A SELF-EFFICACY SURVEY FOR ENGINEERING GRADUATE ATTRIBUTES ASSESSMENT

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ABSTRACT

In this paper, we describe a self-efficacy survey that was developed as part of the graduate attributes assessment and continual improvement process for a Canadian undergraduate engineering program. The aim of this study is twofold: first, to evaluate the reliability of the self-efficacy survey in the context of the graduate attributes; second, to compare the trends in student self-efficacy over multiple years. The survey results, reported from a six-year study of a BSc in Mechanical Engineering program, point to two main conclusions: (1) the self-efficacy survey appears to be a reliable tool for graduate attributes assessment, and (2) students report higher levels of self-efficacy for professional or “soft skills” attributes than for technical attributes; although somewhat counter-intuitive, these results are consistent with the literature on the achievement of mastery given the timing and context of the survey in the students’ program.

KEYWORDS

Student assessment; self-efficacy; accreditation; design education; continual improvement. This paper reports on a CDIO-inspired assessment tool (Standard 12).

INTRODUCTION

In this paper, we report on a self-efficacy survey that was developed by the authors for use in the Schulich School of Engineering’s continual improvement process. Self-efficacy is defined as “the belief in one’s capabilities to organize and execute the courses of action required to manage prospective situations” (Bandura, 1995). This belief in one’s abilities is typically developed through “mastery experiences” (Bandura, 1994). For example, in the context of engineering design, Carberry et al. (2010) note that “the effect of self-efficacy on learning can be more pronounced because of the frequent uses of design tasks as part of an engineering learning experience”; they go on to show that student motivation towards engineering design relates to higher levels of self-efficacy. More recently, Mamaril et al. (2016) showed that their engineering self-efficacy scales can be reliably used to assess undergraduate students’ perceptions of their capabilities in engineering.

Given this link between student self-efficacy and “mastery experiences” in engineering learning, it follows that self-efficacy can serve as a useful measure of whether or not a course has provided an authentic engineering experience for students, and in particular, if the course is successfully motivating students to learn.

The self-efficacy survey used for this study focuses on the Canadian Engineering Accreditation Board's (CEAB) twelve graduate attributes (CEAB, 2015):

1. A knowledge base for engineering
2. Problem analysis
3. Investigation
4. Design
5. Use of engineering tools
6. Individual and team work
7. Communication skills
8. Professionalism
9. Impact of engineering on society
10. Ethics and equity
11. Economics & project management
12. Life-long learning

Under these criteria, Canadian engineering programs are required to assess student graduate attributes in these twelve general areas, and demonstrate that a process is being followed to continuously improve the programs. In order to demonstrate that graduates of an engineering program possess these general attributes, each graduate attribute was expanded into a set of indicators that "describe specific abilities expected of students to demonstrate each attribute" (CEAB, 2015). In addition to providing a means of obtaining evidence to determine if the attribute has been achieved, the indicators had to be acceptable within the context of the program's educational objectives, as well as understood and meaningful to those involved in the assessments (e.g., faculty, students, alumni).

The self-efficacy survey reported in this paper is one of a set of measurement tools that are being used for graduate attributes assessment at the Schulich School of Engineering. The idea is to provide multiple forms of evidence for each attribute (i.e., classroom assessments, student surveys, employer surveys) in order to increase the reliability of our graduate attribute assessment process. In this paper, we report on the student survey aspect of the process, where students are asked to indicate how confident they are in their ability, at the time of the survey, to perform a variety of activities related to the CEAB's twelve graduate attributes.

In this paper, we provide an overview of the self-efficacy survey and reflect on our experience with the survey in the context of graduate attributes assessment over a six-year period. We report on the internal consistency of the survey questions, and evaluate student self-efficacy across multiple years of the BSc in Mechanical Engineering program.

AIM OF THE STUDY

The aim of this study is twofold: first, to evaluate the reliability of the self-efficacy survey in the context of the twelve CEAB graduate attributes. In order to keep the survey to a reasonable length (in this case, 38 questions), each graduate attribute was associated with 3 to 4 survey questions. Despite the relatively small number of questions associated with each graduate attribute, there should be internal consistency within each of the categories (graduate attributes) of survey: i.e., the responses to each of the questions within a graduate attribute category should point in the same direction. The second aim is to compare the trends in student self-efficacy over multiple years, in a single course (a fourth-year, capstone design course). As noted, self-efficacy is related to a belief in one's capabilities and is typically reinforced through learning experiences. Comparing self-efficacy scores over multiple years of a single program can provide a means of identifying potential gaps in students' learning experience.

METHODS

Participants

Our study was conducted with senior (fourth year) B.Sc. in Mechanical Engineering students near the end of their program. More specifically, the self-efficacy survey was conducted late in the final term in the compulsory, senior capstone design course. The BSc in Mechanical Engineering capstone design course runs for two terms (from the start of the Fall term to the end of the Winter term). Students are placed in teams of four to five that work on an industry- or faculty-sponsored design project. These capstone projects involve the student team in the entire product design process from identifying customer needs, through conceptual and detailed design, to design validation (e.g., building prototypes). Course instruction occurs primarily during the first term, and focuses on the product development process (Ulrich and Eppinger, 2015), project management, economics, communication, and teamwork; the second term is dedicated entirely to student work on the design projects.

Altogether, 271 Canadian engineering students (aged mean ± standard deviation = 22.7 ± 1.2, range = 18-25 years) out of which 53 were females and 218 were males participated in this study. As noted, the students were in the final term of their final year of study. The survey was administered over 5 offerings of the mechanical engineering capstone design course from Winter term 2011 and to Winter term 2016 (no data was collected for Winter 2015). The total number of potential participants was 789 students, resulting in a 34% participation rate in the study.

The Survey

The self-efficacy survey was developed by the authors in 2010 to support graduate attributes collection for accreditation and continual improvement purposes at the Schulich School of Engineering. The survey includes 38 questions that are posed in the form of "how confident are you in your current ability to …"; students are required to rate their confidence on a five-interval scale ranging from 0% "no confidence" to 100% "total confidence" (in 25% intervals).

Each graduate attribute was associated with 3 to 4 survey questions, that were developed using the CDIO syllabus (Crawley et al., 2007) and its corresponding mapping to the CEAB graduate attributes (Cloutier, et al., 2010) as a starting point. For example, the survey questions associated with graduate attribute 3.1.4 "design" are:

> *How confident are you in your ability to:*
>
> - *collect and interpret customer needs for a project you were given.*
> - *analyze the trade-offs between alternative design approaches and select the one that is best for your project.*
> - *test a design solution to determine if it meets its specified needs.*

The full set of survey questions are provided in the appendix.

The survey was administered on a voluntary basis to five cohorts of final-year mechanical engineering students from Winter term 2011 to Winter term 2016. When introducing the survey to the class near the end of their final term, it was described as a "survey on engineering competencies developed to date": responses should reflect students' belief in their ability to succeed in the specific situations described in the survey. The survey was administered online using the Survey Monkey tool. Although this provided students flexibility with respect to when and where the survey could be completed, administering the survey online resulted in the relatively low participation rate of 37%.

Statistical Analysis

As noted previously, one of the main aims of this study is to evaluate the reliability of the self-efficacy survey in the context of the twelve CEAB graduate attributes. To evaluate the reliability of the survey, Cronbach's alpha coefficients were computed over the full set of data. More specifically, we use Cronbach's alpha to measure the internal consistency for each graduate attribute based on the correlations between each of the survey questions in each graduate attribute grouping. "Internal consistency" describes the extent to which all the items in a test measure the same concept or construct (Tavokol and Dennick, 2011). For our purposes, we are interested in the inter-relatedness of the questions within each graduate attribute grouping. Cronbach's alpha reliability coefficient ranges from 0 to 1. The basic rules of thumb for this coefficient are: "≥ 0.9 → excellent, ≥ 0.8 → good, ≥ 0.7 → acceptable, ≥ 0.6 → questionable, ≥ 0.5 → poor, and < 0.5 → unacceptable" (George and Mallery, 2003).

The amount of data obtained over five offerings of the mechanical engineering capstone design course also provided us with the opportunity to compare the trends in student self-efficacy across multiple years. For this analysis, paired samples t-test and ANOVA were used to determine if there are any differences in student self-efficacy between graduate attribute, between genders, and between student cohorts.

As noted, students completed the survey on a voluntary basis. In the vast majority of cases, students completed the entire survey; however, any instances of incomplete surveys were treated as outliers and were removed from the data set.

RESULTS

Reliability of the Survey

Table 1 provides a summary of student self-efficacy towards the twelve CEAB graduate attributes for all five mechanical engineering capstone design cohorts.

Table 1. Internal Consistency of the Self-efficacy Survey

Graduate Attribute	**Mean**	**s**	**Cronbach's alpha if item deleted**
1. A knowledge-base for engineering Item-total statistics; Cronbach's alpha = 0.73			
Q10. Use your technical knowledge to participate in a design discussion.	0.77	0.22	0.58
Q11. Describe a well-known experiment that proved an important scientific law.	0.62	0.27	0.73
Q20. Use mathematics to describe and solve engineering problems.	0.80	0.20	0.57

Table 1. Internal Consistency of the Self-efficacy Survey (continued)

Graduate Attribute	**Mean**	**s**	**Cronbach's alpha if item deleted**
2. Problem analysis Item-total statistics; Cronbach's alpha = 0.75			
Q1. Apply your engineering knowledge and skills to solve a real-world problem.	0.75	0.20	0.71
Q16. Make assumptions that successfully simplify a complex problem to make it easier to work with.	0.74	0.21	0.67
Q21. After solving a problem, evaluate your initial assumptions to see if they need to be changed.	0.76	0.18	0.63
3. Investigation Item-total statistics; Cronbach's alpha = 0.75			
Q7. Generate a working hypothesis and a strategy to test it.	0.74	0.20	0.79
Q13. Synthesize information to reach conclusions that are supported by data and needs.	0.78	0.18	0.62
Q14. Analyze and interpret data.	0.83	0.19	0.57
4. Design Item-total statistics; Cronbach's alpha = 0.80			
Q24. Test a design solution to determine if it meets its specified needs.	0.77	0.19	0.81
Q28. Collect and interpret customer needs for a project you were given.	0.81	0.19	0.67
Q29. Analyze the trade-offs between alternative design approaches and select the one that is best for your project.	0.81	0.18	0.68
5. Use of engineering tools Item-total statistics; Cronbach's alpha = 0.79			
Q2. Apply an appropriate engineering technique or tool to accomplish a task.	0.76	0.18	0.69
Q6. Adapt or extend an engineering technique to accomplish a complex task.	0.72	0.21	0.65
Q25. Describe the limitations of various engineering tools and choose the best one to accomplish a task.	0.71	0.20	0.80
6. Individual and team work Item-total statistics; Cronbach's alpha = 0.74			
Q3. Get team members to make personal commitments to deliver what they had agreed to do for a project.	0.79	0.19	0.68
Q8. Review your team's strengths and weaknesses and tell others where the team might need help.	0.78	0.19	0.66
Q12. Help two project team members with a strong disagreement resolve their differences.	0.71	0.21	0.69
Q35. At the start of a project, identify all the roles and responsibilities that your team will need to complete it.	0.75	0.20	0.70

Table 1. Internal Consistency of the Self-efficacy Survey (continued)

Graduate Attribute	**Mean**	**s**	**Cronbach's alpha if item deleted**
7. Communication skills Item-total statistics; Cronbach's alpha = 0.72			
Q19. Deliver a clear and organized formal presentation to a group of professionals.	0.84	0.20	0.66
Q22. Interpret a formal technical drawing in your engineering discipline.	0.74	0.25	0.67
Q26. Use various written styles to communicate complex engineering concepts to your colleagues.	0.77	0.22	0.63
Q30. Prepare a sketch of a design concept that is understood by your colleagues.	0.76	0.25	0.65
8. Professionalism Item-total statistics; Cronbach's alpha = 0.71			
Q9. Identify processes in your project to ensure protection of the public and the public interest.	0.76	0.19	0.54
Q15. Identify the regulatory policies that pertain to a project that you are working on.	0.67	0.24	0.67
Q38. Identify your professional responsibilities within a large engineering project.	0.81	0.19	0.65
9. Impact of engineering on society and the environment Item-total statistics; Cronbach's alpha = 0.69			
Q4. Identify the interactions that an engineering project has with the economic, social, health, safety, legal, & cultural aspects of society.	0.78	0.19	0.66
Q27. Apply technical, social, and environmental criteria to guide trade-offs between design alternatives.	0.76	0.20	0.47
Q34. Incorporate sustainability considerations in project decision-making.	0.72	0.23	0.65
10. Ethics and equity Item-total statistics; Cronbach's alpha = 0.69			
Q18. Admit when you have made a mistake.	0.90	0.18	0.80
Q36. Identify an ethical dilemma when it occurs in a project.	0.81	0.20	0.48
Q37. Analyze opposing positions on an issue and make a judgment based on the evidence.	0.82	0.17	0.46
11. Economics and project management Item-total statistics; Cronbach's alpha = 0.71			
Q17. Apply project cost management principles to ensure that a project is completed within budget.	0.70	0.25	0.64
Q31. Identify and plan for risks in an engineering project.	0.72	0.21	0.52
Q33. Work with others to establish project objectives when different project tasks must be completed.	0.82	0.18	0.67

Table 1. Internal Consistency of the Self-efficacy Survey (continued)

Graduate Attribute	Mean	s	Cronbach's alpha if item deleted
12. Life-long learning Item-total statistics; Cronbach's alpha = 0.63			
Q5. Recognize your strengths and weaknesses when working on a specific problem.	0.85	0.16	0.59
Q23. Identify the best approach that is suited to your learning style.	0.81	0.19	0.42
Q32. Use technical literature or other information sources to fill a gap in your knowledge.	0.81	0.20	0.58

As shown in this table, the self-efficacy survey was found to be acceptable for all graduate attributes except graduate attribute 12 "life-long learning" ($\alpha = 0.63$), which was questionable. For the majority of the graduate attributes, it appears that the three to four questions identified in the survey are needed to maintain internal consistency; however, for graduate attribute 3 "investigation" and 10 "ethics and equity", internal consistency would be improved if one question were removed. In these cases, Q7 (α for 3.1.3 changes from 0.75 to 0.79) and Q18 (α for 3.1.10 changes from 0.69 to 0.80) should be re-evaluated in the context of the CEAB/CDIO mapping (Cloutier et al., 2010) in order to improve the overall reliability of the survey for these graduate attributes. As well, the three questions associated with 3.1.12 "life-long learning" will need to revisited.

Self-efficacy Trends

The average self-efficacy scores with 95% confidence intervals for the period from 2011 to 2016 are shown in Figure 1.

As can be seen in this figure, the top three self-efficacy scores are reported for graduate attributes 4 "design", 10 "ethics and equity", and 12 "life-long learning"; the bottom three self-efficacy scores are reported for graduate attributes 1 "a knowledge-base for engineering", 2 "problem analysis", and 5 "use of engineering tools". The results of a one-way ANOVA test showed that this difference between the top three and the bottom three graduate attributes is significant, $F(11, 251) = 12.19$, $p < 0.01$: i.e., graduate attributes 4 ($M = 79.6\%$, $SD = 15.8\%$), graduate attribute 10 ($M = 83.9\%$, $SD = 12.2\%$), and graduate attribute 12 ($M = 82.1\%$, $SD = 13.8\%$) reported significantly higher self-efficacy scores than graduate attributes 1 ($M = 73.0\%$, $SD = 18.5\%$), graduate attribute 2 ($M = 74.7\%$, $SD = 16.1\%$), and graduate attribute 5 ($M = 73.0\%$, $SD = 16.5\%$).

In order to determine if there were any differences between male and female engineering students' perceptions of their abilities with respect to the twelve graduate attributes, we performed a paired-samples t-test using the five years of data. The results showed that self-efficacy for male students was significantly higher than that of female students for graduate attributes 2 "problem analysis" ($\Delta M = -9.4\%$, $t(48) = -2.96$, $p < 0.05$) and graduate attribute 5 "use of engineering tools" ($\Delta M = -9.5\%$, $t(48) = -2.90$, $p < 0.05$). Although the self-efficacy scores for males were higher than those for females for all graduate attributes except graduate attribute 10 "ethics and equity" ($\Delta M = 1.7\%$, $t(48) = 0.72$, p = n.s.), only graduate attributes 2 and 5 were significant at the $p < 0.05$ level. Given this trend in the results and the relatively small proportion of female students (20% of the population), it would be interesting to extend this study to a larger sample size to further explore the differences between male and female self-efficacy.

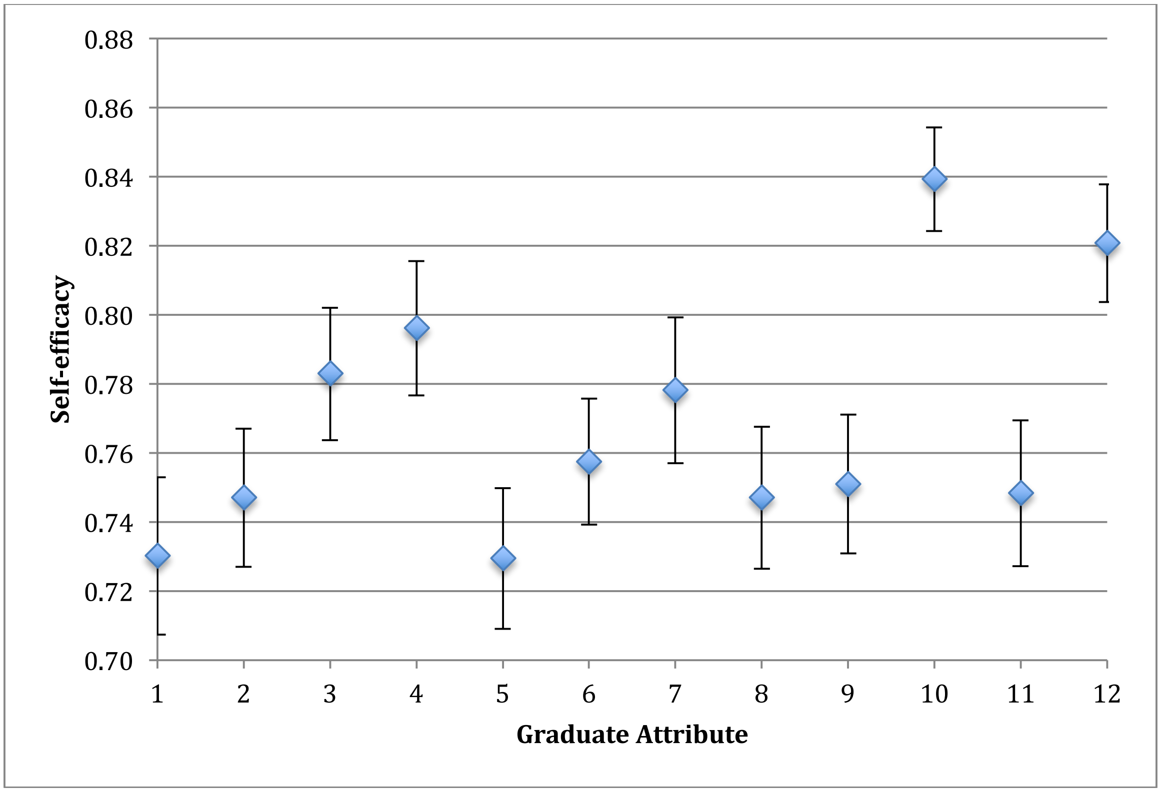

Figure 1. Student self-efficacy towards the CEAB graduate attributes (2011-2016)

As can be seen from the list of CEAB graduate attributes at the beginning of this paper, the twelve graduate attributes are effectively divided in two categories: a group of six "technical" attributes (graduate attributes 1-5 and 11) and six "soft-skills" or "professional" attributes (graduate attributes 6-10 and 12). In order to explore differences between these more general categories, the data was aggregated in this manner. The results of a paired samples t-test showed that student self-efficacy for the technical graduate attributes (M = 75.6%, SD = 14.1%) was significantly lower than student self-efficacy for the professional skills graduate attributes (M = 78.1%, SD = 11.9%), $t(250) = -5.38$, $p < 0.01$. Comparing male and female students across the technical and professional attributes categories revealed a statistically significant difference for only the technical graduate attributes: male students (M = 76.7%, SD = 14.0%) showed significantly higher technical attributes self-efficacy than female students (M = 71.2%, SD = 13.4%), $t(250) = 15.7$, $p < 0.05$.

Finally, self-efficacy scores were also compared across student cohorts (i.e., across each year from 2011 to 2016). The one-way ANOVA results showed no significant difference from cohort-to-cohort. This is not surprising given that there were no major changes to the B.Sc. in mechanical engineering curriculum or admission process during this period of time.

DISCUSSION

Given the relatively high proportion of time dedicated to technical topics in most undergraduate engineering programs, the results of the self-efficacy survey at first seem counter-intuitive. The Schulich School of Engineering's BSc in Mechanical Engineering program does not differ from other undergraduate engineering programs in this regard: approximately 90% of the program's curriculum content is in the form of technical courses (i.e., mathematics, natural sciences, engineering sciences, design). It should be noted that this is not surprising, given that the CEAB's minimum curriculum content criteria require 85% of a program's curriculum to be in these technical areas. However, the results of the self-efficacy survey indicate that students' expectations of personal efficacy in technical areas are lower than their expectations of personal efficacy in professional or "soft-skills" areas.

To understand these results, it is important to look at the survey in the context of where and when it was administered, and also at the nature of self-efficacy. As noted previously, the self-efficacy survey was administered during the final term of students' program in their capstone design course. At this point in the BSc in Mechanical Engineering program, students would not lack component technical skills in mechanical engineering, and arguably, would be relatively comfortable with integrating these skills to solve complex engineering problems. However, they will have had little experience transferring these technical skills to from the very "academic" and compartmentalized context of the engineering and science courses from the past seven terms, to the open-ended and team-based context of a complex design problem. In other words, they are now confronted with an open-ended technical problem that does not have a single "correct" answer, requires some degree of "trial-and-error" to solve, and is too complex to be managed by one individual; a very different prospect from the problems and projects encountered in engineering and science courses encountered up to this point in their programs.

One's expectations of personal efficacy are closely related to mastery experiences. As Bandura (1994) notes, "successes build a belief in one's efficacy. Failures undermine it." However, by nature, the engineering design process is iterative and requires one to "embrace failure" (Kelley and Kelley, 2013). As a result, students' recognition of the limitations of their technical skills during their first major design project should not come as a surprise. In fact, it is promising that students do recognize these limitations: at this point in their progression from novice students to professional engineers, they have advanced to a stage of "conscious competence" where they are "… increasingly aware of what they do not know, and consequently, of what they need to learn" (Ambrose et al., 2010). In this regard, it is also not surprising that students are also confident with their "life-long learning" abilities.

Although it is encouraging that the self-efficacy survey appears to be a reliable assessment tool, more work is required: as noted, our future work on the survey will involve refining questions where internal consistency is in question. In particular, more work is needed on refining the questions associated with graduate attribute 3 "investigation", graduate attribure 10 "ethics and equity", and graduate attribute 12 "life-long learning". As with our early work on the survey, we plan to use the CDIO syllabus (Crawley et al., 2007) as a starting point for this work.

Our future work in this area will also involve analyzing the self-efficacy survey results in the context of the other assessments (e.g., classroom assessments, employer surveys). As was shown in this paper, the nature of self-efficacy assessment can lead to what at first appears to be counter-intuitive results. However, it is our belief that much can be learned about the teaching and learning environment from this additional form of student assessment.

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APPENDIX

The following table lists the 38 questions used in the spring 2011 self-efficacy survey. The survey questions are sorted by graduate attribute with the actual question order shown in column 2 under "survey question".

Graduate Attribute	Survey Question	How confident are you in your current ability to:
3.1.1	10	Use your technical knowledge to participate in a design discussion.
3.1.1	11	Describe a well-known experiment that proved an important scientific law.
3.1.1	20	Use mathematics to describe and solve engineering problems.
3.1.2	1	Apply your engineering knowledge and skills to solve a real-world problem.

Graduate Attribute	Survey Question	How confident are you in your current ability to:
3.1.2	16	Make assumptions that successfully simplify a complex problem to make it easier to work with.
3.1.2	21	After solving a problem, evaluate your initial assumptions to see if they need to be changed.
3.1.3	7	Generate a working hypothesis and a strategy to test it.
3.1.3	13	Synthesize information to reach conclusions that are supported by data and needs.
3.1.3	14	Analyze and interpret data.
3.1.4	24	Test a design solution to determine if it meets its specified needs.
3.1.4	28	Collect and interpret customer needs for a project you were given.
3.1.4	29	Analyze the trade-offs between alternative design approaches and select the one that is best for your project.
3.1.5	2	Apply an appropriate engineering technique or tool to accomplish a task.
3.1.5	6	Adapt or extend an engineering technique to accomplish a complex task.
3.1.5	25	Describe the limitations of various engineering tools and choose the best one to accomplish a task.
3.1.6	3	Get team members to make personal commitments to deliver what they had agreed to do for a project.
3.1.6	8	Review your team's strengths and weaknesses and tell others where the team might need help.
3.1.6	12	Help two project team members with a strong and emotional disagreement resolve their differences.
3.1.6	35	At the start of a project, identify all the roles and responsibilities that your team will need to complete it.
3.1.7	19	Deliver a clear and organized formal presentation to a group of professionals.
3.1.7	22	Interpret a formal technical drawing in your engineering discipline.
3.1.7	26	Use various written styles to communicate complex engineering concepts to your colleagues.
3.1.7	30	Prepare a sketch of a design concept that is understood by your colleagues.
3.1.8	9	Identify processes in your project to ensure protection of the public and the public interest.
3.1.8	15	Identify the regulatory policies that pertain to a project that you are working on.
3.1.8	38	Identify your professional responsibilities within a large engineering project.
3.1.9	4	Identify the interactions that an engineering project has with the economic, social, health, safety, legal, and cultural aspects of society.
3.1.9	27	Apply technical, social, and environmental criteria to guide trade-offs between design alternatives.
3.1.9	34	Incorporate sustainability considerations in project decision-making.
3.1.10	18	Admit when you have made a mistake.
3.1.10	36	Identify an ethical dilemma when it occurs in a project.
3.1.10	37	Analyze opposing positions on an issue and make a judgment based on the evidence.
3.1.11	17	Apply project cost management principles to ensure that a project is completed within budget.
3.1.11	31	Identify and plan for risks in an engineering project.
3.1.11	33	Work with others to establish project objectives when different project tasks must be completed.

Graduate Attribute	Survey Question	How confident are you in your current ability to:
3.1.12	5	Recognize your strengths and weaknesses when working on a specific problem.
3.1.12	23	Identify the best approach that is suited to your learning style.
3.1.12	32	Use technical literature or other information sources to fill a gap in your knowledge.

BIOGRAPHICAL INFORMATION

Robert W. Brennan is Professor of Mechanical and Manufacturing Engineering and Head of Department (Mechanical & Manufacturing Engineering) at the Schulich School of Engineering. He has served on the Canadian Design Engineering Network (CDEN) steering committee, chaired the organizing committee for the second CDEN conference, chaired the Schulich School of Engineering's first Engineering Education Summit, served as an organizing committee member for the CIRP International Design Seminar, and is the current American Society for Engineering Education (ASEE) campus representative for the University of Calgary.

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