Incorporating new ABET Outcomes into a Two-Semester Capstone Design Course

Gregory Watkins
California State University Chico

Many engineering programs conclude with a culminating capstone design experience. Assessment of student outcomes in capstone courses is common for several reasons. Students are typically nearing graduation and are better prepared to demonstrate attainment of the outcome. Capstone courses commonly teach and require "soft skills" such as communication, ethical and professional responsibility, teamwork, and understanding the broader impact of engineering solutions. Outcomes of this type are typically difficult to assess in traditional engineering courses that focus on theory and problem solving.

A majority of engineering programs are accredited by ABET. Criterion 3 prescribes seven student outcomes, the attainment of which prepares graduates for professional practice. The Department of Mechanical and Mechatronic Engineering and Advanced Manufacturing at California State University Chico has developed an assessment plan where five of the seven outcomes are assessed in the two-semester capstone design course sequence. This paper details the assessment methods, instruments, and metrics used to measure attainment of student outcomes within the capstone design sequence. It also shares early experiences from the process.

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Corresponding Author: Greg Watkins, gkwatkins@csuchico.edu

Background - Accreditation

The mechanical and mechatronic engineering programs at California State University Chico are accredited by the Engineering Accreditation Commission of ABET, an accreditor of "college and university programs in the disciplines of applied and natural science, computing, engineering and engineering technology at the associate, bachelor's and master's degree levels."[1]

ABET publishes eight criteria for accrediting engineering programs. The recently revised Criterion 3, Student Outcomes, identifies seven student outcomes tied to readiness for professional practice. The seven student outcomes replace the former eleven outcomes known as "a through k" and are:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Accredited engineering programs "must regularly use appropriate, documented processes for assessing and evaluating the extent to which the student outcomes are being attained[2]"

Student Outcomes and Capstone

Assessment of some student outcomes are much more straight forward than others. For example, outcome 1, "an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics," can be measured in a traditional engineering course that focuses on theory and problem solving. An example is Machine Design which is utilized for the assessment in both mechanical and mechatronic engineering programs. Other possible courses include Energy Systems, a triangulation measure for mechanical engineering and Machine Automation, a triangulation measure for mechatronic engineering.

But several outcomes are more subjective and their attainment is harder to measure. An example is Outcome 7, "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies."

The pedagogical literature shows a range of approaches for assessment of ABET student outcomes 1-7. Bachnak, Marikunte, Abu-Ayyad, and Shafaye[3] provide an overview of the new outcomes and offer recommendations for assessment techniques that will result in a successful accreditation visit. Battistini and Kitch[4] detail a process that separates each student outcome into Key Performance Indicators (KPIs) to aid in assessment. Biney[5] presents a methodology for using capstone courses to assess a number of ABET outcomes but it was developed for the previous "a through k" criteria. Baine, Brakora, and Pung[6] detail how a single ABET outcome (5) is assessed in a multidisciplinary capstone project sequence.

Commonly universities have chosen to measure the more subjective outcomes in capstone courses. One reason is that students are typically nearing graduation and are therefore better able to demonstrate attainment of the outcome. Another is that capstone courses commonly teach and require so-called "soft skills" such as communication, ethical and professional responsibility, teamwork, and understanding the broader impact of engineering solutions.

As with all accredited engineering programs, the mechanical and mechatronic engineering programs at California State University, Chico had to develop assessment programs for ABET Student Outcomes 1-7. The result, presented here, details how five of the seven outcomes are measured in the capstone design courses.

Capstone at CSU Chico

The Mechanical and Mechatronic Engineering programs at California State University, Chico (as well as the program in Advanced Manufacturing and Applied Robotics) conclude with a two-semester course sequence in Capstone Design. The courses include students from all three majors who work in multidisciplinary teams on year-long design projects that are predominantly externally sponsored. The first semester is spent in design activities while the second encompasses prototype building and testing.

Each group is assigned a faculty advisor[7] and self-selects a student project manager[8] and budget analyst. Students are required to maintain design log books for the duration of the project. The course sequence concludes with the Design Expo event.

Students are assigned to projects by the instructor; they are not allowed to self-select projects or teammates. Projects are recruited before the semester begins and are presented to the class at the beginning of the term. Students rank their project choices and also complete a self-assessment of their team role preference[9].

Priority is given to the student's choice of project, with team role preference used as a secondary criterion. The goal is to form teams whose members are interested in the project and also share a range of talents and personalities, hopefully resulting in a cohesive, high performing group.

ABET Outcomes in Capstone

The department's plan for assessment of student outcomes is tied heavily to the two-course capstone sequence. While there is additional triangulation of some of the student outcomes (measurements in areas outside of capstone), five of the seven student outcomes are assessed in capstone. They are outcomes 3, 4, 5, 6, and 7.

The remainder of this paper details of the outcomes measured in capstone, the instruments used to measure attainment of the outcomes, the threshold for successful attainment of the outcome, and early evidence of attainment.

ABET Outcome 3

ABET outcome 3 is "an ability to communicate effectively with a range of audiences." Oral communication is assessed in the first semester of the capstone sequence (written communication is assessed in a different course).

One of the objectives of the capstone design course is for students to present findings orally and in writing. Oral communication is a point of emphasis with three formal presentations during the first semester. Student delivery is graded individually at each presentation. Metrics include: Volume / Projection; Confidence / Enthusiasm; Eye Contact; Pauses / Ums and Ahs; Posture / Mannerisms; and Appearance. Students receive scores for each metric and general written feedback. The presentations are recorded so that students may review them later for further feedback. Presentations are graded by faculty advisors. Each metric is assigned a grade from 0 to 4 (which corresponds to grade points with a 4 equal to an A). The grades for the six metrics are averaged to determine the student's individual grade for the presentation. The outcome assessment is performed on the final presentation and a performance level of 3.5 or better satisfies the outcome. The most recent assessment data show 100% student attainment for both mechanical and mechatronic engineering students. While all students typically achieve the outcome by the third presentation, some do not in the earlier presentations.

ABET Outcome 4

ABET outcome 4 is “an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.” Outcome 4 is assessed in the second semester of the capstone sequence with two different instruments.

One week of class time is dedicated to the topic of Ethics in Engineering. Students are introduced to a standard case study from the literature[10] as well as a personal experience detailed by a program alumnus. Students are referred to the ASME and NSPE Code of Ethics[11] and are required to take and pass the latter's Ethics Exam, the first instrument used to assess the outcome.

The exam consists of 25 True/False questions based on the NSPE Code of Ethics. Questions refer to specific sections of the code which the students have access to. Students are allowed multiple attempts. Completion of the exam with a score of at least 90% satisfies the outcome for this instrument. The most recent assessment data show an attainment of 95% for mechanical engineering students and 90% of mechatronic engineering students.

The second instrument is imbedded in the final design report submitted by each team at the conclusion of the project. Teams are required to summarize the impact of their design solution in a global, economic, environmental, and societal context. Reports are graded by a faculty advisor that did not advise their project. This required element appears on the grading rubric as a pass/fail measure.

Students must satisfy both instruments to satisfy the outcome. This second instrument has not yet been used for assessment of the outcome.

ABET Outcome 5

ABET outcome 5 is “an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.” Mynderse[12] details a tool specifically designed for Outcome 5 that consists of a student survey and instructor-assessed elements. In our program, outcome 5 is assessed in the first semester of the capstone sequence.

All capstone design projects are accomplished by student teams. Each design team is assigned a faculty advisor. The advisor meets regularly with the student teams throughout the semester. The advisor assists with technical issues and also tracks the overall progress of the design. The advisor observes each student's teamwork throughout the term and also examines their logbooks regularly. At the end of the semester, students are surveyed confidentially about their teammates’ and their own performance as team members. This peer evaluation is accomplished via the CATME platform[13]. The advisor uses the survey results, along with their own observations of each individual student on the team they are advising to make the assessment which is a pass/fail measure. The most recent assessment data show 100% student attainment for both mechanical and mechatronic engineering students.

ABET Outcome 6

ABET outcome 6 is “an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.” Outcome 6 is assessed in the second semester of the capstone sequence and is also triangulated by assessment in a measurements and instrumentation course.

Even though all projects are accomplished in groups, all students in the class are assigned an individual test procedure assignment. The group has previously developed a complete set of engineering specifications for their capstone project. Individual students select a subset of specifications and develop a procedure (designed experiment) to evaluate the performance of their design with respect to the chosen requirement(s). The assignment includes instructions for interpretation of the test results including uncertainty analysis. The individual test procedure assignments are graded by the group’s faculty advisor and are also are evaluated for basic competency which is a pass/fail measure for attainment of the outcome. The most recent data show 89% attainment for mechanical engineering students and 80% attainment for mechatronic engineering students.

ABET Outcome 7

ABET outcome 7 is “an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.” Outcome 7 is assessed in the first semester of the capstone sequence.

In the capstone program, students apply prior knowledge gained in engineering coursework to solve a real-world design problem. Students quickly learn that fundamental knowledge from their coursework must be augmented by new information relative to their particular project.

A point of emphasis during the first semester (and a student realization throughout the entire course) is that despite having completed most of their engineering classes, there is still a tremendous amount of information in various application areas that that the students simply don’t know. They are coached to read, research, and learn the many aspects of their particular project application area, and are reminded that learning does not cease at graduation.

The groups share their experience in the application of new knowledge as a required element of the Final Design Review presentation at the end of the semester which marks the end of detailed design. A required element of the presentation is the application of new knowledge in the course of their project. Student prompts are: "*What have you learned this semester that you didn't learn in your traditional engineering courses*?"; "*What learning strategies did you employ to acquire this new knowledge*?"; and "*How was it applied to your design project?"*

Presentations are graded by faculty advisors in three areas: Content, Visuals, and Delivery. The rubric for content includes an assessment of the "Application of New Knowledge" as detailed in the presentation. The grading scale is 0 to 4 with 3.0 or better satisfying the outcome. The most recent assessment data show 100% student attainment for both mechanical and mechatronic engineering students.

Conclusion

As all engineering programs accredited by ABET are required to do, the mechanical and mechatronic engineering programs at California State University Chico have implemented an assessment plan for ABET student outcomes 1 through 7. Five of the seven outcomes are now measured in whole or in part within the two-course capstone design sequence taken by students in both programs.

The assessment plan has been in place for one academic year cycle and a years' worth of data is now available. Faculty generally have praised the assessment program and data received to date does not indicate significant issues with the plan thus far.

The engineering and computer science programs within the university underwent an accreditation visit during the fall 2021 semester. While final reports are not yet available, ABET's *Draft Statement*, released shortly after the visit, made no mention of student outcome assessment for the mechanical or mechatronic engineering programs. Much more about the efficacy of the assessment plan will be known after receipt of the final report in summer 2022. A follow-up paper on the results of the ABET accreditation process is planned for the 2024 Capstone Design Conference.

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