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Cornerstone to Capstone Engineering Design: Evolving Student Perspectives through the Academic Journey with Implementable Curricular Implications

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Abstract

Several years ago, Northeastern University's College of Engineering (COE) adopted a cohesive "Cornerstone to Capstone" curriculum model focused on bookending the engineering design experience in the undergraduate curriculum. In this study, we examine both first-year and final-year cohorts to investigate patterns in perception, mindset, and motivational differences between students entering Cornerstone and exiting through Capstone, focusing on the definition of engineering and the essential design skills to solving engineering problems. In addition, Cooperative Education faculty were surveyed to record experiences with industry partners and document their recommendations for essential technical and professional competencies required to succeed in today's workforce. The results were analyzed with a focus on students' professional development and academic-industry alignment. Students highlight divergent levels of competency compared to the industry requirements and expectations. Our findings indicate that first-year Cornerstone students have a split engineering design perspective. Specifically, some students defined engineering design as simply a solution to a problem, exclusive of any mention of a process or plan. Others describe it as a means engineers take to design a solution to a problem, replete with iteration, and trial and error. However, seniors in Capstone revealed a more apparent pattern of the requirements and attributes of engineering design, such as planning and gaining clarity on approach, acquiring the technical skills, and knowledge to solve problems through research and background development. The key findings from this research point to opportunities for further emphasis in the early Cornerstone offering in the areas of planning and project management as well as the need to conduct research and obtain data and background information as a priority. Likewise, the seniors in Capstone Design can learn from the first-year students who identify the need to understand and empathize with end users and target beneficiaries, which also includes maintaining an ethical compass. This outward-facing perspective is found much lower on the seniors' list. Similarly, the concept of failing, iterating, and retrying is near the top of the first-year list yet is virtually absent on the Capstone list. This research provides a useful investigative approach for other engineering educators to examine their programs and informs more focused planning through the curriculum for students' future success.

Keywords

Cornerstone, Capstone, Engineering Design, Technical Skills, Professional Competencies, Co-op, Cooperative Education, Work Experience

Introduction

For the past few decades, several initiatives have been designed to improve and strengthen students' outcomes in the Science, Technology, Engineering, and Mathematics (STEM) fields at all levels of the educational system. For example, the Department of Education published a letter that guides local officials on accessing the federal funding reserved for supporting innovative and equity-focused STEM education strategies from Pre-K–12 grades [1]. Additionally, initiatives such as 'You Belong in STEM' and the 'STEM Education Coalition' aim to strengthen STEM education locally and nationwide. This push to increase access to STEM courses and experiences has boosted students' knowledge of problem-solving and project-based learning.

Research shows successful engineering education requires experiential project-based, hands-on, and interdisciplinary learning elements to engage and motivate students, increasing retention and graduation rates [2]–[4]. This includes identifying clear applications of their acquired skills and finding purpose in their work. At the university level, a concentrated focus on the design component in academic engineering programs is championed by the Accreditation Board for Engineering and Technology (ABET's) Criterion 3, Student Outcome 2 [5], and the American Society for Engineering Education (ASEE). Design in engineering plays a key role in integrating these elements into courses spanning the curriculum from First-year Cornerstone to Senior Capstone. In the past, Senior Capstone design was the standard by which students could apply their engineering foundation to a real-world problem before graduating. However, many schools have book-ended the design experience by providing one in the first year to provide students immediate exposure to how design in engineering works–taking an idea from the drawing board to an actual working prototype. This first course is called Cornerstone of Engineering at Northeastern University and other institutions.

The importance of professional skills in these courses is well documented and has been the focal point of industry, professional organizations, and research [6], [7]. A professional skills list published by Baukal et al. includes communication skills, emotional intelligence, teamwork, curiosity, a persistent desire for continuous learning, project management, critical thinking, self-drive and motivation, and cultural awareness [8]. Shuman et al. classified professional skills into two categories to examine them better: process skills, such as communication, teamwork, and the ability to recognize and resolve ethical dilemmas, and awareness skills, such as understanding the impact of global and social factors, knowledge of contemporary issues, and the ability to do lifelong learning [9]. Communication itself can be divided into three primary categories: *Graphical communication,* which covers technical requirements of sketching, drawing, and visual skills; *oral/spoken communicatio*n, which includes formal presentations of the material to a technical audience and communicating with colleagues inside and outside of the organization, and *written communication* in all forms from report writing, letters, and memos to proper etiquette in emails [10].

Additionally, teamwork, leadership, and followership are professional skills that may include the understanding that individuals are part of a larger group and must work well with other members to complete required tasks. Competency in such skills involves the exhibition of interpersonal competencies such as teaching others new skills, exercising leadership by communicating ideas to justify a position, negotiating to work toward an agreement, and having the ability to work with a diversity of backgrounds, individuals, and processing/thinking modes [11].

For years, the ASEE and ABET have emphasized how essential the above competencies are to succeed in today's workforce. For example, ASEE published a series of reports on Transforming Undergraduate Education in Engineering (TUEE), which in phase 1, assess the value of 36 characteristics most sought by industry from engineering graduates, referred to as KSAs: knowledge, skills, and abilities [12]. The high-priority list included: proficient communication skills, engineering fundamentals, systems integration, curiosity, self-drive, cultural awareness, economic and business acumen, high ethical standards, critical thinking, teamwork, entrepreneurship, willingness to take calculated risks, and the ability to prioritize.

Another outcome of the TUEE reports was identifying how specific attributes could be acquired at universities during work experiences or collaborations with industry. This was related to the concept of the T-shaped engineering graduate as someone with a breadth of knowledge across domains but possessing enough expertise within a single domain to go in-depth on a topic. The recommendations were that the industry provides relevant case studies, be more realistic about giving time to train new hires, and provide learning materials to universities [12].

Likewise, ABET published eight general criteria for programs seeking accreditation at the Baccalaureate Level. Criterion 3 focuses on seven student outcomes that must be attained before a graduate is to enter the professional practice of engineering. The outcomes are summarized as having the ability to solve complex engineering problems, apply engineering design, communicate effectively, recognize ethical and professional responsibilities, function effectively on a team, develop and conduct appropriate experimentation, analyze and draw conclusions, and acquire and apply new knowledge as needed [5]. Again, communication, problem-solving, teamwork, lifelong learning, and professionalism are emphasized here too.

Motivation

As faculty and experienced industry professionals, we have a strong sense of the foundational skills required to succeed in the engineering design domain. At times we delightfully align with our students. At other times, we detect gaps in what we know is required versus what students believe is needed when identifying "what it takes" to develop as a successful design engineer of high character. A typical undergraduate curriculum starts with Cornerstone and culminates with the Capstone experience aiming to foster a growth and solution-oriented mindset regarding the key components of successful engineering design as described above. These skills, combined with qualities related to ethics, productive perceptual shifts, and perseverance, combine to develop competent, principled engineering professionals [3].

Consequently, in this study, we investigate which design competencies our students at Northeastern University gain as they traverse through our curriculum. Specifically, we are interested in three key themes –among others–to guide engineering education across academic levels, from first year to graduation:

- Growth and development, in particular technical skills *and* mindset,
- Reinforcement of fundamental engineering processes such as problem-solving and decision-making, and
- Preparation for the industry beyond university settings, including leadership, teamwork, communication, and ethics.

In addition, this multiphase research sets out to examine whether there are gaps in perception across academic levels and to identify where bridge-building opportunities exist to equip our developing engineers with the mindsets, technical skills, and professional competencies to function successfully.

Background

A few years ago, Northeastern University's College of Engineering's curriculum moved to a "Cornerstone to Capstone" experience for all incoming engineering students. The model begins with a common first-year experience with Cornerstone, experiential learning opportunities through Co-op, and culminates with the Senior Capstone Design experience, which intentionally revisits the Engineering Design Process as the students take on real-world projects in their final year. As engineering educators, our goal is to foster evolving perspectives and a growth mindset regarding the essential components of engineering design and integrate them into the academic and experiential curriculum described in the next.

Cornerstone Overview

At Northeastern University, the first-year curriculum is standard for all engineering majors and requires the completion of two 4-credit-hour courses. The primary reason for this approach is that in a typical year, ~40% of students enter with an undecided declaration. In addition, ~73% of incoming students also have Advanced Placement credits with a range of high school STEM experiences from 'none to advanced' such as FIRST or Vex Robotics. A typical Cornerstone course is populated by students who declare from all engineering majors, those who select engineering but are undecided in their discipline-specific major, and students who are entirely undecided on the college and explore class offerings from across the university's ten colleges.

The Cornerstone of Engineering ('Cornerstone') courses incorporate hands-on project-based design work arranged around engineering themes, such as robotics, sustainability, resiliency, gaming, biomechanics, energy, power conversion, and a few do integrate the service-learning experience. Within each theme, engineering concepts such as the engineering design process, data analysis, computer-aided design, algorithmic thinking and programming, the use of programmable microcontrollers, engineering ethics with ethical reasoning, and value-sensitive design are all incorporated to help facilitate solutions to the problems at hand. The philosophy behind Cornerstone is that engineering concepts are introduced around a problem statement developed by the student teams or with the instructor's guidance. The engineering concepts are integrated naturally and not forced- that is, to solve a part of a problem, students will need to understand how to use a specific tool to get the job done. The teams can explore and research engineering principles based on interests and project requirements to simulate real open-ended projects with authentic complexities.

In addition, within this framework, students have the experience of building a first-year community centered around a dedicated Makerspace –a collaborative workspace and tutoring center exclusively for first-year students [2]. The Cornerstone of Engineering course is the first instance in which engineering students begin to develop their professional skills and cultivate foundational technical competencies in a college setting that inspires and instills a passion for the engineering profession. There are multiple opportunities and requirements to document the engineering design process and describe the technical background required to facilitate solutions. In addition, first-year students must apply effective teamwork strategies, collaborate, and learn how to make decisions as a group to successfully develop a solution to the problem they are working on.

Capstone Overview

Upon approaching graduation, the undergraduate program at Northeastern University requires a 2-semester Senior Capstone Design ('Capstone') sequence as part of its accredited engineering degree program. It contributes to all categories of the new ABET assessment standards [13]. Four-or five-person teams are formed to tackle projects proposed by faculty, industry sponsors, or community partners (the 'clients'/sponsors). The teams are supervised by individual faculty members (advisors), all overseen by a Capstone coordinator or a partnership of co-coordinators.

Capstone 1. During Capstone 1, teams more thoroughly outline the problem, conduct necessary background research, outline solution prospects, and make preliminary selections of tools and potential solution techniques. There are a variety of capstone-specific class sessions, exercises, and assignments in the first semester to coach students to key milestones and encourage initiative and autonomy. Examples of module topics include Meeting the Client, Formulating a Problem Statement, Project Management, and Conducting Background Research. Capstone 1 work concludes with a presentation and a report. By the end of Capstone 1, teams are expected to have outlined a path forward in preparation for Capstone 2 to realize a final deliverable. Teams do not always make comparable progress in Capstone 1, owing to the variety of projects and factors unique to each project, problem, team, and client.

Capstone 2. Most of the technical work is accomplished in the second semester– Capstone 2. Among other assignments, a SWOT analysis, an external design review, a background research document, and the midterm presentation and paper serve as a chance to iterate towards the final products, which include a final deliverable, an executive summary, an online juried presentation, an in-person Posters-&-Pitches day, and a final report.

To enroll in Capstone, students must have senior status, which means they have completed most of their coursework and cooperative education employment cycles. Thus, gaining experience in the industry and applying engineering principles. Naturally, Capstone students have more industry experience and have multiple opportunities to apply engineering principles.

Cooperative Education

At the center of Northeastern University's experiential learning is its renowned cooperative education program (Co-op). This program positions undergraduate students to work in the industry for one, two, or three six-month cooperative education experiences. The number of Co-op cycles depends on whether a student prefers to graduate in 4 years (2 cycles), 5 years (3 cycles), or chooses to enter a combined BS/MS program (1 cycle). Co-op provides students with real-world employment opportunities to develop expertise in their area(s) of interest. Students apply what they have learned in the classroom and try out aspects of a career domain before potentially committing to a permanent position following graduation. Co-op is highly valued by all as it provides employers with a talent pool typically unavailable to most companies and provides students a strong competitive edge in finding quality employment after graduation. The Co-op faculty work directly with employers and students to identify placement opportunities that meet the needs of businesses and students alike.

Methodology

For this study, data were collected from three groups: first-year students enrolled in Cornerstone, senior-level students enrolled in Capstone, and the College of Engineering Co-op faculty. Under full IRB evaluation, this study obtained Northeastern University's IRB approval #22-11-45. Co-op faculty reported their views in an open-ended questionnaire; their responses informed the profile of the most important skills employers do seek during placement. The students' survey comprised quantitative and qualitative questions and was administered near the 4th week of the Fall semester. Responses were used to analyze engineering design perspectives across the academic levels and to learn of the students' open-ended views and areas of focus at very different points in their academic and employment journey. Responses were evaluated in light of students' work experience and academic level accounting for both duration and number.

The survey prompted students to provide their own unresearched and intuitive definitions of engineering and engineering design. The survey questions focused on demographic, academic, and work history information, open-ended definitions of the engineering discipline, required and/or desirable skills for effective engineering design projects, contributing factors to failed projects, and self-assessment readiness in terms of skills and attributes needed to be successful, along with associated explanations.

A total of 152 Participants were recruited from multiple sections of Cornerstone and Capstone to complete the survey voluntarily and confidentially per IRB guidelines. All open-ended responses were systematically analyzed and classified using validated qualitative content analysis [14]. In the next section, we present and discuss the foundational findings and significance of the survey results.

Results & Discussion

Engineering Cooperative Education Faculty Perspectives

First, to better understand what employers currently need from our students and graduates in terms of technical and professional skills, ten actively practicing Co-op faculty responded to and reported on two open-ended questions. Their responses were analyzed using rule-guided qualitative text analysis to identify categories, patterns, and themes with measurable relevance for each level [14]. Responses were evenly distributed amongst the five departments, that is, Mechanical & Industrial Engineering, Electrical & Computer Engineering, Civil & Environmental Engineering, Chemical Engineering, and Bioengineering. These outcomes are presented below.

Competencies & Technical Skills. Results are shown in Figure 1 for Question 1 that asked, "*From your interactions with Co-op employers, please share what they report to be the technical competencies required for our students to be successful in the positions available to them.*" Thematic analysis binned responses into five encompassing categories. As observed in Figure 1, 70% of responding Co-op faculty mentioned problem-solving skills, including those related to using engineering software, design and programming, and 60% of the respondents stated design and graphical communication skills, including using 3D design software. Computer programming and lab experiences were parsed out as separate requirements in 50% of the respondents, respectively, and hands-on fabrication using machining and basic tooling was listed 30% percent of the time.

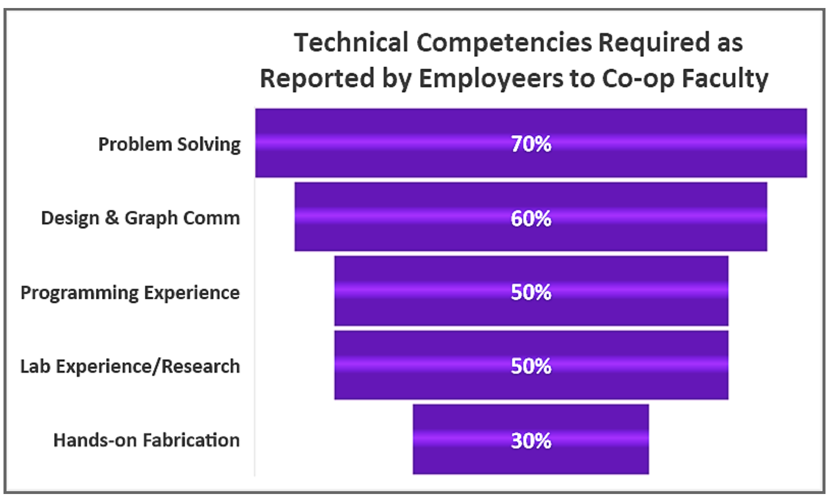

Figure 1. Results of open-ended content analysis of Co-op faculty to the inquiry outlining requested/required technical skills for success.

Professional 'People & Power' Skills. Figure 2 below highlights the findings for the second survey question that asked the Co-op faculty, "*From your interactions with Co-op employers, please share what they report to be the general (professional, personal, 'people and power') skills required for our students to succeed.*" The results of the open-ended content analysis show that 90% of the respondents overwhelmingly name communication as a required competency, followed by critical thinking and teamwork at 40% each. Other areas noted are being an initiative-taker at 30%, and being motivated and passionate, tied with time management at 20%. It is not surprising that employers want people who are competent communicators and effective teammates, as these interpersonal elements are core to establishing a successful workforce. These findings reinforce the required technical skills highlighted earlier and justify interweaving them into the curriculum and reinforcing them throughout.

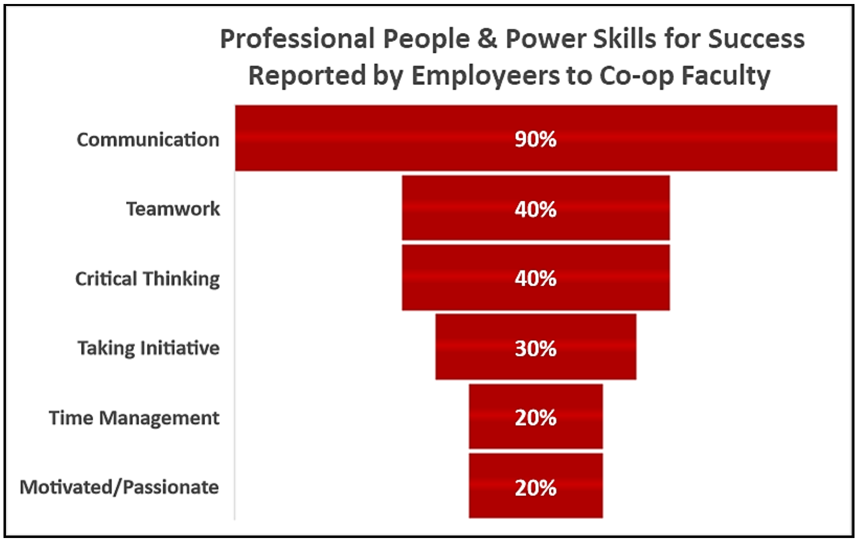

Figure 2. Results of open-ended content analysis of Co-op faculty to the inquiry to outline professional people and power ('soft') skills needed for success.

Students' Survey: Cornerstone and Capstone Perspective

Cornerstone & Capstone: Demographics. Moving next to the student survey, we look at patterns in perception, mindset, and motivation in relation to academic level and work history regarding the foundational engineering design skills essential to solving engineering problems. The demographics of the total number of students surveyed in first-year Cornerstone and senior-year Capstone are N=152; approximately 54% male, 45% female, and 1% self-reported as 'other'. Some students did not respond to all questions in the survey yet still provided valuable responses to key questions, and those responses were evaluated.

The first-year students who participated in this study are part of an overall cohort in which ~63% entered the first-year Cornerstone course in the Fall term, and ~8% are transfer students who may be older and have some industrial experience. The remaining ~29% of first-year students begin their fall semester studying abroad before arriving to join Cornerstone in the Spring term and this cohort is not part of this study.

Cornerstone & Capstone: Work Experience. For the work history information, Students were asked to add up the years and months of work experience they had accrued to date and report that. Responses from students in both cohorts who had 7 years or more of work background were removed to avoid skewing the otherwise representative data. As a follow-up on work profiles, students also were asked to list their co-op time and total count. Using a χ^2 analysis, there was no significant difference in gender mix between the Cornerstone and Capstone populations $F(3,2)=0.43$, $p=0.81$. Thus, there was no need to conduct an Analysis of Covariance on the factor of gender.

However, in Table 1 and Figure 3, we do observe significant differences between the Cornerstone and Capstone populations when considering the average age ($p < 0.001$) and average work time ($p<0.01$) as evidenced by the results of independent *t*-tests. Likewise, the seniors' work experience in terms of the number of distinct jobs and the number of Co-ops were also significantly greater (both at $p<0.001$), as evidenced by both parametric *t*-tests and non-parametric Mann-Whitney U tests. This reaffirms what is expected as representative samples for these academic levels. For instance, we do not expect many mature age/non-traditional/late transfer students in Cornerstone. Traditional first-year Cornerstone students will have limited work experience compared to Capstone students who are more mature in age and have been out on Co-op cycles.

Table 1. Key Population Demographics from the Cornerstone to Capstone (C2C) Populations.

Results: Demographics & Work Profiles *N*=152	**Cornerstone Values**	**Capstone Values**	**Total or Weighted Average**
Fully Completed Surveys	82	30	112
Gender: Male	54.9%	53.3%	54.4%
Gender: Female	43.9%	46.7%	44.6%
Gender: Other	1.2%	0%	~1%
Factors & Tests Conducted	**Values & Statistical Significance in Outcomes**		
Gender: M ◆ F ◆ O Expected, χ^2:	54.4% ◆ 44.6 % ◆ 1%		*NSD, p= 0.81*
Average Age, years: *t-test*:	18.95	22.3	*p<0.001*
Average Work, years*: *t-test*:	1.24	1.81	*p<0.01*
# Distinct Job Exp: avg/mode: *Mann Whitney U test*	1.4 / 0	3.0 / 3	*p<0.001* *p<0.001*
# Co-ops/Industry Work: avg/mode: *Mann Whitney U test*	0 / 0	2.24 / 3	*p<0.001*
**Adjusted for rare outliers of over 7 years to avoid data skew*			

In Table 1 and Figure 3, we observe Cornerstone students have just over 1.2 years of work time with no Co-op experience. Typically, their first Co-op opportunity would occur in their sophomore year. Capstone students have closer to 2 years of work experience, and up to 3 Co-op experiences as shown in Figure 3. As anticipated, we have two distinct populations whose responses are likely to differ because of variations in age, academic training, work experience, and life experience. Finally, however unsurprising these foundational statistics may be, this information will be useful in understanding the differences in how students define engineering, what students believe is needed to conduct effective engineering, and how prepared they feel they are to succeed. The key outcomes related to the differences are described next in the thematic results.

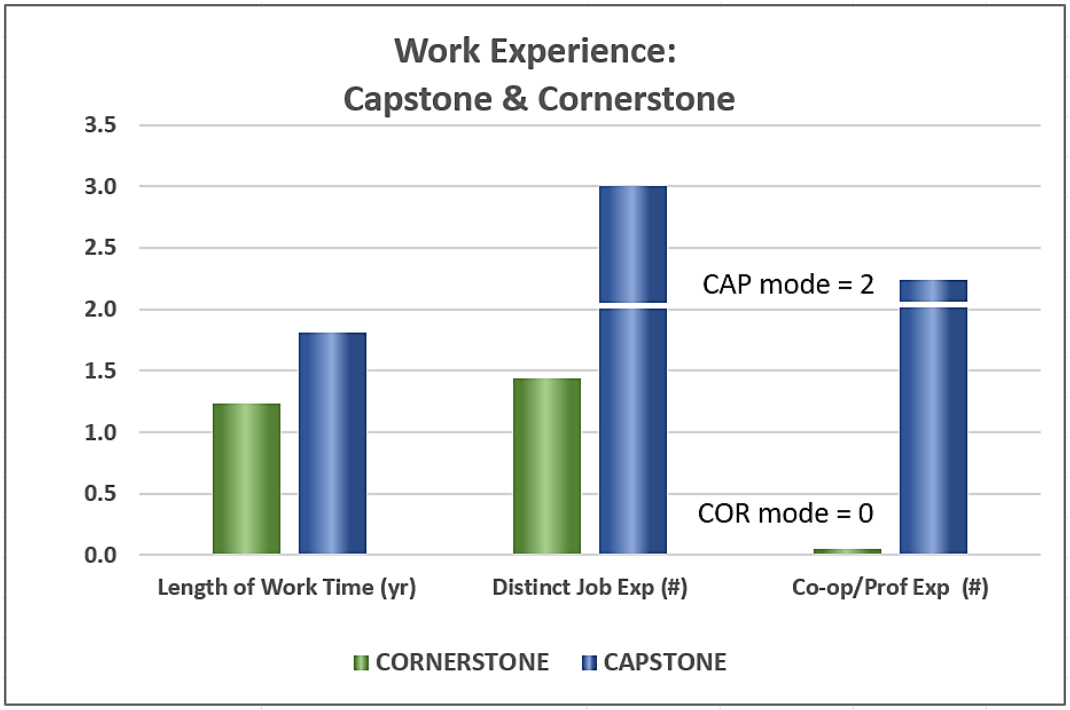

Figure 3: Foundational computations illustrating the differences in work experience between Cornerstone (COR) and Capstone (CAP) populations. All factors are statistically different: Length of Work Time $p<0.02$, Distinct Job Experiences $p<0.001$, and Number of Co-op experiences $p<0.0001$.

Cornerstone & Capstone: Engineering Definition. To build a basis for understanding engineering design perspectives, students in both populations were first prompted to respond to the question, "*Without referencing any sources: How would you define engineering?*". The goal was to capture and identify their vision and impressions of engineering as a discipline at each distinct academic and experience level. This would help detect differences in perspectives and note opportunities in our program(s) to build and fortify a comprehensive and representative overview of engineering across the academic spectrum while fostering opportunities for impressions of engineering to develop over time. The data were analyzed in a similar fashion to that of the Co-op faculty data using rule-guided qualitative text analysis to identify emerging categories, patterns, and themes with measurable relevance for each level [14]. Figure 4 presents the listing of top items included by each cohort. These included:

- problem-solving as a fundamental practice
- application of technical knowledge using scientific principles and rule-based methods
- identifying a focused goal, purpose, or objective
- innovating, creating, ideating, and developing
- designing; using the actual word 'design'
- incorporating systems and/or multiple components

  and finally:
- applying a process, including studying concepts, and involving research

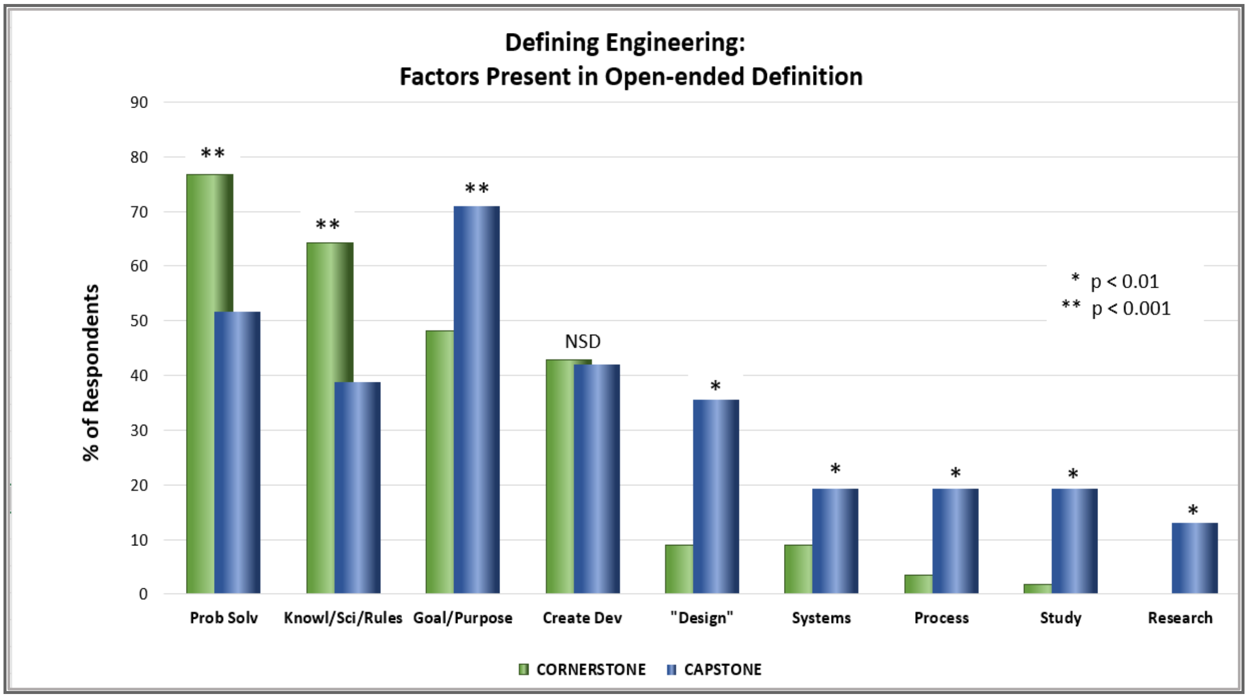

Figure 4: Factors listed by first-year Cornerstone students and final-year Capstone students when asked to define engineering. Significance levels found through binary analyses are shown above the tallest bars.

Using Fisher's Exact Tests [18] to determine whether or not there were significant associations between pairs of categorical variables, the significance of the findings are presented in Figure 4. Testing for the binary presence or absence of a particular factor across the two populations revealed key patterns discussed next, along with recommendations for related curricular modifications.

Analyzing the relative proportions in Figure 4 above, we see that both groups' definitions have *problem-solving* in common, with 77% of the first-year respondents listing it most often and just over half of the seniors at 52%. Over 64% of the Cornerstone group emphasize a *technical and/or scientific knowledge base* as a key component in engineering definition, while the seniors seem to downplay that as essential at 39%. The mode response from the Capstone contingent in defining engineering was *practicing their trade for a purpose, or goal* at 71%; nearly half of the first-year engineers (48%) named this as a top focus. Around 42% of each set of respondents listed being *innovating, creating, and developing solutions* in their engineering definitions.

Interestingly, while over a third of the responding seniors explicitly used '*design'* in their engineering definition, less than 10% of the first-year students included the word '*design'*. Rounding the picture, about 20% of the seniors noted *working in systems, following a process*, and/or defined engineering as "*the study of …*", and 13% even noted *research* as part of engineering. These last four factors were notably low or absent from the first-year definitions.

Our findings indicate that first-year Cornerstone students, in effect, have a split perspective of what engineering is about. Some defined engineering as simply a solution to a problem, exclusive of any mention of a process, while others in Cornerstone do mention it as a path engineers take to create a solution to a problem to help society. In contrast, Capstone students focused more predominantly on the iterative process of problem-solving with a top goal of improvement and a combination of creativity, systems thinking, and research to develop a plan to lead to and meet a key objective. In addition, the seniors mention applying science and technology and the multidisciplinary aspects of engineering.

Narrowing the lens to look only at the listings of "Goals and Purposes" named in the engineering definitions, we see that the Cornerstone and Capstone populations diverge appreciably in their focus. Student responses like *"profession centered around solving problems in technical fields"* and "*using technical skills in math and science to solve problems to benefit society"* were analyzed for specific areas of concentration using the thematic analysis described previously.

In Figure 5, these differences in the cohorts are apparent in the contrasting percentages across four distinct categories:

- improving/optimizing an item or process
- nonspecific or general goals
- helping people/society/world
- generating technical solutions, or
- a combination or more than one:

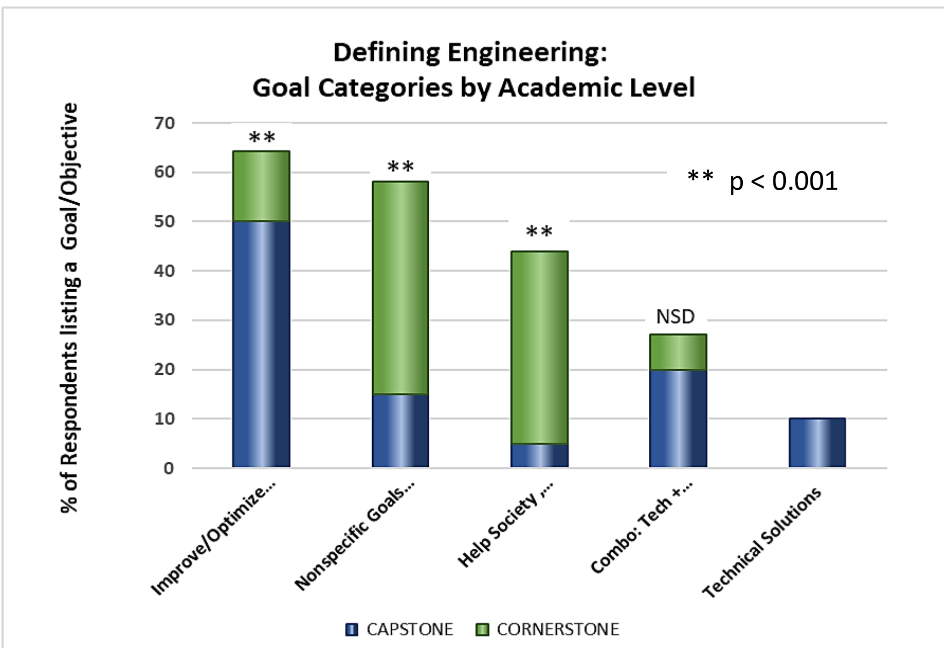

Figure 5: Types of goals listed when defining engineering, by Cornerstone and Capstone students. Significance levels found through binary analyses are shown above the stacked bars.

It is also interesting to note the low incidence of 'design' as a part of the Cornerstone description of what engineering entails. Again, this provides an opportunity to illustrate and emphasize design as an integral part of engineering through the Cornerstone experience.

Some results fit expectations, while others illuminate opportunities to coach and prepare our students more intentionally. We do not expect the first-year and final-year perceptions to be identical. However, these inputs identify opportunities at the beginning of the curriculum, possible gaps in mid-curricular course design, and areas in Capstone that could use intentional focus regarding standing impressions of engineering. As we analyzed the students' open-ended commentary on their understanding of effective engineering design, we also sought to unearth missing elements at Northeastern University compared to the industry requirements or expectations.

Cornerstone & Capstone: Attributes & Abilities for Effective Engineering Design. This inquiry segment focused on students identifying the attributes and abilities needed for effective engineering design. In the survey, we asked students to respond to *"Without referencing any sources: What do you think a person needs, knows, and does to conduct effective engineering design projects? Make a list of words and phrases."* There was no restrictive limit on the number of factors, as each student was free to list as many factors as they can to answer the question. At the start, the number of factors each student listed was computed and evaluated quantitatively and qualitatively. Next, the content was statistically analyzed. Even though the Capstone seniors listed more elements than the first-year Cornerstone students, no significant differences across populations were found in the average number of elements listed (p=0.32) with the following average values: Cornerstone $\bar{x}$=3.18, mode=3 versus Capstone $\bar{x}$ =3.52, mode=4. Figures 6 and 7 outline the response categories for both populations.

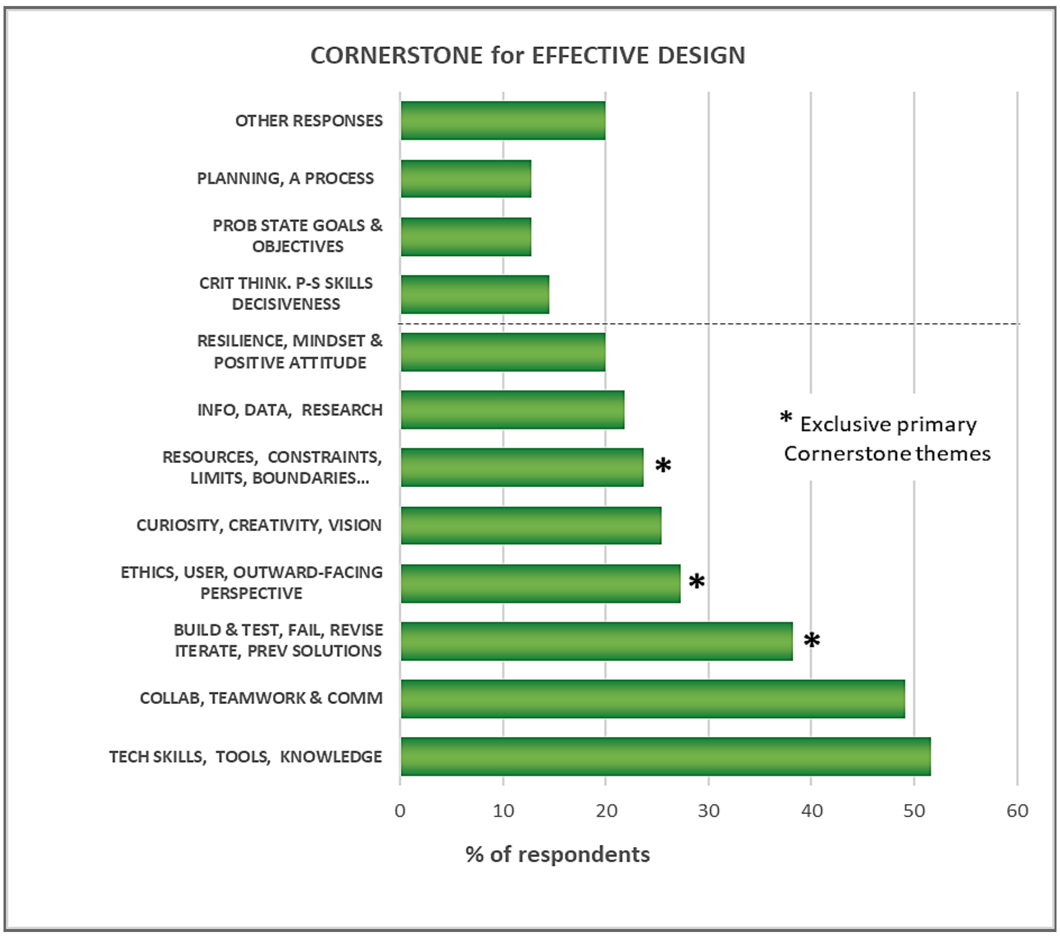

Figure 6: Cornerstone students' responses from thematic content analysis of the question about skills, attributes, and actions for successful engineering design.

Systematic content analysis revealed clear category sets for each population. A thematic prevalence of >20% establishes a primary category. Operationally, eight(8) primary themes emerged for Cornerstone students, as seen in Figure 6; equally, there were eight(8) primary themes in Capstone, as shown in Figure 7. There were some overlaps and key distinctions across the two groups. The factors denoted as *'exclusive'* were named by only one population but effectively were not noted in the counterparts' primary categories as determined by the <20% response occurrence. This cutoff of less than 20% is shown with the dashed horizontal line in both Figures 6 and 7.

Figure 6 above presents the categories for Cornerstone students. We observe that the most highly listed factor was *technical skills knowledge* at 51%, followed by *collaboration, teamwork, and communication* at 49%; then *inclination to test, fail, iterate, revise, and look into previously attempted solutions* at 38% (*exclusive*). More than a quarter of Cornerstone students also listed *a* focus on *understanding the user population*, *practicing inclusive ethical behavior*, and *exhibiting empathy* (*exclusive*) at 27%. Similarly, more than a quarter of the Cornerstone cohort see the value of *being visionary, creative, and innovative*; but have concerns about *identifying limits, boundaries, constraints*, and *guiding methodologies* (*exclusive*) at 24%; then from 20% down to 10% we see the need for *information, data, and background research*; *being resilient, agile, and open-minded with a positive attitude*; *critical thinking and problem-solving skills*; *identifying goals/objectives*; and *planning and gaining clarity on the approach.* Other mentions such as *dedication and passion* and *being willing to ask for help* conclude the rest of the open responses for the Cornerstone cohort.

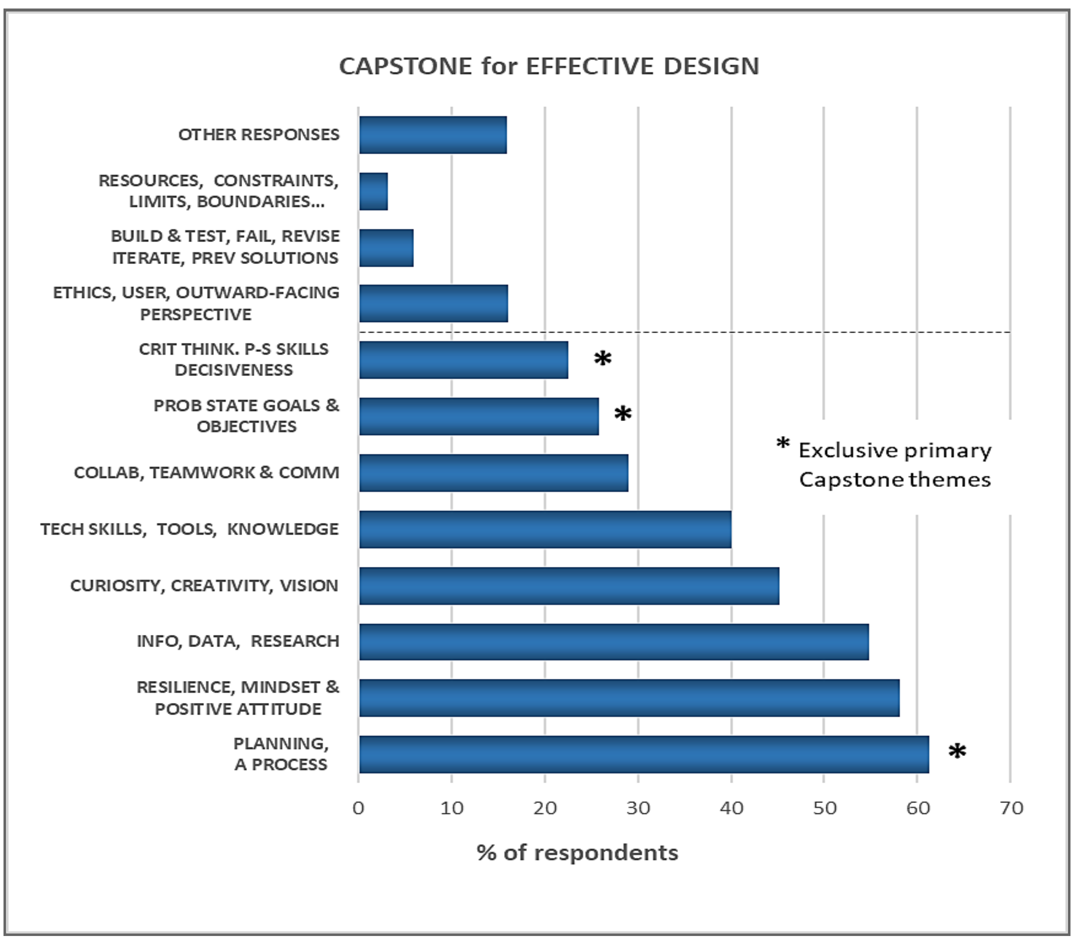

Figure 7: Capstone students' responses from thematic content analysis of the question about skills attributes and actions for successful engineering design.

Likewise, the Capstone seniors responded to the 'effective engineering design question' as shown in Figure 7 above. Some clear patterns emerged. The seniors in Capstone revealed a distinct profile of top requirements and attributes for effective engineering design that focus predominantly on the process and mindset at the top level with little prospect of failing and/or iterating.

Capstone students had *planning, and gaining clarity on an approach* as the most listed at 61% *(exclusive),* followed by *being resilient, agile, having an open mindset and positive attitude* at 58%; *gathering information, data and background research* at 55%; *possessing vision, creativity, curiosity, ideation* at 45%; *having or acquiring technical skills, tools and knowledge* at 40%; *collaborating, teaming, communicating* at 29%; *developing a problem statement, identifying goals and objectives* at 25% *(exclusive)*; and *thinking critically, demonstrating problem-solving skills and decisiveness* at 23% *(exclusive)*. Additional factors at the end of the spectrum under 20% were: *understanding the audience and users, practicing ethically and inclusively, exhibiting empathy; considering resources, constraints, boundaries, and defining methodology*. Four (4) other notable mentions made the list, namely, *creating hypotheses, analyzing risks, taking initiative*, and *being efficient*.

Reflecting on the above results, we observe that the Cornerstone and Capstone populations did have many similarly established categories for this inquiry with the specific distinctions marked by '*exclusive'*. The largest high/low range happened with the Cornerstone students emphasizing failure and iteration, highlighting trial and error as a good practice in the design process, while Capstone preferred to plan and research in advance to avoid failure. This may be explained by noting that in a first-year design course, faculty will certainly emphasize the point that it is okay to fail if you are "failing forward," whereas seniors are conditioned not to fail as this leads to lost time, wasted resources, and unnecessary expense. In addition, Cornerstone first-semester projects are typically more tightly defined and supervised and are not as open-ended. Students tend to not want to go too far afield from the problem statement given and therefore do less planning and background work. First-year students see iteration as a strong pathway to design and this is understandable given their level of experience. While we acknowledge the value of iteration and trial-and-error, we can further emphasize the background research and planning that can preclude avoidable restarts.

Another '*exclusive'* difference is highlighted where Cornerstone students emphasize knowing the client or end user and contributing inclusively to societal good, while Capstone students did not express this as a focus. A part of Cornerstone is dedicated to highlighting the value of sensitive design and ethical reasoning and accounts for the only required element of ethical theory in the COE program. Thus, first-year students are keenly aware and empathetic to their clients' situation. With no required follow-up exposure, we can identify this gap where intermediate technical courses may be missing opportunities to focus on ethics and caring about the end user. Finally, Cornerstone students express concern about boundaries like resources and permissions, possibly because there is a limit on the budget and use of their funds and because their projects are more tightly constrained and supervised than Capstone Projects. Of note is that external clients or department funding typically covers Capstone students' project budgets. Thus, there is a lack of emphasis on costs and expenditures. Nonetheless, the concept of fiscal responsibility should be included in Capstone.

Finally, Capstone students listed planning and process as a top '*exclusive'* and advanced research to limit reliance on trial and error. There is a clear emphasis on developing a clear problem statement that was notably missing for Cornerstone students. A difference in the curriculum may explain part of this as Capstone students spend an entire semester developing their project proposal -carefully laying out the plan that will lead to a successful solution. However, Cornerstone students may be provided with a theme or needs assessment, and the students are directed to revise and develop it further based on research. They then solve the problem over one term. We recommend that enough time be given to developing a proper problem statement and providing some guidance in project management. Specifically, in Cornerstone, we recommend emphasizing planning and research; even though the first-year students may be working on a more directed project instead of an open-ended one.

Cornerstone & Capstone: Relationship between Work Experience & Design Attributes. For individuals in the Cornerstone and Capstone cohorts, Pearson product-moment correlations were computed to identify the strength of the relationship between work experience and the number of attributes listed for effective design. The results are summarized in Table 2 and presented in Figure 8 and Figure 9.

Table 2. Computed strength of the relationship between work experience and the number of factors listed for effective engineering design.

Correlation Coefficients*	**# of Distinct Work Experiences vs # Engineering Design Elements listed**	**Length of Work Time (years) vs # Engineering Design elements listed**
Cornerstone	$R = 0.276$ (weak)	$R = 0.536$ (moderate)
Capstone	$R = 0.635$ (moderate-strong)	$R = 0.768$ (strong)
**Strength of relationship drawn from* [15]		

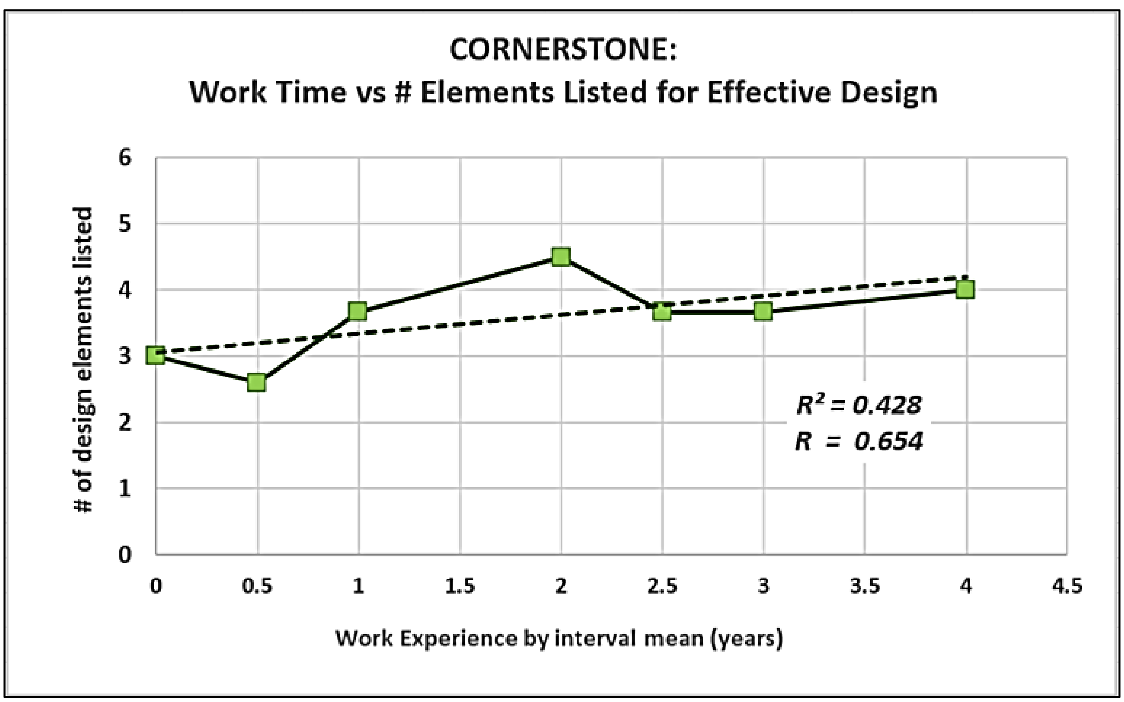

Figure 8: Work time vs. the number of listed elements for effective design for Cornerstone.

In relation to outlining elements for effective design, we can observe from Table 2 and the figures that both populations show a positive correlation between work experience and the number of elements listed by everyone. Specifically, the number of different jobs does not seem to inform Cornerstone students early in their engineering career in terms of defining effective design *R*=0.276, but there is a moderate-strong correlation for the Capstone students *R*=0.635 for the number of distinct jobs.

While the Cornerstone correlation coefficient for length of work is moderate *R*=0.536, there is a compelling correlation for Capstone work time *R*=0.768 and the associated listing of key elements for effective design. The number of attributes listed for Cornerstone students varies from 3 to 4 distinct items listed over the work interval while for Capstone students they vary from 2 to 5 distinct items listed as shown in Figures 8 and 9. This agrees with the previous results of more work experience for Capstone students is associated with a broader understanding of the design process and its requisite components.

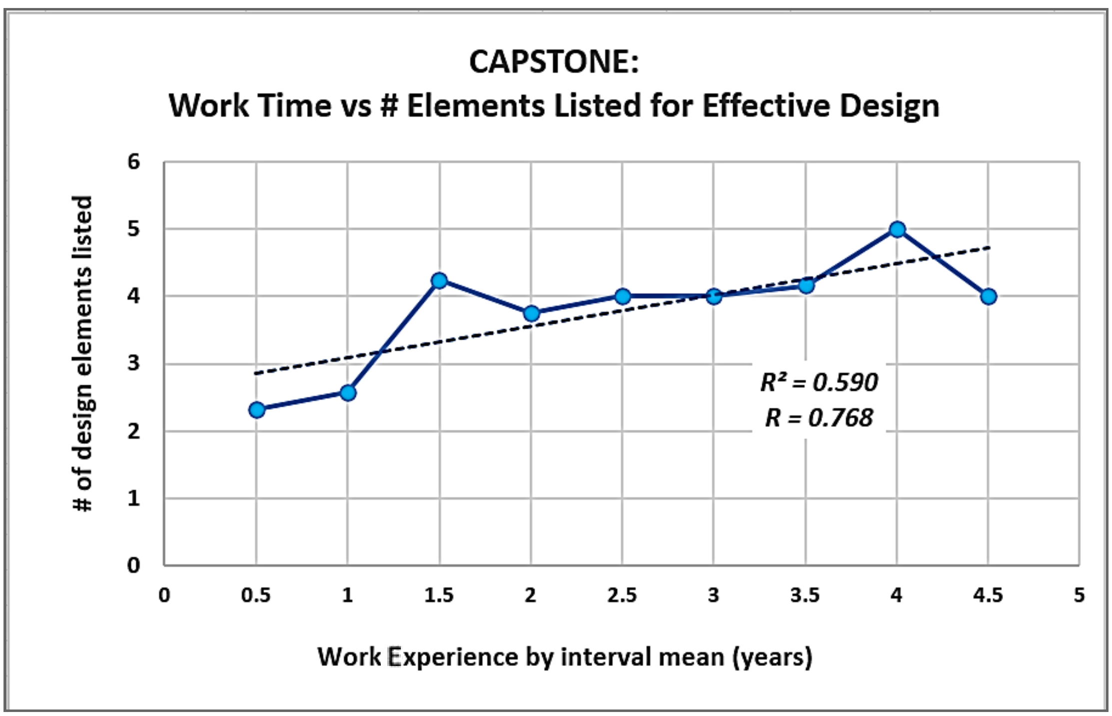

Figure 9: Work time vs. the number of listed elements for effective design for Capstone.

Cornerstone & Capstone: Feeling Ready to Succeed. Focusing on the future, we also asked the students to respond to the following statement: "*At this moment, I feel I have all the attributes I listed above to succeed and attain my full potential as an effective engineering designer.*" The results are shown in Figure 10 where we see distinct profiles for Cornerstone versus Capstone.

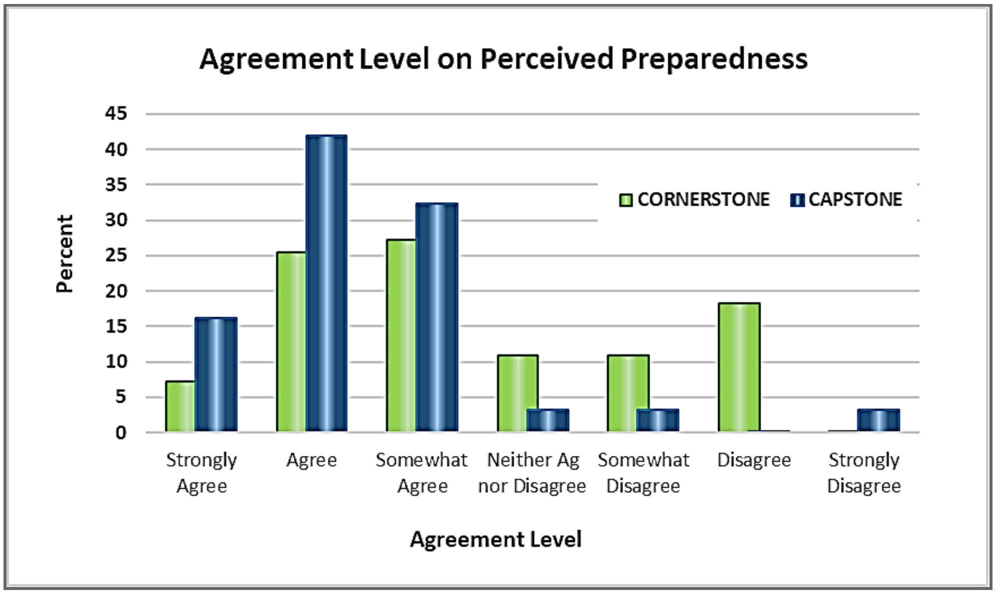

Figure 10: Confidence level on perceived preparedness to be effective design engineers for Cornerstone and Capstone students.

Just under one-third (32%) of first-year Cornerstone students reported that they *"agree to or strongly agree*" when asked whether they already had the required attributes, as shown in Figure 10. Equally, over 30% of Cornerstone students from the same cohort feel they are *not* prepared by choosing *"somewhat disagree to or disagree*" for this statement. This is a common occurrence in a first-year design course as there are students with a wide range of backgrounds in employment and STEM experiences from none to a lot resulting in some with a great deal of confidence while others sitting next to these students with little background feel completely inadequate. These higher confidence values for Cornerstone were initially surprising and they may indicate that the students might have an augmented sense of reality regarding what they think they know or don't know. On the other hand, Capstone students are concentrated almost completely around "*agree to"* with very few in disagreement to the statement.

Assigning ordinal integer values to the Preparedness Likert scale from 1=*Strongly Disagree* up to 7= *Strongly Agree*, the two populations differ in both mode and mean, with the mode being 5=*Somewhat Agree* for Cornerstone and *6=Agree* for Capstone. Likewise, the computed means were Cornerstone 4.51 and Capstone 5.45 on the Likert agreement scale. Through a 2-tailed Mann-Whitney U test, the difference in Perceived Levels of Preparedness differs significantly $p<0.002$, indicating that the seniors feel significantly more prepared to succeed in engineering design than the first-years. The question is, to what can we attribute this difference? We next take another look at work experience.

Work Experience: Feeling Ready to Succeed. While determining the contributory factors to success is challenging due to many intervening life experiences between Cornerstone and Capstone, the relationship between work experience and readiness to practice in the engineering domain may tell part of the story. Given the findings above relating to Perceived Preparedness, the last two items we explore as supporting factors are (1) length of work time in years and (2) number of distinct jobs/work experiences in integers. Figure 11, shows Correlations computed for the paired individual responses to each of the work values in relation to perceived preparedness to "succeed as an effective engineering designer". All correlations were in the moderate range, with the number of work experiences exhibiting a stronger effect than absolute work time. This is likely due to the variety of experiences that multiple work or job scenarios can offer. Interestingly, the effect of work time and distinct jobs each had a stronger effect in first-year students, possibly providing a basis for some of their confidence.

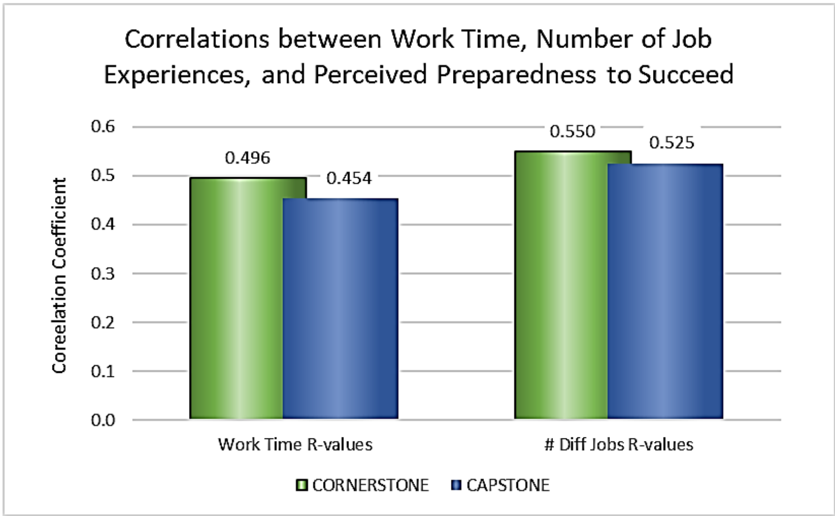

Figure 11. Computed relationships between preparedness to succeed agreement and work experience, namely work time and number of distinct jobs held.

It is apparent from these results as students move through the curriculum, gain competencies, and have practical hands-on learning experiences, they gain confidence in their preparedness to be an effective engineer -in this case, in the area of effective design. These findings make a case for a diversity of experiential work opportunities before and during university life.

Conclusions & Recommendations

In this study, we investigate student perspectives to defining engineering, achieving a successful design, and on self-reported preparedness to practicing in their field of study. Through this research it was possible to identify paradigm shifts across the first-year Cornerstone experience, senior-year Capstone experience, and from first-year to senior year. With the knowledge gained in the study, we outline some missed opportunities to infuse practical and curricular opportunities for overall improved outcomes for students' technical and professional competencies and overall career preparedness.

It is known that students require applicable needs assessment, problem formulation, project planning, goal-setting, research competencies, technical skill development, problem-solving approaches, testing methodologies, productive iteration, and objective decision-making to arrive at viable engineering solutions [16]. These capabilities, combined with qualities related to ethics, teamwork, communication, productive perceptual shifts and perseverance, combine to develop competent, principled engineering professionals [17]. Thus, findings from this research suggest opportunities for further emphasis in the early Cornerstone offering in the areas of planning and project management and the need to conduct research and obtain data and background information as a priority.Specifically, emphasis should be made to include activities that enhance research, needs assessment, problem formulation, and project planning competencies [1] and if possible, provide opportunities for open-ended projects to help facilitate this development at the first-year level.

Likewise, seniors in Capstone can gain some insights from first-year Cornerstone students. When outlining elements for successful engineering design, the latter readily identified the need to understand and empathize with end users and target beneficiaries, including maintaining an ethical compass. Unfortunately, this outward-facing perspective is much lower on the seniors' list. Similarly, the concept of failing, iterating, and retrying is near the top of the first-year list, yet it is virtually absent on the Capstone responses. Thus, this highlights an opportunity to emphasize these characteristics to our seniors as they work on their capstone projects, while conveying the value of research and planning to the first-year students. Here we need to acknowledge the value of productive iteration and a modicum of trial-and-error, while emphasizing the background research and planning that can preclude unnecessary revisions and restarts.

Even though there may be contributory factors of academic, work, and life experience between the first-year Cornerstone students and their senior-level Capstone counterparts, our findings make a sound case for the value of infusing intentional internships, fieldwork opportunities, Co-ops, and professional work opportunities in the engineering pathway. The industry work experiences reinforce the importance of the essential skills graduates must harness as they move through the engineering curriculum and beyond. Students develop their own perceptions about the skills they have developed and those that need to be strengthened. The intentional curricular redesign can catalyze key alignments.

As this is ongoing research, additional questions will be explored going forward with the above goals in mind. This work has set the stage for a deeper dive into the effects on critical thinking, motivational factors in work and class, retention considerations, URM, gender, and/or admission path differences, and how we can do better on the entry, the exit, and in the *"between curriculum"*.

From here we can explore new ways to incorporate key low-prevalence/high-value engineering design elements into the respective course levels and throughout the curriculum with a view to personal and professional development as well as career preparation. This investigative approach provides a valuable tool for other engineering educators and programs seeking curricular continuity and fortification in engineering education. This research design and methodology provided an insightful inquiry method to illuminate what Cornerstone can learn from Capstone, what Capstone can learn from Cornerstone, and what we can all learn from industry to develop well-prepared, innovative, collaborative, and compassionate systems-oriented engineers.

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