Triangulation: An Effective Assessment Tool for Capstone Design Program Evaluation

Daniel Knight * Daria Kotys-Schwartz* Gary Pawlas
University of Colorado at Boulder

Capstone design courses are typically the final step in an undergraduate engineering curriculum. How do we know that engineering students are exiting the curriculum with the skills that match program objectives? How can industry rest assured that they are receiving qualified graduates? The present study investigates the development of engineering skills through the lens of triangulation, a useful assessment tool for evaluating Capstone program student outcomes. Data from an industrial-sponsored, team-based Capstone design course was collected at the end of the course. Engineering student technical and professional skills were rated by industry and faculty mentors and triangulated with student self-assessments. Similarities and differences are discussed with implications for applying results for Capstone course evaluation and improvement.

Corresponding Author: Daniel Knight, Daniel.Knight@colorado.edu

Introduction

A sizeable number of skills are expected of US engineering graduates. A heavy emphasis on technical skills and engineering science has been in place since World War II.\(^1\) This was followed at the end of the Cold War with an increased emphasis on professional skills to meet the needs of industrial employers.\(^2\) This led to an emphasis by ABET, via EC 2000, on the demonstration of both technical and professional skills by engineering students as a necessary precursor for university accreditation.\(^3\)\(^-\)\(^4\) These requirements raise questions about how best to determine technical and professional skills development in engineering students. Which skills are we to target? Whom do we assess? How are the results to be presented?

The present study investigates this matter through the vehicle of Capstone design. Capstone design courses, present in most engineering curricula, offer an alternative to the traditional “chalk and talk” method of teaching engineering skills. Many Capstone courses offer hands-on work, team-based design, team mentoring and opportunities to work with clients through service learning experiences or industrial sponsorship. One survey of Capstone Programs found 71% of respondents had industrial partnerships.\(^5\)

The Capstone course structure lends itself to some unique assessment opportunities not found in the traditional classroom where conventional exam style tests and brief, university-wide course ratings are common. For example, industrial mentors for each team offer the opportunity for an external perspective on the development of engineering skills from the viewpoint of a potential employer. Faculty advisors also have a unique perspective in Capstone courses that is often different from the lecture setting. These faculty advisors work closely, for consecutive semesters, with groups of students that are small relative to many traditional classes. This context offers faculty an up-close and personal viewpoint on student skill development that can be missed in exam style results.

Industry and faculty skill ratings can be combined with student self-ratings in an assessment method known as triangulation. Triangulation can be defined as, “the combination of two or more theories, data sources, investigators, and methods in the study of a single phenomenon.”\(^6\) Introduced in 1966, the concept has become important in the assessment and program evaluation literature for establishing the validity of a proposition by helping to reduce the bias inherent in any one research method.\(^7\) For example, there is considerable controversy over whether students can accurately rate themselves on the development of their own skills, but this controversy is eased by comparing student ratings to those of faculty and industry representatives.\(^8\) Four types of triangulation are commonly used involving the use of theories, data, investigators, and methods.\(^7\) The present study makes use of a between methods, multiple investigator triangulation procedure as applied to a Capstone design course. The multi-investigator aspect involves ratings made by faculty, students, and industry representatives. The multi-method aspect involves both self-assessments and objective assessments of skills.

Both technical and professional skills were chosen for investigation. Students were rated on whether they had...
the technical background necessary to accomplish the project. Technical background skills included manufacturing skills and knowledge of the software necessary for the project. For professional skills, both oral and written communication skills were rated along with teamwork and project management skills.

**Method**

Participants were 135 students, 9 industry mentors, and 10 faculty advisors participating in a two-semester industry-sponsored Mechanical Engineering Capstone design course. Students were placed into teams and assigned projects from industry sponsors. Some projects were new and others were continuations from the previous year. Teams were mentored weekly by faculty mentors and industry advisors. Teams faced a number of milestones during the year, such as design reviews, technical reports, and an expo of their work. These milestones offer good opportunities for gathering assessment information on student performance from all raters.

At the end of the year, students, faculty, and industry representatives completed a skills survey targeting the skills chosen for assessment. Skills were selected for assessment based on departmental and course objectives. On the skills surveys, skills were typically broken down into separate topics (e.g., oral and written communication skills) and assessed with multiple questions to better improve the reliability of responses. Survey questions targeted raters' confidence in students' skills with ratings made on a five-point scale indicating a skills rating of “confident.” Ratings were also followed with open-ended questions to offer raters the opportunity for additional explanations of their ratings.

**Results and Discussion**

Table 1 below depicts the results of the assessment triangulation. For the purposes of course evaluation, assessment criteria cutoffs were set at a rating of 4.0 on a 5-point scale indicating a skills rating of “confident.” Ratings above 4.0 are considered more favorable while ratings below 4.0 are cause for concern.

<table>
<thead>
<tr>
<th>Skills</th>
<th>Student Self-Rating</th>
<th>Industry Rating</th>
<th>Faculty Rating</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teamwork</td>
<td>4.32</td>
<td>4.12</td>
<td>4.46</td>
<td>4.30</td>
</tr>
<tr>
<td>Project Management</td>
<td>4.32</td>
<td>4.24</td>
<td>4.15</td>
<td>4.24</td>
</tr>
<tr>
<td>Communications</td>
<td>3.99</td>
<td>3.94</td>
<td>4.21</td>
<td>4.05</td>
</tr>
<tr>
<td>Technical Background</td>
<td>3.64</td>
<td>3.76</td>
<td>3.85</td>
<td>3.75</td>
</tr>
</tbody>
</table>

Table 1: Triangulation of Assessment Results

**Faculty Advisor Evaluation of Student Skills**

A second step is to see if open-ended responses support these numerical ratings. Some evidence was uncovered in open-ended statements that faculty advisors did not feel that students had the relevant technical background needed for Capstone Design. For example, one faculty advisor commented, “More experience in instrumentation and electronic and mechanical assembly would have been useful.” Another faculty advisor commented, “The team could have also benefited from a better understanding of practical parts machining and the time required to do so.” A third faculty member commented, “I would say that the group’s ability to create drawings was poor.”

**Industry Mentor Evaluation of Student Skills**

Industry mentors echoed the sentiment that students lacked the necessary technical background for the Capstone project. One mentor’s expressed that: “Curriculum needs to include more GD&T, CAD skills, and following a project from requirements definition through integration and test.” A second industry mentor commented, “Technically the team has done an average job; in the 2nd semester the team should focus on adding depth to the analytical equations.” Another industry mentor recognized the difficulties, but also provided perspective, “The team has run into problems in getting the freezer going. They seem to be doing a pretty good job fighting through these difficulties. The instrumentation is coming along, albeit also slowly. Not that uncommon in a project with this complexity and novice researchers. The software development is going slow but OK.”

**Student Self-Evaluation of Skills**

When reviewing student open-ended responses, there was several pieces of supporting evidence that student did not feel that they were technically prepared when entering the Capstone course. One student reported on his/her self-assessment, “We have software and electrical issues that are above our heads.” Another student reported, “Anticipating the potential movements and kinetics of our designs has also been challenging. Theory is different than reality.” An additional student
reported, “The design phase was also very difficult because it felt like none of us knew what we were doing as far as analysis went and it is frustrating when there is not enough time to learn more.” One student commented, “I'd like to see a couple workshops on machining and using the tools in the Durning Lab. That's really lacking in the entire curriculum, not just this course.” Another student suggested, “maybe some more guidance on the analysis we should perform on our projects. Again, “More building. Definitely should have more fabrication labs. A junior level fabrication lab may be better suited for this. Most ME students machining experience consists of making a bottle opener freshman year..... which doesn't translate well to building what is supposed to be a professional prototype 3 years later.” Finally, “Maybe provide more support with heat transfer, and fluid dynamics”

Across raters, additional suggestions for development include increased student skill at instrumentation, assembly of the project, manufacturing including CAD and parts machining, and design analysis. With both qualitative and quantitative evidence indicating a need for greater technical preparation for the course, a case can be made during the evaluation of the course for revising some of the lower level classes to better prepare students for the Capstone project. For the current academic year, revisions were made to the junior-level Component Design course to better prepare students for Senior Capstone Design.10

**Inter-rater Disagreement**

Step three of the triangulation analysis is to look for differences between ratings. A good method for determining differences between ratings is through statistical analysis and the one-way ANOVA procedure.11 For example, we could test the Teamwork skills ratings to determine whether the 4.12 rating made by industry mentors is significantly lower than the ratings provided by faculty and students. Unfortunately, we have not accumulated enough cases to allow for statistical analysis at this time. Barring statistical analysis, the one difference that stands out is a trend for lower ratings from industry advisors with three of four ratings lower than equivalent student and faculty skills ratings. This could illustrate the greater degree of difficulty between academic and industrial teams, which would raise some concern about making a smooth jump from college teams to working teams, particularly in those areas rated below 4.0 by industry advisors – communications and background technical skills.

**Limitations and Suggestions for Future Research**

One lesson learned during the assessment process is the need to carefully coordinate surveys with respect to the skills assessed. For this study, the student skills survey was developed from a different background than faculty and industry surveys, which led to an inability to compare design skills across all three types of raters. This oversight will be corrected in future assessments.

Another direction for future research is to increase the sample size to include multiple years or ratings. This will be addressed as the program expands.

An additional limitation of the study is that only one Capstone program is represented by the results. The next step in the research program is to include different departmental Capstone programs within our College. The present study included a mechanical engineering sample, but samples from differently constructed programs such as the aerospace engineering Capstone program would provide a useful comparison group.

Another direction for future research is to investigate quantitatively the development of skills across all four years of the curriculum. Some work in this direction has been completed, by comparing the skills of a group of freshmen enrolled in a first year design project course with senior level skills. Results indicated a type of Sawtooth model where students developed confidence in their skills by the end of the first year only to find these skills had deteriorated significantly by the senior year.10 Skills were successfully rebuilt by the end of the senior year (with the exception of manufacturing skills) but only to the same level as at the end of the first year.

A final direction for future research is to compare results from assessment surveys developed in-house to surveys developed for research purposes. An example would be the Academic Pathways for People Learning Engineering Survey (APPLES) developed from the Academic Pathways Study.12

**Summary**

A potentially useful assessment method for Capstone program evaluation is to triangulate assessment results from multiple raters to gain a more comprehensive perspective on the development of student engineering skills. The present study describes a triangulation of ratings on engineering students’ technical and professional skills. Ratings from faculty advisors, industry mentors, and students themselves were compared. Results across raters revealed needed improvements in the area of the technical background necessary to complete the project. The utility of triangulation results for improving a junior level course was also described. Suggestions for future investigation include the need to collect enough data for quantitative investigation of differences between raters, the need to
better coordinate assessment topics across surveys, and
the need to compare across different Capstone
programs.

References

illustrated history of engineering education in the
2 Shuman, et al. (2005). The ABET professional skills –
Can they be taught? Can they be assessed? JEE, January
2005.
engineers. IJEE, 13, 325-332.
4 Phillips, et al. (2000). Quality assurance for
engineering education. IJEE, 16, 97-103.
5 Howe S., & Wilbarger J. (2005). National Survey of
Engineering Capstone Design Courses, ASEE
Conference, Chicago, IL.
Triangulation: Operational Definitions. Nursing
Research: November/December 1991 - Volume 40, No.6, 364-366
Self-Assessments. ASEE Conference, Montreal,
Canada.
Gender Differences in Skills Development in Hands-on
Learning Environments. FIE Conference, Boulder, CO.
First Year Engineering Projects To Senior Capstone
Design: Are Students Gaining Technical And
11 George, D. & Mallery, P. (2000). SPSS for Windows:
12 Chen, H., et al. (2008). From Pie To Apples: The
Evolution Of A Survey Instrument To Explore
Engineering Student Pathways. ASEE Conference,
Pittsburgh, PA.