techniques they acquired. A number have suggested that they have taught or are teaching elements from the MDS to colleagues in the workplace, either formally or informally—a very gratifying result for their instructor.

Feedback from our industry partners is typically very favourable, and reinforced by the 90% return rate for at least one further project. Four partners have been with the program for 5 or more years, and in fact one of those clients has sponsored 3 projects in each of the last 3 years. This same partner has hired 6 MDS graduates in that time frame, 3 of whom are now involved with the ongoing projects on behalf of their employer. Needless to say, these students are incredibly dedicated and enthusiastic to support current students, having been through the program themselves. A number of past students have become 'ambassadors' for the MDS program, from encouraging their employer to get involved with a project, to being a guest speaker, or by providing assistance to the program while continuing post-graduate studies at Queen's.

With the wide variety of projects in the MDS, our industry partners see a broad range of results. There have been instances of new products, improved processes, successful feasibility studies, and other similarly positive results.

For example:

- A project to redesign both hardware and process for a critical piece of labeling equipment for an automaker has generated several hundred thousand dollars in annual savings for the last 3 years.
- Process and hardware improvements for a professional hockey facility that increased the ice quality rating from 22nd to 4th in the league.
- A design modification for military tent hardware to correct a failure issue with an optimized new component, avoiding replacement of over 50,000 tent hardware systems.
- A novel product for an industrial safety hardware manufacturer that solves a long-standing annoyance with using the safety hardware while wearing gloves.
- An engineering study for an energy distribution company regarding future electric vehicle charging that has resulted in significant pro-active initiatives to avoid future power failures.
- A multi-year ongoing project that has significant potential to substantially extend the life of smelting furnace liners, with resultant multi-million dollar savings.

Even seemingly negative results can also generate positive outcomes. It is common for our students to take on relatively high risk projects that have not been pursued by the company due to their application of resources to other projects with higher likelihood of success. In many cases the students are not able to achieve a clear success in the intended direction, but they typically generate alternative options, some of which have been successfully undertaken by the client. This was, in fact, the case with the industrial safety hardware product mentioned above. However, even if the concept originally presented by the client is not feasible after concerted efforts by the students, this too is typically a success, in that it has avoided the expenditure of significant corporate resources to pursue the idea themselves.

Compared to non-fee based discipline specific projects that the author has supervised, it is generally observed that industry representatives have quicker response and invest more time and support to the MDS projects. It is not clear as to the reason, but one might speculate that the $5,000 support fee may encourage the companies to pay more attention to their project. Whatever the reason, such responsiveness and interest undoubtedly enhance the student experience, as well as the overall progress and outcome of the project.

In addition to the potentially beneficial project related outcomes, many corporate partners see their involvement in these projects as an excellent recruiting opportunity. After working with a team of students for eight months, it is relatively easy to identify a student or students that would fit well with their needs and operational culture. The aforementioned corporate partner who has hired 6 MDS graduates consistently requests that the whole graduating MDS class forward their resumes for employment consideration. A senior executive in that same company has written in an endorsement for the Design Chair program that the MDS 'adds about one year's working experience to an engineering graduate's training', reinforcing the qualitative feedback from students and graduates.

It is also clear that many clients see these partnerships as a way to support the education of engineering students. It is not surprising that half of our corporate representatives are Queen's alumni, and there is a strong sense of 'giving back' to their Alma matter.

3.2 Challenges

Introducing and operating the multidisciplinary design stream has not been without challenges. Although engineering education literature has widely reported a perceived need for design and multidisciplinary skills, many programs continue to be heavily loaded with core science based courses. Hence, for students in most disciplines, the third year of the engineering program leaves little room for additional electives, and the question of opting out of one science course in order to add one in design is not typically well accepted by the departments.

Scheduling of multidisciplinary courses is also a challenge. Difficulty in finding three hours in the normal daily course slots without conflict for students from all ten engineering disciplines led to the evening offering. Although relatively uncommon in the engineering program at Queen's, the evening scheduling seems to be well accepted by the students. From an instructor's point of view, it also allows flexibility in duration of class activities and also works well to accommodate guest speakers.

Acceptance of the multidisciplinary design project as an acceptable alternative to discipline-based capstone courses is constantly in flux. Some departments have allowed students to opt out of their departmental capstone course, while others have only allowed their students to enroll in the MDP as a technical elective. However, the latter is difficult for many students as it creates significant course overload in their schedule. Since its inception, there have been students from all 10 programs at Queens in the MDS. In any given year, it is typical for 7 to 9 of the disciplines to be represented. At the time of this publication, 6 programs accommodate capstone substitution, 3 allow it as an open technical elective, and one allows it only with permission from the departmental undergraduate chair. This varies from year to year, and in fact can fluctuate with changes in appointment in the role of departmental undergraduate chair.

Resources to operate the MDS are also challenging to maintain. The third-year course runs nominally with one instructor and three teaching assistants. However, in order to provide broad and effective support for students in the fourth year experience, the current instruction team includes an instructor/coordinator, three part-time engineers in residence (EIR), two post-graduate teaching assistants, and a part time course administrator to manage finances, purchasing, and travel assistance. Faculty funds currently cover most of the teaching assistant salaries, but all of the additional costs are borne by the program. At the moment, the combination of client fees, grant funds from the Ontario Centers of Excellence (OCE), and supplements from the NSERC chair funds are able to cover all costs in the program. However, shrinking university budgets, the uncertainty of OCE grant continuity, and fluctuating conditions in the economy, cause concern for long-term financial viability.

4. Conclusions

There has been significant evolution of the overall curriculum in the Faculty of Engineering and Applied Science at Queen's. Since the inception of the MDS, there has been increasing awareness of the need for design instruction throughout the curriculum. During this time, there have been at least three new design courses introduced at the second or third-year level, and in 2009 there was agreement amongst all departments to create a new faculty-wide design and professional practice sequence across all four years of every undergraduate engineering program. The first year course in this sequence was introduced in September 2010, and a new second year course with a novel shared faculty-departmental delivery began in September 2011. There is also general agreement for similar instruction at the third-year level in all departments as well, although it remains to be seen as to whether this will be a faculty or departmentally operated offering. There is some question as to what the development of this new third year design offering will have on the first course in the MDS. If the new course is multi-disciplinary, there will no longer be a need for the MDS elective, and in fact, that result would be an outstanding achievement. However, should the new third year course be offered in a discipline specific manner, it is proposed that the MDS will remain as a substitution for those students who prefer the multi-disciplinary experience. Either option will fulfill the overarching goal of enhanced design competency for all engineering students.

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Prior to his appointment at Queen's, David spent over two decades in the private sector in engineering and management. His experience spans three different areas: the primary aluminum industry, biomedical and biotechnology instrumentation, and high volume consumer products. David holds patents in broad areas of practice and has led award winning design teams, one of which received a Gold Medal in the Invention Category of the Canada Awards for Business Excellence. Throughout his career in industry, David played an active role in supporting engineering education at Queen's through sponsorship and mentoring of undergraduate and graduate projects. He was a member of the Queen's University Engineering Advisory Council prior to his appointment at Queen's.

David's research areas include engineering education, design optimization, and applied research and development activities in partnership with industry.