Capstone Prepares Engineers for the Real World, Right? ABET Outcomes and Student Perceptions

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Abstract

Capstone design is expected to tie together several components of a student's engineering degree program, provide valuable skills for the student's transition to real-world employment, and in the process satisfy a large number of the program's ABET requirements. Typical capstone course objectives reflect this ambitious set of requirements, and student outcomes can be aligned with these objectives. This work addresses the links among course objectives, what students think they learned in capstone, and the competencies reflected in their final work. This analysis contributes to the assessment of how capstone prepares students for their careers and makes recommendations to fortify that connection.

The objectives of Northeastern University's Mechanical and Industrial Engineering (IE) Capstone Design course map strongly to the new ABET student outcomes. The students' progress in meeting those objectives was evaluated from multiple perspectives. 1) Faculty advisor evaluations assessed technical problem-solving success, 2) a validated tool judged the completeness of the prototype solution and validation testing, and 3) a systematic examination of capstone teams' final reports evaluated application and synthesis of knowledge obtained earlier in the curriculum. Additionally, students were asked individually to reflect on and outline the skills and competencies they learned as well as the characteristics they discovered about themselves during their capstone experience. Twenty industrial engineering capstone teams of 4-5 students (n=83 total) from the Spring 2018 semester were evaluated.

In this research, prototype/project completeness scores indicated that 80% of the teams demonstrated a high ability to solve engineering problems and create design solutions. The assessment of skills from earlier in the curriculum showed that teams typically applied from 17-52% of learning objectives of their previous core courses. The student reflection questions asked what they learned or developed through the capstone experience. Open-response answers focused on very specific technical skills, along with project management; when asked what they learned about themselves, they mentioned communication, teamwork, and personal development skills such as time management, perseverance, and tolerance for ambiguity. This revealed an interesting disconnect: Students rarely, if ever, mentioned problem solving, design, experimentation, or typical major-specific skills as things they cultivated during capstone.

This study demonstrates a number of ways that student success in meeting course and ABET objectives can be measured. It also illustrates gaps in the measurement of student achievement, and a notable disparity between the students' perceptions of what they learned and the desired learning outcomes. Finally, evidence suggests that students do recognize gaining competencies and developing characteristics that will translate to real-world success. From this work, suggestions are offered to foster and strengthen the perception-outcome connection.

The Challenge

In industry, engineers make careers solving open-ended problems [1], [2]. However, the well-structured, constrained problems that engineering students tend to solve in coursework –particularly at the early levels– do little to prepare them for the complexity of vague and unstructured workplace problems [1], [3]. Capstone by design introduces unstructured and unformulated problems, which challenges many students who are unaccustomed to dealing with this type of engineering ambiguity [4].

Senior Capstone Design is regarded as the culminating experience in an engineer's undergraduate academic career. The goals in capstone aim to integrate previous undergraduate coursework, encourage intellectual growth through the acquisition of new and relevant competencies, and provide a taste of real-world problem-based learning and its application. Capstone courses are ubiquitous in engineering programs. The authors in [5] received data from 444 programs and identified a potential 1724 programs nationally. Capstone courses are de-facto required by ABET, as General Criterion 5 requires "a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work" [6].

The above goals map directly to ABET Program Objectives that are intended to prepare engineering students for meaningful, productive post-graduate careers in their chosen disciplines. Capstone is expected to tie together a student's engineering degree program, provide valuable skills for the student's transition to real-world employment, and in the process satisfy a number of the program's other ABET requirements.

Capstone courses meet this challenge by using many learning methods not typically found in the rest of the curriculum. Students engage in open-ended, ambiguous problems, with uncertain and incomplete information. These problems are often supplied by outside sponsors, and often students are exposed to industry workers and experts [5]. As a general practice, they work in small teams, and are responsible for their own project, time management, and solution path. The problems are chosen to require use of prior coursework, but often students need to acquire new knowledge, or learn new tools, to solve them. Solutions are not obvious, and often first attempts will fail, or experiments are required to explore aspects of the potential solution set [4], [7].

Developing an original solution to a novel problem engages multiple learning modes not usually found in a lecture or even an experimental classroom, and requires knowledge and a mindset that may not be part of the prior curriculum. Typically, some of this knowledge gap is bridged with focused lectures on topics such as communication, teamwork and project planning and management during the capstone course [5]. Students must seek out other knowledge on their own, providing an early opportunity to cultivate continuous lifetime learning. Students work with a faculty mentor, and often a sponsor/mentor from industry, introducing a learning style that may be new to the students and is known to be essential in most careers. As noted earlier, students must deal with ambiguous information and poorly defined problems, with multiple solutions that require trade-offs. They work in physical, social, and organizational circumstances, in which they do not control all of the conditions, thus requiring flexibility and agility to deal with uncertainty, risk, and incomplete information. These conditions may not be fully "real-world" [8], but they are certainly more so than students have seen in classroom or lab settings. Students working in teams of 4-5 must manage team interactions and project planning on an ongoing, iterative basis [5]. Finally, students must document and present their work, requiring several different communication skills, and creating at least one round of reflective learning by requiring students to re-tell their story to peer, mentor, and sponsor audiences.

Best Practices

Aligning with ABET is good practice. The Program Objectives and Student Outcomes set out by ABET serve as a sound standard by which to calibrate engineering curricula and capstone is no exception [6]. Table 1 shows the current ABET Student Outcomes mapped to the Senior Capstone Design course objectives at Northeastern University. Capstone is effective for teaching and assessing ABET outcomes 2, 3, 5, 6, and 7. Student Outcome #1 on problem formulation and complex problem solving may not be directly assessed, but it is a necessary skill in order to successfully complete a design. Student Outcome #4 on ethical and professional responsibilities and global/cultural factors may be difficult for students to apply consistently, and may not be captured by typical capstone assessment instruments, yet the importance of this factor is emphasized.

Previous work has discussed the challenges of assessing the ABET objectives, particularly those relating to professional skills [9]. Although the ABET criteria, program objectives and student outcomes have evolved, the difficulties with assessing open-ended and non-numerical skills remain. Because engineering is an iterative process, ABET includes Continuous Improvement as a key criterion: "The results of program evaluations must be systematically utilized as input for the continuous improvement of the program [5]". As such, instructors who collect and evaluate data and student feedback for capstone to be incorporated into future terms can model this practice for their students.

Table 1. Coverage of ABET Criteria by Capstone Course Objectives and content.

New ABET Criteria Student Outcomes	Current Course Objectives/Outcomes
1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. *	Identify, formulate, and solve engineering problems by applying principles learned beyond their academic exposure.
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*	Apply both analysis and synthesis in the engineering design process resulting in designs, systems and/or processes that meet desired needs.
3. An ability to communicate effectively with a range of audiences. *	Communicate their design ideas effectively to a variety of audiences. The concept of 'design' applies to research projects as well. *** Effectively convey and document processes and solutions through written, spoken and presented media. ***
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. *	Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of their designs in global, economic, societal, and environmental 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. *	Function effectively on teams that establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty. ***
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions. **	Develop and conduct appropriate observation, measurement and experimentation, analyze and interpret data, and use engineering judgement to draw conclusions needed to plan, develop, and validate their design solutions.
7. An ability to acquire and apply new knowledge as needed using appropriate learning strategies. *	Recognize the need to learn material outside of their current knowledge base and locate, evaluate, integrate, and apply this knowledge appropriately. ***

** Primary course focus per department plan*
***Secondary course focus per department plan*
****Lecture materials included in course*

The authors in reference [10] conducted a systematic search of the engineering literature to determine which skills (correlated with the previous ABET outcomes a-k) were considered "most important for professional practice across disciplines and work contexts." Their conclusion was that *all* of the ABET competencies were in fact vital for professional practice, but the three competencies of Problem Solving (former outcome e, closely aligned with current 2), Communication (former g, closely aligned with current 3), and Teamwork (former d, closely aligned with current 5) were statistically significantly more important. These are of course capstone focus areas, and two of them, Communication and Teamwork, were the elements most noted by Northeastern University industrial engineers when they reflected on their own capabilities after capstone. This will be explained further in the Results section.

Real-world connection is best experienced, not told. Educators seek to instill the competencies above –and others– by the time of graduation and promote their ongoing development after university. A common struggle in academia concerns bridging the connection between course content and real-world application. This is true for technical concepts, as well the development of professional skills –such as leadership and management– and the cultivation of personal qualities such as integrity and ethics, empathy, listening, and interpersonal communication. There are two aspects to this: 1) students' perception of the applicability of skills and competencies to their future work and career, and 2) the actual translation of these to their professional and personal lives.

A 2015 *op ed* in University Affairs states, "Many undergraduate students don't understand the connection between classroom learning and post-graduation success in the labor market…. The disconnect students feel between what is expected in the classroom and what they perceive are the demands of the "real world" is a recent phenomenon" [11]. While the prevalence of this perceived divide is not fully quantified, most educators have witnessed it on some level. The goal is to not only prepare students for industry practice, but to help them prepare themselves with competencies and mindset.

In terms of technical aptitude, Capstone at Northeastern University explicitly outlines that, in addition to integrating skills from their major, students are expected to transcend beyond prior course material to learn and apply new skills. One of the course objectives states "Recognize the need to learn new material outside of their current knowledge base and locate, evaluate, integrate and apply this knowledge appropriately."

In the areas of personal and professional development, it has been shown that beyond engineering content, there is measurable value derived from out-of-class and beyond-textbook experiences in developing competency in both of these areas [12]. These experiences can include co-op and internship opportunities, global opportunities, and service learning among others. In addition to these experiences, capstone is intended to be a primary opportunity for growth beyond the classroom.

A paper in the Interdisciplinary Journal of Problem-Based Learning describes students' impressions of and experiences in a course as they worked to solve the final problem at the end of the semester [3]. The work compares end-of-term impressions to those gathered near the beginning of the semester and the authors report various factors that students for which student wished they had more guidance and structure. One is adjusting to self-directed problem-based learning which requires more self-reliance than that of many typical engineering classes for which there are recitations and tutors. Another is group work. They note that additional structure imposed on the collaborative aspect would have better supported learning. These sentiments reiterate those reported in an earlier paper on project work with the title "We kind of got pushed off into the deep end" [12].

One set of researchers used the MUSIC Model of Academic Motivation –Usefulness, Success, situational and individual Interest, and academic and personal Caring– to examine how the instructional elements of problem-based learning in capstone engineering affected students' motivation to engage in the course and empower them [13], [14]. When looking at project type and scope, they noted, among other motivational factors, "Participants found the project useful because it provided them with practical experience and the chance to apply knowledge gained across their undergraduate coursework to a single problem." Clearly, the prospect of real-world application is a motivating factor to students themselves in capstone.

The questions remain. With all of the challenges of the capstone experience:

- What do the students feel they have learned?
- In what ways do they feel they have developed?
- What have been the measureable outcomes that they can bring to their careers?
- Do they recognize the practice of transcending their existing knowledge and its future value?
- How does this calibrate with our educational priorities to best prepare new engineers?

Reflection yields insight. Reflecting on past experience is, at the philosophical level, critical to one's life experience and sense of self. In a narrow pedagogical sense, reflection on past learning (for example to prepare for a test) is known to have a powerful effect on the long-term recall of that learning. Reflection can also lead to the consolidation and abstraction of knowledge that makes it useful in general situations outside of the context in which it was first acquired [15], [16]. Capstone projects have very rich potential for reflection at all of these levels.

As part of their project work, capstone students must recall and use prior course content. At a minimum, this reinforces their knowledge of the content. It is more likely that they will have to abstract it or synthesize it with other knowledge to make it useful for their project. Throughout the project, memos, draft reports and practice presentations require the students (usually as a group) to reflect on their recent experience, then record and communicate it. This mode of reflection manifests in final reports, posters, and/or presentations in which their experience with the course, the associated project, and all of its complexities must be reduced to a coherent narrative "story" for an external audience. This reflection through storytelling helps the students make sense of learning that is much less structured than they have previously seen. As a final top-level reflection, students are asked, essentially, "What have you learned/developed?" and "What have you found out about yourself?" The contemplation of, and answers to, these questions provide insight into the way the capstone experience has changed students perceptions of their competencies as well as their character traits.

This reflection is often a novel thing for students. In recommendations for incorporating their findings on applying ethics beyond the theoretical realm, Burt et al noted that although involved students were able to articulate elements of their development, many students were reflecting upon their out-of-classroom experiences for the first time [12]. They note, "Undergraduate engineering classes and programs that intentionally require students to reflect on their out-of-classroom experiences may better connect students' learning." The capstone experience supports this.

Capstone Design at Northeastern University

Program overview will provide context. Capstone Design in the Mechanical and Industrial Engineering Department at Northeastern University is a two-semester sequence. Both the Mechanical Engineers (MEs) and the Industrial Engineers (IEs) have the same goals and objectives, although single discipline teams are the most prevalent. This work focuses on the industrial engineering capstone program which shares resources with the mechanical engineering program as applicable. The overall goal of the combined-major course is to have a working prototype or solution to the assigned project at the end of the second semester of the sequence. Projects may be proposed by faculty, industry sponsors, or students. All projects are vetted by the capstone coordinators, who serve as the instructors of record for the course. The industrial engineering students are divided into two cohorts. One cohort takes Capstone 1 in the Summer 1 semester, followed by 6 months of co-op. The other cohort has Capstone 1 in the fall semester. Both cohorts enroll in Capstone 2 together during the spring semester.

We can measure success. Over the past 9 years, a validated rubric has been used to gauge completeness of each team's design and assess the validation of that design [17]. The design solution is judged two weeks prior to the end of the final term based on a required 5-page executive summary assignment. This summary reflects a snapshot of the project at that point in time, rather than the final finished project. At this stage projects range from essentially complete, to prototyped and ready for testing, to projects that will clearly not be finished by the end of term. Although many groups do go on to do an incredible amount of last-minute work in the final two weeks of term, previous work by one of the authors has shown that groups with high prototype scores two weeks before the end of term have demonstrated excellent planning and project management skills. These high scoring teams also had the opportunity to further develop and improve their design in response to their test results.

Using the rubric above, design solutions or prototypes are scored on a 5-point scale where 5 = functional solution, 4 = partially functional solution, 3 = expected functionality by end of course, 2 = solution in progress, but not expected to be functional, and 1 = no solution, solution unlikely by end of course. The testing was rated on a similar scale where 5 = testing completed, 4 = testing substantially completed, 3 = testing in progress, 2 = testing planned, and 1 = no testing planned/testing not discussed. Although the word 'prototype' is often used, it is fully understood that for industrial engineers the 'prototype' may be a database, a facilities layout, aa new scheduling scheme for a health care office, and/or some other solution to an industrial engineering problem.

In addition to the executive summary, teams are also required to write one report at the end of Capstone 1, two interim reports during Capstone 2, and a final report documenting their design process and their chosen path and solution. They are required to give oral presentations at the same time the written reports are submitted. These are evaluated by the course instructors, other advisors, and by their peers. The final end-of-capstone presentation is accompanied by a poster session, both of which are evaluated by an alumni jury. The final grade depends on the advisor's evaluation of the chosen solution, the coordinator's evaluation of team performance and participation, and the communication instructor's evaluation of the written and oral reports. The final report ideally provides a complete record of the design process, including initial ideas, background research, justification for design choices, and a complete description of the final design and the steps taken to test and validate it.

Objectives of prior coursework have been quantitatively mapped to ABET outcomes. As noted above, capstone courses tend to be responsible for the majority of the ABET student outcomes [18]. At Northeastern University, capstone was expected to cover 6 of the 7 ABET student competencies as "a primary focus of the course," and the remaining one as a "secondary focus." See Table 1. No other class was expected to address more than 3 as a primary focus, and capstone is the only course with a primary emphasis on Outcomes 4 (Ethics) and 5 (Teamwork). ABET is not the only driver, however; the need for a unifying design experience is recognized in most attempts at creating an improved engineering education [19]. Figure 1 below shows the number of ABET outcomes addressed for each of a number of core IE courses in the department.

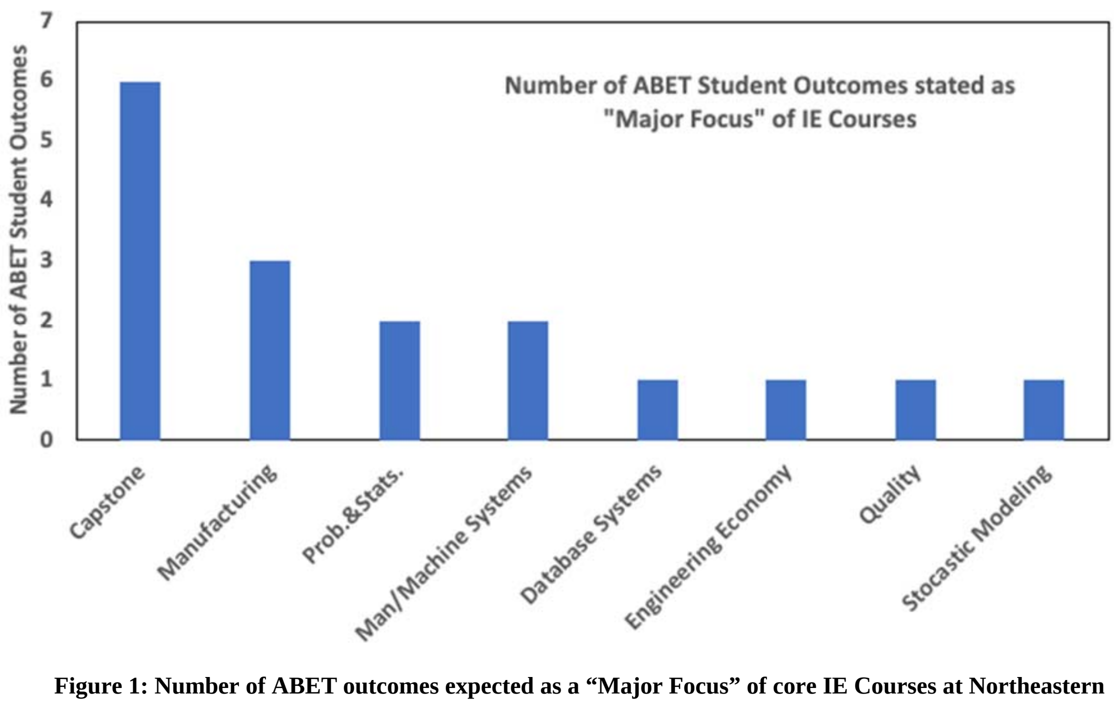

Figure 1: Number of ABET outcomes expected as a "Major Focus" of core IE Courses at Northeastern [20]

The mapping in Figure 1 accomplishes two goals. First, it illustrates that core courses are covering ABET objectives. More so, it illustrates the significant role that Capstone serves in incorporating so many of these objectives. The next sections describe the research methods used to determine the levels of success in meeting the goals of capstone, ABET, and working to prepare our engineers for their careers.

Methodology: What was the protocol?

This research was conducted on 20 industrial engineering capstone teams, each with 4-5 members, for a total of N=83. This work is grounded in two forms of inquiry, namely 1) a set of open-ended reflection questions about what the capstone students perceived they learned or developed through the capstone experience and 2) a mapping of outcomes to a validated success metric. These methods and tools are described below. With these, relative alignment of perceived and acquired competencies can be assessed.

Research questions and analytical tools guide and inform inquiry. In order to be clear on the direction of this research given the foundational principles and motivations above, research questions and associated methods framed the next steps:

- What skills or competencies did we want our students to learn?
  → ABET Program and Student Outcomes, measurably mapped to Course Objectives

- What skills or competencies were demonstrated in our students' work?
  → Analysis of reports for use of major-specific tools

- What skills or competencies did students say they learned?
  → Reflection survey and associated content analysis

- What characteristics did they discover about themselves; how did those map to required skills?
  → Reflection survey and associated content analysis

Students were asked to reflect and respond. At the time of the second Capstone 2 presentation, teams were asked to reflect on various aspects of their capstone experience. As such, there was plenty of time for students to contemplate and add to their responses over time. Students replied to these statements:

- Note something that seeing the presentations inspired you to do better or differently.
- Describe new competencies you have learned/developed (skills, tools, methods, software).
- Describe qualities you have discovered about yourself (characteristics, traits, features) through the Capstone experience. Consider those you may not have otherwise emerged in this time period and ways you have been challenged and have triumphed.
- Note any new aspects of IE, research, and/or project work that impressed you, you might look into, or try to use.

A multirater content analysis was conducted. All responses to the questions and requested descriptions above were recorded and categorized independently by two raters [21], [22]. For the topic areas, a reliability commutation with Cohen's Kappa was a 0.80. Common themes were identified, aggregated, and quantified to identify top responses. Responses noting technical coding skills such as using particular simulation programs, for example, were grouped under 'Software'. Core IE skills such as human factors, Lean concepts, facilities layout, and process flow charts were classified as 'IE tools'. In addition, students identified some skills which were extremely project specific. One group, for example identified having learned about intubation techniques in operating rooms because it pertained to their project. Highly specific skills such as this were outlined as instances for which a team had to learn and acquire new domain-specific knowledge for their project, but the skills were not included in the list of top responses.

Target Student Outcomes were mapped to actual findings. Course syllabi for the core IE courses were examined to determine a list of key industrial engineering skills, which are listed in Table 2. The highlighted objectives were mentioned by students in their response to the question "What skills or competencies did you learn/develop/apply in Capstone Design?" The final reports were examined for evidence of these objectives. Multiple readers were used in cases where there was ambiguity. Reports were marked as having or not having used a particular IE skill or tool. The number of individual skills used by each group was also compared to the prototype scores for each group.

Table 2: Key Course Objectives for Industrial Engineering core courses and named skills used in capstone.

Course	Goal/Objective from Course Report Form*
IE2310 Introduction to Industrial Engineering	Apply layout and location techniques to design facilities
	Use flow process charts, time study, occurrence sampling
	Statistical process control
	Perform engineering economic analysis
	Use project management methods
IE3412 Engineering Probability and Statistics	Set a test of hypothesis and conduct hypothesis testing
IE3425 Engineering Database Systems	Use MySQL, XHTML and Python to design and implement databases
	Perform database mining and warehousing
IE4510 Simulation Modeling & Analysis	Translate narratives and problem statements into flow models and simulation scenarios.
	Interpret output and key performance indicators that emerge from simulation runs for operational decision making
IE4512 Engineering Economy	Calculate the time value of money
	Choose optimum replacement alternatives
IE4515 Operations Research	Formulate and solve a transportation problem
	Solve a shortest path problem with an appropriate algorithm
	Solve a linear programming problem
IE4516 Quality Assurance	Apply design of experiment for quality improvement
	Determine sample size and use proper statistical measurement
	Apply process monitoring methods
IE4520 Stochastic Modeling	Identify, formulate and solve an appropriate queueing model that applies to a given queueing system
	Formulate and solve problems using dynamic programming
IE4522 Human-Machine Systems	Carry out background research
	Conduct laboratory experiments in human response and performance,
	Interpret results statistically, use findings to design human-asset systems
IE4525 Logistics & Supply Chain Management	Apply concept of supply chain management
	Be familiar with analytical tools necessary to develop solutions for supply chain management, logistics, and design problems
IE4530 Manufacturing Systems & Techniques	Learn and apply Lean Six sigma concepts

***Highlighted** *objectives were specifically mentioned by students in their open-response replies.*

Results and Discussion:

What did students say they learned? Students' responses to the reflection question "Describe new things or competencies you have learned (skills, tools, methods, software) through the Capstone experience" are tabulated in Table 3 and presented in Figure 2. The responses were scanned for specific key words, such as the names of software programs used, as well as for responses that came up repeatedly and were grouped by common themes. For example, responses such as 'became better at public speaking' and 'learned to write a literature review' were grouped under "Public speaking/presentation/ communication". "Statistics" and "Research" were considered general engineering skills, as opposed to skills taught primarily to IE students, such as 5S, DMAIC, and facility layout.

Table 3: Tabulation of the most common student responses to the question "Describe new competencies you have learned" (% of total students, N=83).

Skill or Competency	% Students Responding
Software (Simulation, Excel, Arena, etc.)	38
Project Management	15
IE Tools (DMAIC, Human Factors, 5S, etc.)	15
Data Mining	12
Probability & Statistics	7
Public speaking/presentation/communication	7
Research Methods	5
Workings of health care systems	4
Interviewing skills	3
Website development	2
Critical thinking	2
IRB - Human subjects research protection	1
Conducting meetings	1
Conducting experiments	1

The results show that the bulk of the responses had to do with particular software and computer related tools. Although students had relatively few core courses that involved software tools, these tools were called upon and elaborated on extensively throughout the design experience. Project management, which is typically covered in the Introduction to Industrial Engineering course, turned out to be another commonly recognized tool that students really drew on in order to finish their projects. It is interesting that some of the 'soft skills' such as critical thinking and public speaking are less recognized by the students as a skill learned in capstone. Student quotes illustrate the range of ways that students interpreted this question. Some responses were very specific and detailed:

"I have learned how to use IE tools to complete a problem. Ex: DMAIC, Fishbone diagram, Agile Development"

Others indicated that 'traditional' IE tools were less helpful, requiring the students to learn new skills:

"I have learned much more about software programming techniques because our project requires more of the skills rather than traditional IE techniques."

Particularly encouraging were students who not only recognized that they learned new skills, but recognized that these skills would be useful beyond the course:

"Data mining, motion data, project management, Python scripting. I have taken the lead on this, I think it's awesome to learn, I talked to the team I will be starting with fulltime after graduation. They are excited for me to bring these skills."

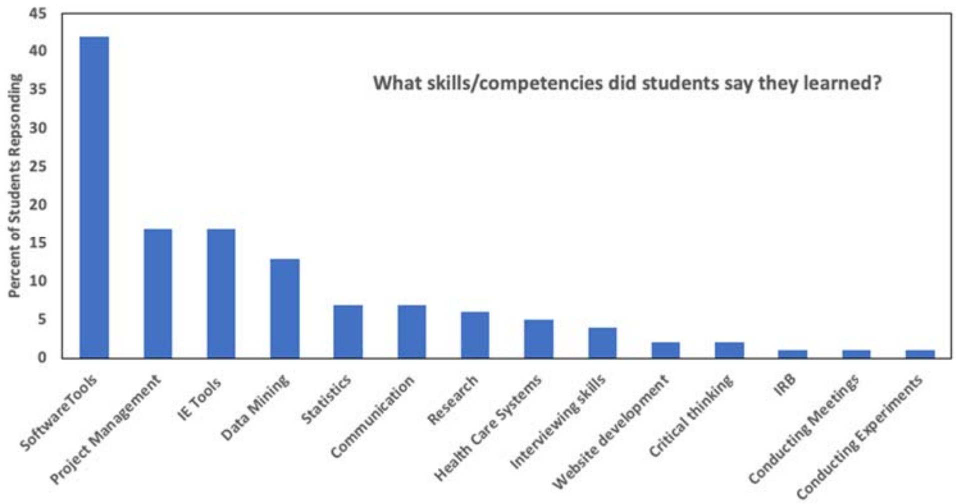

Figure 2. Graph of skills capstone students said they developed/learned through the capstone experience.

What skills or competencies were evident in the student Capstone work?

As the first indicator of acheivement, student reports were analyzed to determine what skills from previous courses were evident in the final student outcomes from the course. The results of this analysis are shown in Figure 3 below. There was some overlap between what students *thought* they learned and what was *actually produced*. The top three skills identified by students were software skills, project management, and IE tools such as Human Factors and Lean concepts. Project management was used by all of the teams. Software based skills centered around data mining were also used by more than half the groups. Probability and statistics techniques were also used by at least half of all teams. Skills related to manufacturing concepts tended to be the least represented. This is not particularly surprising, as manufacturing is not a primary focus of the program. It is encouraging to see that all of the major course objectives throughout the entire curriculum were represented at least once in the final reports.

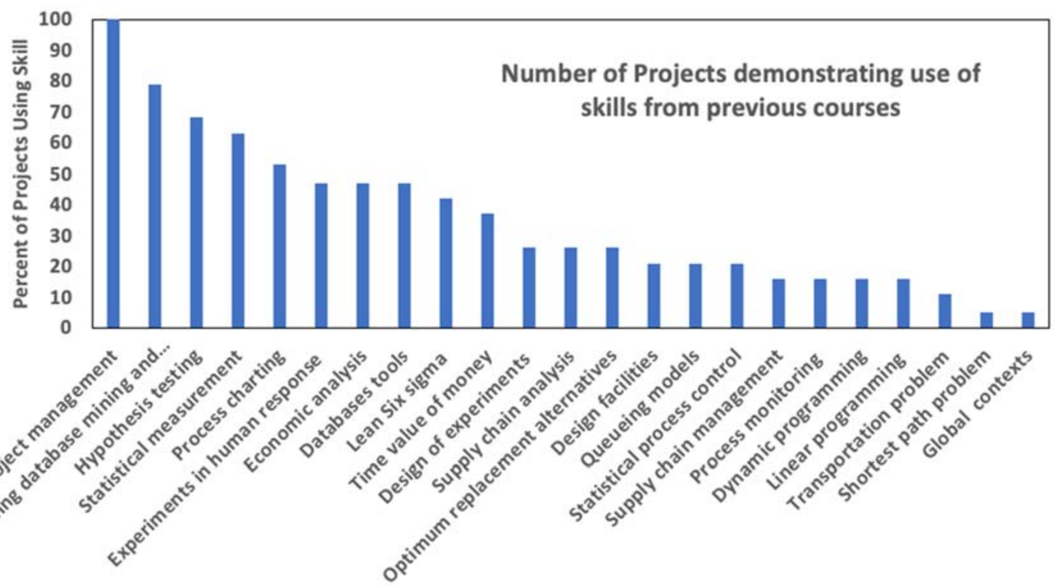

Figure 3: Results of report mining for associated industrial engineering course objectives

The second indicator of student achievement is the prototype scores for the groups. A prototype score of 6 or higher indicates a group that has a complete or nearly complete prototype that has been at least partially validated at a point two weeks before the end of term. Teams with scores of 4-5 tend to either have a mostly complete though unvalidated solution, or a partially complete solution with some initial testing done on the completed section. Low scoring teams typically had poor project management skills, or scope changes that required major revisions in initial solutions. The results from the term in question are shown in Figure 4 below. The project management skills that were evident in both the student comments and in the report analysis clearly allowed students to manage their projects such that most (80%) were substantially finished prior to the end of term. A Pearson's product moment correlation found a value of $R = 0.33$ ($P = 0.014$, $\alpha = 0.05$) indicating a moderate correlation between the number of course objectives used by each team and their prototype scores.

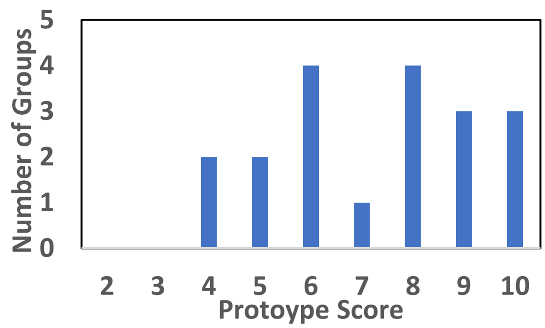

Figure 4: Number of groups achieving each total prototype score

What characteristics did students discover about themselves? Students were asked to identify characteristics that they discovered about themselves in the reflections. The most common responses are presented in Table 4 below. The skills associated with ABET student outcomes #3 (Communication) and #5 (Teamwork) were heavily represented in the student responses. Relatively few students articulated the need for learning new information, leadership skills, idea generation, and other characteristics that would be beneficial for future work in their careers.

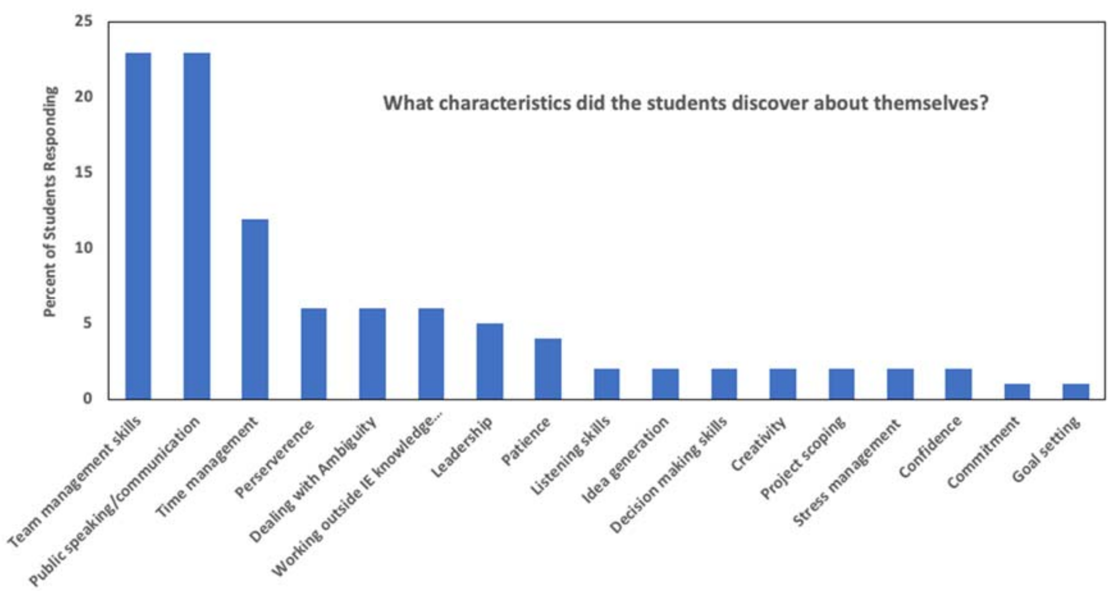

Figure 5. Characteristics that students reported discovering about themselves.

Table 4: Characteristics students discovered about themselves.

Characteristic	#% Students Responding
Team management skills	21
Public speaking/communication	21
Time management	11
Perseverance	5
Dealing with ambiguity	5
Working outside IE knowledge base	5
Leadership	4
Patience	3
Listening skills	2
Idea generation	2
Decision making skills	2
Creativity	2
Project scoping	2
Stress management	2
Confidence	2
Commitment	1
Goal setting	1

Student quotes associated with this question showed a range of insight. For example, one student expressed that they learned about themselves and others during the course of the project:

"I would say I have developed more than discovered personal characteristics throughout this project. As the PM, I have worked on leading my peers and planning for varying interrelated aspects of this project. Particularly, I am trying to balance making sure we move forward with not stressing people out/causing us to burn out, especially when also considering non-capstone priorities. It is always interesting and valuable to see how people manage stress differently."

Another comment indicated a new appreciation for Industrial Engineering:

"I really started to appreciate how diverse IE is and how it can be applied in wholly different and creative settings."

However, some students showed less growth and development in relation to group work:

"I hate group projects still."

"I have felt challenged by group dynamics."

"Capstone will destroy your friendships."

Other comments showed that even students who profess to dislike group work seem to recognize the skills that are related to group work:

"I have learned to relinquish some control."

"I have developed increased patience."

"I have learned to delegate."

From this feedback we have learned that personal and professional growth, development, and awareness are also by-products of the Capstone experience that are highlighted through inquiry and reflection.

Conclusions and Implications for Practice

The ultimate goal of an engineering program is to produce engineers and send them out into the world to do engineering. Northeastern University has been successful in developing a capstone program that satisfies ABET objectives. For students, ABET objectives are rarely considered, nebulous concepts that don't have a great deal to do with their day-to-day life as apprentice engineers. However, a well-constructed capstone program serves as a way to allow students to discover and develop for themselves the characteristics and skills they need to succeed in their profession, as well as providing them the opportunity to integrate the knowledge learned throughout their undergraduate curriculum.

Analysis of student reflections showed that students readily recognized skills and competencies that either required significant effort (i.e., learning a new simulation software) or had to be used continuously during the course of the project (i.e., project management). Typical IE skills were also recognized, but as some skills were only applicable to certain projects, the overall impression was that of few students using some key skills. For example, not every project required data mining, or the need for extensive statistical analysis. With 83 students surveyed, only 13% mentioned data mining and only 7% mentioned statistics, despite the fact that these concepts are covered in multiple courses. Modeling and simulation are covered in coursework and were present in half of the reports, yet no student specifically mentioned either of these skills in their reflections, except by referring to learning software to accomplish them.

The final reports collectively covered the entire range of core skills being taught in the IE curriculum. The 'professional skills' of teamwork, time management, and communication were clearly recognized by the students as having been developed during capstone. Skills in written and oral communication were not applied equally by all teams, as expected. But the ABET skills which can be the most difficult to assess, such as Outcomes #3 (Communication) and #5 (Teamwork), are valued and recognized by the students.

Outcome #7, which relates to applying new knowledge, is inconsistently achieved by the students. Learning new hands-on skills and software packages is relatively easy for students. One relative weakness, however, is the ability of students to conduct scholarly research and integrate it into their design process. Research skills were only mentioned by 6% of the students in their reflections, and historically this is a topic with which they struggle. Students understand the need to learn a specific tool to solve a specific problem, but they fail to recognize the need to connect their work to the previous body of knowledge in their field. This happens despite multiple lectures devoted to the topic, along with detailed feedback on multiple reports. The relative weakness in this outcome may be related to the fact that Northeastern University with its strong co-op program sends many more students into industry jobs directly after graduation as opposed to post-graduate studies where scholarly research seems more useful. Perhaps inviting speakers from industry who could provide concrete examples of how and where research skills are used in industrial settings would provide students more context for these critical skills.

Recommendations for Future Work: What else can be done to contribute to this work?

It would be beneficial to study whether specifically explaining and presenting the ABET outcomes to undergraduate students during the course of their studies changes the degree to which the related course objectives are achieved. Anecdotally, there have been a number of occasions when the authors, upon mentioning an upcoming ABET visit, received the response "What's ABET?" from a student. Students are expected to achieve goals based on ABET standards, but are not often made specifically aware of them. Discussing ABET and how it informs course goals during capstone design would be relatively easy to do. Reflection responses of students specifically exposed to ABET material can be analyzed and compared to previous responses to determine any changes. However, methods of connecting ABET, course goals, and longer term professional goals may be something that must be done repeatedly during the curriculum in order to see an effect. In addition, alumni surveys could be analyzed to determine whether any of the outcomes were still seen to be valuable once students entered the professional world.

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