Reinforcing Skills and Building Student Confidence through a Multicultural Project-based Learning Experience

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ABSTRACT

In this paper, we report on the impact of a Project-based Learning (PjBL) course on student self-efficacy in fundamental engineering attributes. The study was conducted as part of a four-week course on renewable energy in the spring of 2011 at Shantou University and compared student self-efficacy at the start and at the end of the course. Students showed increased levels of self-efficacy in all of the attributes, with the largest increases in the attributes that were most closely aligned with the intended learning outcomes of the course.

Keywords – Project-based Learning, Self-efficacy, Graduate Attributes Assessment

Introduction

In the spring of 2011 a group of 20 Canadian students from the Schulich School of Engineering (SSE) and 20 Chinese students from Shantou University (STU) participated in a four-week course on renewable energy at Shantou University. The project-based learning (PjBL) experience consisted of four build-test activities performed by mixed groups of SSE and STU students (further details on the course are provided in [1]).

At the beginning and end of the course, students were required to complete a 38-question self-efficacy survey that focused on the Canadian Engineering Accreditation Board's (CEAB) twelve graduate attributes [2]. Self-efficacy is defined as "the belief in one's capabilities to organize and execute the courses of action required to manage prospective situations" [3]. In this case, students were asked to indicate how confident they were in their ability, at the time of the survey, to perform a variety of activities related to the CEAB's twelve graduate attributes: i.e., each graduate attributed was associated with 3 to 4 survey questions.

The intention of the study was not to determine student achievement of the course's learning outcomes (this was accomplished by standard classroom assessment techniques), but instead to determine if the PjBL course had a positive impact on student self-efficacy. Bandura [4] notes that "the most effective way of developing a strong sense of efficacy is through mastery experiences". In the domain of engineering education, Carberry et al. [5] 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.

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. Our hope was that the test-build experiences would reinforce the students' mastery of fundamental engineering skills while building their confidence as active participants in team-based projects.

This paper begins with a brief overview of the PjBL course. Next, we describe the self-efficacy survey used to conduct the study. Next, we present the results of the surveys conducted at the start and end of the renewable energy at STU in the spring of 2011. We conclude with a brief discussion of our interpretation of the results along our future plans in this area.

The PjBL Course

The Renewable Energy Practicum course consisted of four implement-operate exercises and two field trips. All of the exercises included both a build phase and a testing phase. Students were put in teams of 5 students, and student teams were altered for each exercise. Teams consisted of a mix of SSE and STU students, and gender balance was ensured for all teams. The exercises consisted of: (1) construction and testing a solar-photovoltaic cell, (2) construction and testing a solar fan, (3) construction and testing of a wind turbine and, (4) construction and testing of a solar-thermal water heater. Each implement-operate exercise was taken from the project-sharing website Instructables (www.instructables.com) [6 - 9]. The Instructables website provides step-by-step instructions on how to build a wide array of devices, and consequently it proves to be a very useful resource when planning implement-operate exercises. The following is a brief summary of the four projects:

1. Solar Photovoltaic Cell: This project involved fabrication and testing of a copper-cuprous oxide photovoltaic cell. A copper plate heated on a hot plate resulted in the formation of a fine cuprous-oxide layer on the surface of the copper plate. The plate was then mounted in a case filled with a water / baking soda mixture. An electrical circuit was completed through the addition of a second copper plate. This project was relatively simple and provided a gentle introduction for the students to both the workshop and the nature of the implement-operate projects.
2. Solar Fan: This project involved the use of two solar cells and two NiCd batteries (1.2V and 600 mAh) from commercial garden lights. The solar cells were used to charge the batteries during the day, and at night the charged batteries were used to power a 12 V (0.15A) computer fan. Use of two 1.2 V batteries to power a 12 V fan requires the use of a Linear Technologies micropower DC/DC converter (LT1073). The circuitry and fabrication in this project were more complex than the first project, requiring the students to be both organized and focused.
3. Wind Turbine: This project involved the fabrication and testing of a vertical-axis wind turbine of the Savonius rotor design. The most complicated aspect of this project involved the fabrication of the electrical generator. Eight rare-earth permanent magnets (NdFeB) were mounted to the rotating Savonius turbine, and twelve generator coils were fabricated by winding aluminum bobbins using either

32 AWG or 36 AWG magnet wire. This project proved to be the most challenging given the complexity of the generator section. Placing it during the third week was optimum as students had honed both their mechanical and electrical skills in the two previous projects. Testing was performed at speeds up to 10 m/s in the STU wind tunnel laboratory (3 m X 2 m test section; 45 m/s max velocity).

4. Solar-thermal Water Heater: This project involved the fabrication and testing of solar-thermal water heater that mimicked the performance of an evacuated tube collector. Students fabricated the water heater using nested plastic bottles. Reflective tape was used to increase the concentration ratio of the collector. A simple child thermometer was used to measure the temperature of the water within the heating section. This was the simplest project and it was placed at the end of the course during the week with the least amount of time for the Practicum course. The students were skilled in the workshop by the final week and consequently the building phase of the project was completed in the first day.

Self-efficacy Survey

As noted previously, the self-efficacy survey used for this study focused on the Canadian Engineering Accreditation Board's (CEAB) twelve graduate attributes [2]. In 2008, the CEAB updated their criteria and procedures, moving toward a model that emphasizes continuous improvement, and more specifically, program outcomes. Under these new criteria, Canadian engineering programs are required to assess student graduate attributes in the following twelve general areas, and demonstrate that a process is being followed to continuously improve the programs.

3.1.1 A knowledge base for engineering

3.1.2 Problem analysis

3.1.3 Investigation

3.1.4 Design

3.1.5 Use of engineering tools

3.1.6 Individual and team work

3.1.7 Communication skills

3.1.8 Professionalism

3.1.9 Impact of engineering on society and environment

3.1.10 Ethics and equity

3.1.11 Economics and project management

3.1.12 Life-long learning

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" [2]. 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).

We describe the general process that was followed to develop this set of indicators in [10]. For this paper, we use the survey that was developed for indirect assessment of the twelve graduate attributes. In this survey, each graduate attribute is addressed by three to four questions that were formulated from the set of indicators.

The full set of survey questions are provided in the Appendix. As can be seen from the question order, the survey questions were sorted to spread the questions relating to each graduate attribute throughout the survey. All questions were posed in the form of “how confident are you in your current ability to …”, and students were required to rate their confidence on a five-interval scale ranging from 0% “no confidence” to 100% “total confidence” (in 25% intervals).

The survey involved the entire class of 40 students (20 Canadian students from SSE and 20 Chinese students from STU) and was performed at the start of the course and four weeks later at the end of the course. Both instances of the survey were paper-based, and students were given sufficient classroom time to complete the survey. In the next section, we summarize the results of the surveys.

Results

Figure 1 provides a summary of the results of the study: the twelve graduate attributes categories are provided along the horizontal axis, and student self-efficacy (i.e., “average perceived competency”) is provided along the vertical axis. As can be seen in this figure, increased levels of confidence were reported across all graduate attributes by the end of the term. Most notably, the three largest increases related to attributes that were closely linked to the intended learning outcomes for the course: i.e., “use of engineering tools” (10% improvement), “investigation” (10% improvement), and “problem analysis” (8% improvement).

Though these are very promising results for all students in the PjBL course, they were even more promising for the STU cohort who reported greater increases in self-efficacy in each graduate attribute category. In order to obtain a better understanding of these results, we show the combined results along with the individual SSE and STU results in the remainder of this section. We focus on the three graduate attributes that show the greatest improvement in student self-efficacy (3.1.2 "Problem analysis", 3.1.3 "Investigation", and 3.1.5 "Use of engineering tools"), and also include 3.1.4 "Design", 3.1.6 "Individual and team work", and 3.1.7 "Communication skills", given that the design-build exercises contained strong elements of these three attributes.

Figure 2 shows the results for graduate attributes 3.1.2 "Problem analysis", 3.1.3 "Investigation", and 3.1.5 "Use of engineering tools". The figure shows the improvement in student self-efficacy from the start to the end of the course along the vertical axis (“Perceived Improvement – Start to End”) and plot the SSE, STU, and combined results for each of the questions that correspond to the graduate attribute (e.g., “Q1”, “Q16”, and “Q21” for Graduate Attribute 3.1.2 in Figure 2). The specific survey questions are provided in the Appendix.

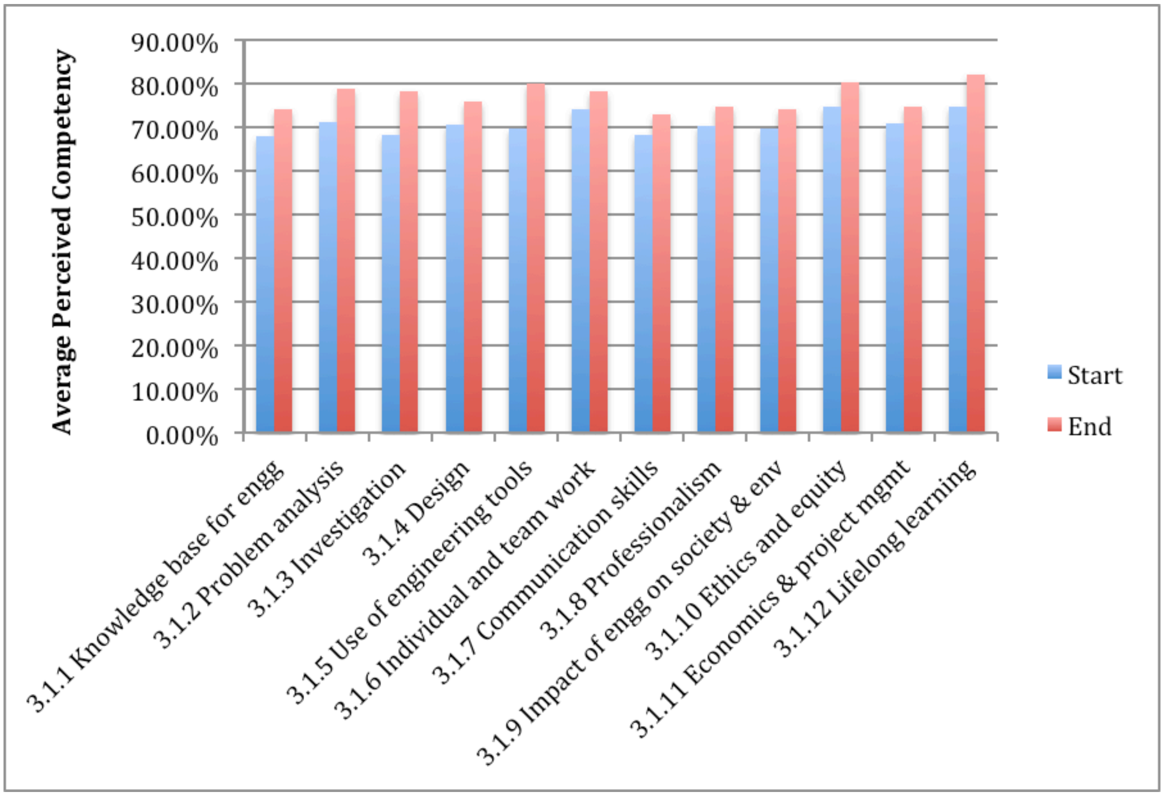

Figure 1. Summary engineering competency survey results

As can be seen in Figure 2, the STU students' sense of self-efficacy showed the greatest improvement from the start to the end of the course. The only exception was Q7 "generate a working hypothesis and a strategy to test it" for 3.1.3 "Investigation", where both the SSE and STU students showed approximately the same level of improvement.

More notably, the SSE students showed a slight decrease in Q1 "Apply your engineering knowledge and skills to solve a real-world problem" of 3.1.2 "Problem analysis", while the STU students showed a relatively large improvement (approximately 15%). We can only speculate on the cause for this relatively large difference between the SSE and STU students; however, it seems likely that the difference may have been a result of the academic background of the two cohorts. The PjBL course was designed as a third-year (i.e., junior) course. However, the 2011 SSE cohort included a number of the fourth-year (senior) students. It is possible that there may have been a mismatch with respect to the interpretation of the appropriate level of "engineering knowledge and skills" between the two cohorts given that some of the SSE students had already completed most of fourth year as well as the senior capstone design course prior to the PjBL course.

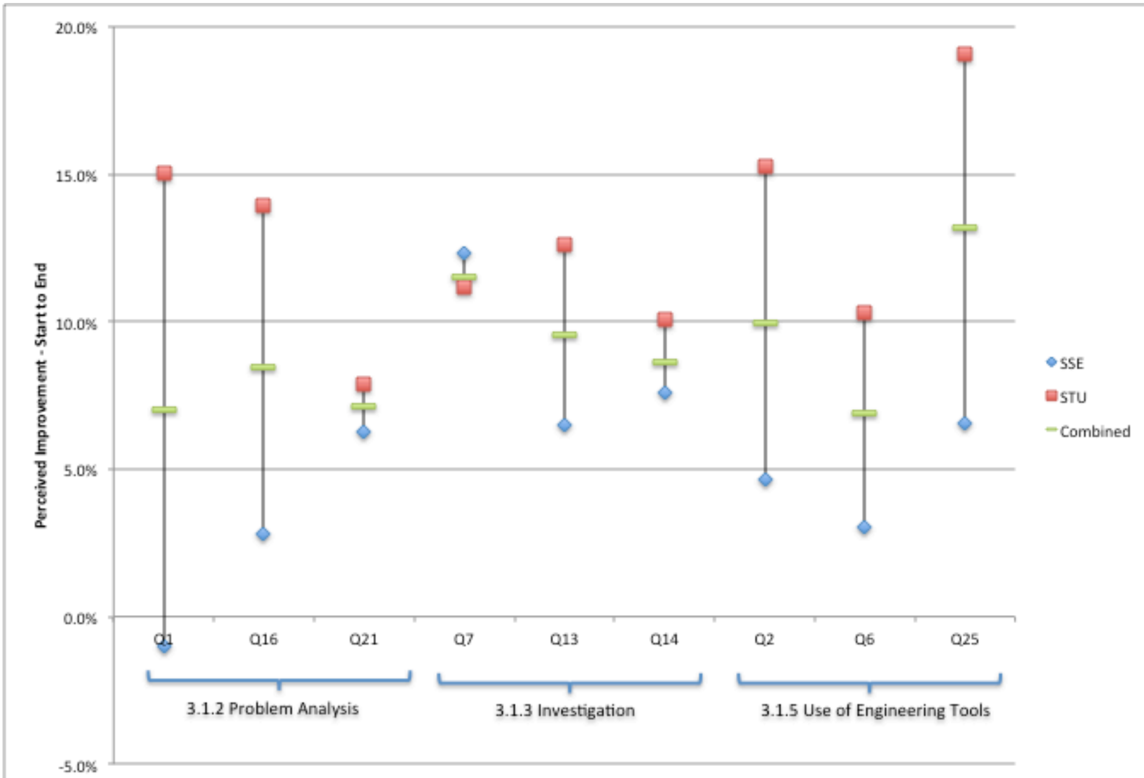

Figure 2. Self-efficacy improvement for graduate attributes 3.1.2, 3.1.3, and 3.1.5

Figure 3 shows the results for graduate attributes 3.1.4 "Design", 3.1.6 "Individual and team work", and 3.1.7 "Communication skills". The results for Q28 "collect and interpret customer needs for a project you were given" show the largest difference between the SSE and STU cohorts. This very likely a result of the fact that the PjBL projects did not require students to collect and interpret customer needs. In this case, it is possible that students misinterpreted this question in the context of the course projects, resulting in the inconsistent shown in Figure 3.

The increases in self-efficacy for 3.1.7 "Communication skills" were less that those shown for 3.1.2, 3.1.3, and 3.1.5; however, the pattern of STU students showing greater levels of improvement were consistent with these results. The only exception was for Q19 "Deliver a clear and organized formal presentation to a group of professionals". Although all of the STU students' command of English was very good, we did observe that they found the English language presentations to be a very challenging aspect of the course.

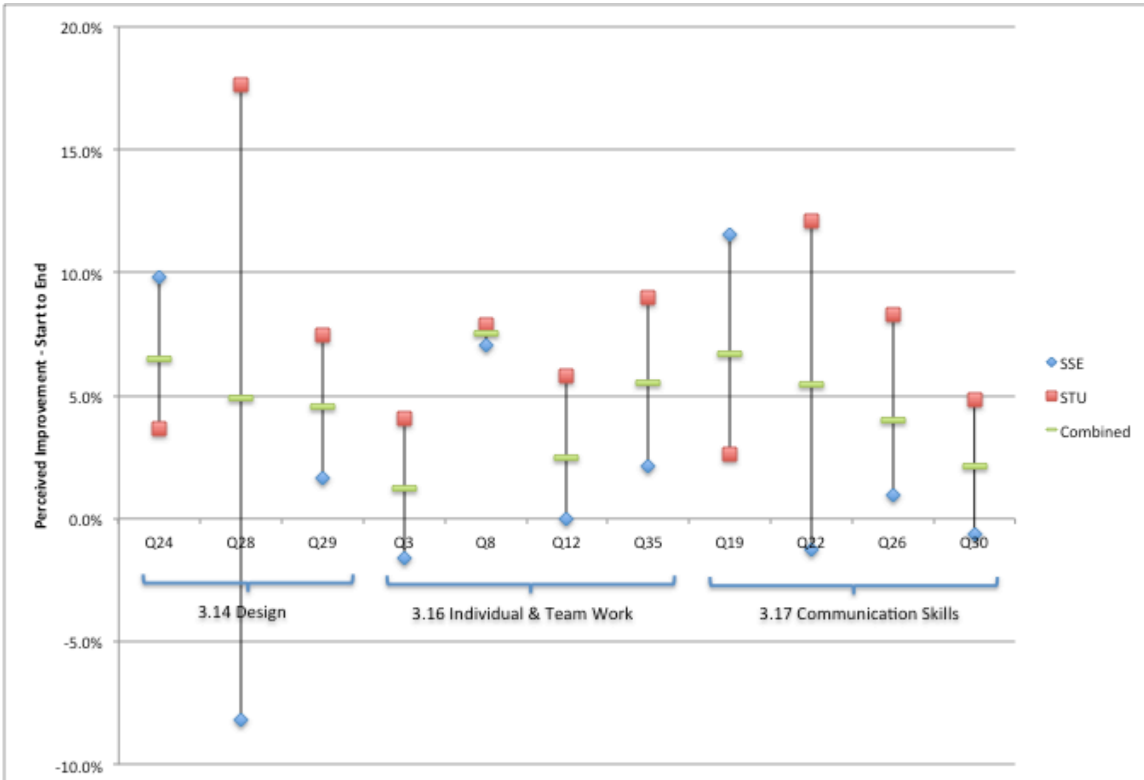

Figure 3. Self-efficacy improvement for graduate attributes 3.1.4, 3.1.6, and 3.1.7

Conclusions

As discussed previously, the focus of this study was on whether or not the joint SSE/STU project-based learning course could provide an authentic experience that reinforces students' mastery of fundamental engineering skills and motivates learning. Overall, we are very encouraged by the survey results. Although there was some variation in the results across individual questions, the overall trend was an increase in student self-efficacy across all twelve CEAB graduate attributes. As well, the graduate attributes that had the closest link to the course's learning outcomes showed the largest increases in self-efficacy.

Given the small sample size for this study (40 students), the results clearly cannot be generalized for all project-based learning courses. However, the results do point in the right direction for this particular course, indicating that it did have a positive impact on student learning.

For the spring 2012 offering of the course, we plan to combine the self-efficacy survey results with direct, in-class assessments using the indicators that form the basis of the survey. This combination of indirect and direct assessment will provide insights into student achievement of the course learning outcomes, and also assist with further validation of the assessments.

References

1. Hugo, R.J., Brennan, R.W., Gu, P., and Lu, X., "Quantifying the efficiency of project-based learning experiences", 7th International CDIO Conference 2011, Technical University of Denmark, June 20-23, 2011.
2. Canadian Engineering Accreditation Board, Accreditation Criteria and Procedures, www.engineerscanada.ca/e/files/ Accreditation_Criteria_Procedures_2010.pdf, 2010.
3. Bandura, A., Self-Efficacy in Changing Societies. Cambridge University Press, 1995.
4. Bandura, A., "Self-efficacy", In V. S. Ramachaudran (Ed.), Encyclopedia of human behavior, 4. New York: Academic Press, pp. 71-81, 1994.
5. Carberry, A.R., Lee, H-S, and Ohland, M.W., "Measuring engineering design self-efficacy", *Journal of Engineering Education*, 99 (1), pp. 71-79, 2010.
6. "My home made solar cell step by step" submitted by member alessiof76 on May 3, 2009, www.instructables.com.
7. "How to make a solar powered fan!" submitted by member Gjdj3 on May 7, 2008, www.instructables.com.
8. "Pringles wind turbine (Pleech) - Version One" submitted by member mikejedw on May 3, 2007, www.instructables.com.
9. "Solar Hot Water Kettle From Plastic Bottles (and Glass)" submitted by member robbtoberfest on January 11, 2009, www.instructables.com.
10. Brennan, R.W., Hugo, R.J., and Rosehart, W.D., "The CDIO as an enabler for graduate attributes assessment in Canadian engineering schools", 7th International CDIO Conference 2011, Technical University of Denmark, June 20-23, 2011.

Biographical Information

Robert W Brennan is a Professor of Mechanical and Manufacturing Engineering and the Associate Dean (Academic & Planning) at the Schulich School of Engineering. He has served on the steering committee of the Canadian Engineering Design Education Network (CDEN) and as chair of the Schulich School of Engineering's Engineering Education Summit. His current scholarly interests focus on intelligent automation and control systems and engineering education.

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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.
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.

Graduate Attribute	Survey Question	How confident are you in your current ability to:
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.
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.