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Assessing the Outcomes of a Liberal Engineering Undergraduate Education through Alumni Perspectives on Skill and Mindset Development and Application

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Abstract

As engineering institutions update their offerings to respond to our society's current and future needs, it is imperative to understand how existing programs have prepared students for their post-baccalaureate careers. To ensure preparation, various organizations—from ABET to discipline-specific societies to industry-based organizations—call for engineers to gain specific knowledge, learn skills, and develop mindsets in their four-year programs. While these directives can guide instructors' learning outcomes in their courses and committees' department-level evaluations, understanding their impact at an institutional level can be difficult. Further, these guidelines are often too high-level to provide direct, actionable insights to curriculum developers. Detailed alumni perspectives can provide this critical information. To respond to 21st-century challenges, Olin College of Engineering started as a new, four-year program in the early 2000s that offered three distinct engineering degrees. Since then, by focusing on experiential learning, interdisciplinarity, and sociotechnical integration, Olin College has offered a liberal education for engineers. Two decades later, the present study used a mixed methods approach to evaluate how Olin's undergraduate experience (including the curriculum, extracurriculars, and community) has prepared graduates for their careers. First, the research team conducted 33 semi-structured interviews to build a qualitative understanding of the knowledge, skills, and mindsets alumni frequently use in their current careers and ones developed at Olin. Integrating these findings with those in literature, a list of 45 key skills and mindsets was developed. These items were included in the study's second stage: a survey sent to Olin College alumni who had graduated in 2009, 2014, 2019, and 2024. Survey items quantitatively measured alumni' career satisfaction, the degree to which they use the 45 items in their current careers, the degree to which they developed the 45 items during their undergraduate experience, and their perceived development between technical and enduring skills. Participants' (N = 62; 19.0% of recruited alumni) career paths followed both technical and non-technical paths. 60.% of respondents claimed to be satisfied with their careers while also feeling that they were stronger in their enduring skills than their technical skills upon graduating from Olin College. Of the 45 studied items, alumni reported that their most frequently used items were, on average, teamwork, problem solving, oral communication, and understanding others' thoughts and ideas. Technical skills were, on average, the least frequently used items in alumni' current careers when compared to interpersonal skills, mindsets, and high-level thinking items. There existed a positive correlation ($r = 0.55$) between how frequently alumni claim to use the 45 items and how much they developed them at Olin College. This result

suggests that the school's program, which provided a sociotechnical education, prepared graduates well for their careers. This work adds to the collection of compelling evidence that justifies the importance of developing mindsets, interpersonal skills, and high-level thinking skills, in addition to technical skills. Further, the methods described in this work outline an approach that other programs could use to assess their own programs by soliciting alumni perspectives.

1 Introduction

Undergraduate engineering programs routinely strive prepare students for their post-baccalaureate careers, whether they be technical or non-technical. Today, the challenge of doing so is heightened by rapid technological development[1,2] and the need for technology to be better contextualized in social, political, environmental, and economic systems[3]. To add complexity, the value of higher education is being questioned at an unprecedented rate[4,5,6,7]. To respond, programs nationwide are adapting. For example, many have introduced new degree offerings, updated learning objectives or mission statements, or are currently planning to do so. Curriculum developers recognize that a range of items—knowledge, skills, abilities, practices, behaviors, and mindsets—are all important for successful and satisfying careers. Curricula shift to emphasize the relevant items and de-emphasize outdated ones. Now more than ever, both technical and non-technical abilities are recognized as important in an engineering education[8].

Before undergraduate programs introduce drastic changes to address today's challenges, they should assess how their current offerings prepare students for their careers. Equipped with such information, programs could better identify their strengths and weaknesses in order to develop data-informed plans to redesign their approaches. Integrating alumni perspectives into curriculum development is a promising way to conduct such an assessment[9,10,11]. Alumni are intimately familiar with their career paths, have experienced feeling under- or well-prepared for their jobs, and know what is expected of them in their current work. However, using alumni-provided information in curriculum development can be challenging. On one hand, program-level goals and objectives are often well-stated but high-level. Alumni responses to these statements do not provide specific, actionable feedback to educators. On the other hand, alumni take diverse career paths, so the specific items (e.g., skills, abilities, or mindsets) they use are equally diverse. One compelling benefit of a liberal engineering education is that it prepares students for diverse career paths. When assessing a program, finding a balance of specific yet diverse, actionable data is critical to inform effective change in undergraduate programs.

This work details how Olin College of Engineering, a four-year engineering college in the United States, conducted an alumni assessment that aimed to (1) be specific enough to provide actionable feedback to faculty and curriculum developers and (2) encompass the skills and mindsets that graduates use in a diverse set of career paths. In 2002, Olin College introduced a new engineering program to address engineering education challenges identified at the beginning of the 21st century[12]. The College emphasized elements of a liberal education, such as a greater emphasis on enduring skills (e.g., teamwork, communication), increased offerings of experiential and project-based learning, and stronger interdisciplinarity and sociotechnical integration in the curriculum. At the time the present work began, graduates of this program were well into their careers, so an assessment of how well this program had prepared graduates was timely.

The key objectives of this work are to:

1. Develop a list of specific technical and non-technical items that engineering alumni of Olin College have found important in their diverse post-baccalaureate careers, by interviewing alumni and other key constituents,
2. Assess Olin College's sociotechnical undergraduate engineering program by using the list of technical and non-technical items to identify areas of strength and potential improvement, via a survey sent to four alumni classes, and
3. Discuss how the methods used to assess Olin College's program and the resulting findings could inform other engineering programs as they implement institutional changes.

Beyond impacting change efforts at Olin College alone, the findings of this assessment can inform the efforts of the numerous engineering programs with similar goals. For institutions with alternate missions, the methods described here can be implemented to assess their program's unique effectiveness in preparing students for their careers. As the value of higher education institutions is questioned and as graduates face continually shifting workplaces, engineering programs will respond and adapt. This work can support and inform institutions as they undertake that process.

2 Related Work

2.1 Career paths of engineers and the skills they use in these paths

The career paths of engineering graduates in the United States are diverse. The NSF's 2015 National Survey of College Graduates (NSCG) reported that 1.72 million college-educated people worked in engineering occupations[13], breaking the field into 19 disciplines. To contribute as an engineer in any discipline, one must have knowledge, practice skills, or follow processes that are specific to that area. Further, the majority of engineering graduates move to adjacent or even non-adjacent fields. The NSCG showed that in 2013, 65% of all degreed engineers were working in occupations not considered engineering[13]. This statistic shifts as people move through their careers, with recent graduates more frequently in engineering roles. The 2013 NSCG, found that 54% of recent engineering graduates were employed in engineering occupations[13] and that 25.5% would leave their engineering occupation within five years. They reported a similar trend for mid-career engineering graduates, with 25% leaving engineering occupations within five years.

What engineering students develop in their undergraduate programs should prepare them for the diverse career paths they will later face. To achieve this, the emphasis on non-technical development is just as important as the emphasis on the technical. For example, practicing engineers spend a significant portion their time engaging in tasks that are not engineering-specific. Robinson tracked 78 design engineers over twenty working days and found that, on average, they spent 37.08% of their time conducting non-technical work[14]. In another study, Lynn and Salzman found recent engineering graduates' largest skill deficit was their ability to span engineering disciplines, not their technical depth[15]. The ABET Student Outcomes encompass both engineering-specific items (e.g., Student Outcome #6: an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions) and engineering-agnostic items (e.g., Student Outcome #7: an ability to acquire and apply new knowledge as needed, using appropriate learning strategies)[16]. Countless others have called for engineering programs to better develop students' enduring skills,[†] with strong emphases on communication and teamwork. These items—the ability to span disciplinary boundaries, the ability to learn and apply new knowledge, communication skills, teamwork skills, and others—are hallmarks of a liberal education. They are critical for engineering graduates, whether they stay in engineering occupations or not.

2.2 How institutions capture and use alumni perspectives

Higher education institutions capture alumni perspectives in several ways. Basic statistics, like donation trends, can provide a sense of alumni sentiment. However, their limited perspective means they should not solely influence specific curricular decisions. On the other hand, individual educators within an institution may hear detailed stories from alumni they taught. These conversations may influence those individuals' work, but are limited in that alumni stories are not typically shared broadly across institutions. Surveys lie in the middle of these two extremes. Surveys capture many perspectives and can include questions that are tailored to curriculum redevelopment. To this end, the present work implements a survey informed by stories of Olin College alumni and surveys conducted at other institutions.

Alumni surveys are used throughout higher education. Yet, using them to assess how well an institution has prepared graduates for their careers is challenging for several reasons. First, many alumni surveys measure graduates' satisfaction with the program and current career success. For example, MIT's 2021 Undergraduate Alumni Survey asks recent graduates about graduate school enrollment, employment status, occupation type, personal well-being, involvement in the community, financial status, and connection to the school[18]. These metrics do not directly indicate the effectiveness of learning experiences so should not direct curricular change.

Second, when alumni surveys do assess learning-specific metrics, their measures are often too high-level to direct specific change efforts. For example, MIT's Undergraduate Alumni Survey, mentioned above, includes a limited number of curriculum-related questions: *"How would you change the emphasis MIT places on these aspects of undergraduate education and college life?"* (answered on 5-point Likert scales for eight topics, such as 'Developing skills valuable in the workspace') and *"Based on what you know now, how well do you think your undergraduate experience at MIT prepared you to..."* (answered on a 5-point Likert scale for 11 specific items, such as 'work effectively as a member of a team')[18]. In a second example, the Gallup-Purdue Index measures six items that are linked to graduates having fulfilling lives after graduation. One of the six items is 'While attending [College name], I worked on a project that took a semester or more to complete'[19]. In a final example, Hofstra University implements an alumni survey concerning graduates' development of ABET criteria (e.g., 'knowledge of contemporary issues')[10,20]. While all relevant, the items included on these example surveys and others are broad, program-level metrics. Individual curriculum developers may find it difficult to address

[†]We use the term "enduring" skills, which are also called professional skills, power skills, non-technical skills, soft skills, and more. There are important reasons why "soft" is an inadequate qualifier in engineering education[17].

shortcomings in their own domains.

One particular alumni study that appeared to address the limitations found in others assessed MIT's Mechanical Engineering Department in 2004, and again in 2015 [21,22]. The 2004 study was sent to alumni who had graduated 8–12 years prior and evaluated 25 specific skill items in four areas: technical knowledge and reasoning, personal and professional skills and attributes, interpersonal skills, and engineering skills. For each of the 25 items, participants were asked three questions:

1. *"For people in your line of work and at the same stage as you are in your career..., how competent are they expected to be?"*, answered on a 6-point Likert scale
2. *"In your present position, how frequently do you employ the knowledge and skills from each of these areas?"*, answered on a 6-point Likert scale
3. *"Where did you gain the most understanding about each topic?"*, with options: 'Undergraduate Program at MIT,' 'Graduate School,' 'Job,' 'Somewhere Else,' or 'Did Not Learn'

For both Questions 1 and 2, the items with the highest average ratings were: personal skills and attributes, independent thinking, teamwork, communications, and professional skills and attributes. Interestingly, these items were among the lowest reported items reported as gained in the undergraduate program in Question 3. The items most reported to be gained in the undergraduate program were the 11 technical knowledge and reasoning items, along with 'engineering reasoning & problem solving' and 'experimentation & knowledge discovery.' This example study, which assessed MIT's Mechanical Engineering undergraduate program, highlights a notable disconnect between what students develop in a traditional engineering program and what graduates use in their careers. The 2015 study followed similar methods and showed progress towards aligning these two but not perfect alignment. Along with others, these examples highlight the need for liberal education approaches to be integrated into engineering programs.

2.3 Olin College's approach to a liberal engineering education

This subsection provides a summary of Olin College's context and how it has provided a liberal engineering education. Olin is a residential undergraduate college in the northeast of the U.S. with fewer than 400 students. In 2002, it opened as a new, four-year engineering college with three degree programs: Mechanical Engineering, Electrical and Computer Engineering, and Engineering [23]. These programs are currently ABET-accredited.

Olin College's curriculum has evolved over the past two decades, and elements of a liberal arts education have always been present. These elements—namely flexible degree options, experiential and project-based learning, contextualized technical work, and extensive collaboration—make it unique. First, flexible degree requirements allow students to explore areas that align with their personal interests. For example, the Engineering degree program asks students to follow a common concentration path (e.g., Computing or Sustainability) or design their own (e.g., Biomechanics Design or Social Engineering) [24].

Second, a majority of both required and elective classes implement project-based learning, so students are exposed to real-world scenarios from their first day on campus. Many of these projects ask students to consider more than just the technical aspects of their work. By requiring students to contextualize their work through technical, social, environmental, historical, and political lenses, Olin students experience a high degree of interdisciplinary thinking and sociotechnical integration. For example, the curriculum houses a design stream, requiring students to take an engineering design process course in their first semester[25,26], an integrated and systems engineering design course in their third semester[27,28], a human-centered design course in the fourth[29], and a design depth elective (typically third or fourth year)[12]. As design courses, these courses naturally engage students in multiple disciplines.

Finally, the vast majority of course projects throughout Olin's curriculum are executed collaboratively. This approach aims to develop students' teamwork, communication, project management, and other enduring skills that may not be developed as rigorously in traditional engineering programs. Early parts of the curriculum were shaped in response to challenges outlined in Section 1 and studies like the MIT Mechanical Engineering study introduced in Section 2.2[21]. It should also be noted that Olin College's Admissions emphasized achieving gender parity in the incoming classes, and this goal was met[30].

Despite these approaches, Olin College has not conducted a formal study to assess how they have prepared graduates for their careers. Instead, many alumni perspectives have been gathered via personal connections. Annually, Olin College surveys alumni who graduated two, five, and 10 years ago on high-level topics: life experience, satisfaction with Olin College, career satisfaction, and employment status[31]. This survey includes curriculum-related questions (*"What is one thing in the curriculum that should be changed or strengthened?"* and *"What is one thing in the curriculum that is great the way that it is?"*). As noted in Section 2.2, these high-level assessments can be valuable tools to certain individuals within an institution but lack the depth to provide actionable feedback to curriculum developers. This work aims to address such a gap.

3 Methods

A two-part, mixed-methods approach was used to capture the benefits of both qualitative and quantitative research. First, in-depth interviews were used to understand the important skills and mindsets that alumni developed at Olin College and/or ones used in their current careers. The results from this work were applied to the second stage: a survey tool used to elicit responses from a larger number of graduates. All study protocols were approved by the institution's IRB.

3.1 Interviews to build a qualitative understanding

Interviews were chosen as a data collection tool for Research Objective 1 due to their qualitative nature as well as their behavioral nature, in which we would be able to verify important skills based on our interviewees' words, insights, and emotional output. We conducted a total of 33 30- to 60-minute interviews with alumni, faculty, staff, employers of Olin graduates, and current students about their experience at or with Olin College (which we will call the Olin Experience, and encompasses courses, extracurricular activities, student support services, and other facets of the college experience that participants note). These diverse perspectives provided context beyond what alumni alone could provide. To ensure many perspectives were captured, we recruited participants of various genders and racial backgrounds, alumni from a range of class years, and alumni who followed both traditional and non-traditional engineering career paths. Interviews were held in person or on Zoom.

A semi-structured interview protocol was designed to elicit a participant-driven narrative on what the Olin Experience is/was to them, what skills and mindsets are/were developed at Olin, and what skills and mindsets are/were *not* developed at Olin. Depending on a participant's role within the institution, the protocol varied slightly. Alumni were asked to reflect on their Olin experience in terms of how it had or had not prepared them for their careers. Current students were asked to provide a prospective outlook on how they believe Olin is preparing them for their futures. Faculty and staff (current and former) were asked what skills and mindsets they purposefully develop(ed) within their programs. Finally, employers were asked what values they observed in Olin alumni relative to their peers. Appendix A.1 documents the questions asked to each constituent group. These questions ensured a generalization among interviews, but the semi-structured nature of the interviews meant that participants were asked additional followup questions to gather further details.

Transcripts of each interview were inductively coded to create an exhaustive list of all skills and mindsets mentioned during the interviews. These items describe what students developed at Olin College and/or are used by Olin alumni in their post-baccalaureate careers. The items included ones developed in courses as well as in other parts of the Olin Experience, such as engineering- and humanities/social-based extracurriculars and the close-knit community. To create a list concise enough to include on a survey, items on the exhaustive list were sorted, combined, and/or removed using the understanding built through the interviews and literature review. Once a concise list was created, it was was integrated into a survey tool. For analysis, the items were further organized into subgroups described below.

3.2 Survey tool to elicit quantitative responses from alumni

To achieve Research Objective 2, a survey tool was chosen because surveys can reach large audiences and provide quantifiable insights, compared to interviews. Using the compiled list of items found from the interviews, we designed a survey tool rooted in the methods of Wolfe's 2004 study of the MIT Mechanical Engineering Department[21]. The tool collected data on participants' background, experiences at Olin College, and experiences after graduating:

- Their educational background (graduation year and degree program), post-baccalaureate career path, and current sector
- Their satisfaction with their current career (5-point Likert scale)
- Their rating of the *frequency* of item use in current work for each of the items on the concise list (same 6-point Likert scale as used in Wolfe's MIT Mechanical Engineering study[21])
- Their rating of the *frequency* they developed each item on the concise list in their undergraduate program at Olin (4-point Likert scale)
- Their rating of their perceived relative strength between enduring and technical skills upon

graduating from Olin College (5-point Likert scale)

- Demographic data (race, gender, first-generation college status, US Citizen/international student status)

A full preview of the tool is available online at `https://olin.qualtrics.com/jfe/form/SV_4Pjk12lVqvw2YTA`.

While the survey was inspired by one previously used by Wolfe, some key changes were made. First, the list of items was tailored specifically to Olin's program, given qualitative findings from the interviews. Second, the tool asked alumni about career satisfaction to understand how content they were beyond their time at Olin College. Third, the tool asked alumni for their perceived balance between their enduring skills and technical skill development upon graduation. Finally, compared to the MIT Mechanical Engineering survey, we removed a question asking participants to rate the expected proficiency level of people in their line of work and career stage (5-point Likert scale). We chose to remove this question to decrease the length of the survey, and because it would be more difficult for our participants to accurately assess compared to the frequency of use question we included.

Via institution-maintained email lists, the team recruited participants from four graduating classes: those who had graduated six months, five years, 10 years, and 15 years prior. This group of participants would capture insights from varying degrees of career progression and could elucidate trends over time. The survey was open from October 16th, 2024 to December 3rd, 2024. Recruitment emails followed best practices for engaging engineering alumni[32].

To address Research Objective 2, we analyzed the results through the following lenses:

1. *How did the items used frequently correlate with the items developed at Olin?* To understand the efficacy of the program, we specifically looked for skills that were not strongly correlated (i.e., largely developed at Olin college but not used as much in current work, or vice versa). These might indicate a deficit in the program. Strongly correlated items likely indicate a strength of the program.

2. *What is the relationship between career satisfaction and perceived relative strength between technical and enduring skills?* To see if Olin's idea of the enduring skills being important in career development, we looked for a correlation between alumni's reported strength in enduring skills and their career satisfaction.

4 Results

4.1 Qualitative results from the interviews

A diverse set of interviewees who gave their perspectives on Olin's program (Table 1). The coding of the 35 interview transcripts led to an initial, comprehensive list of 81 skills and mindsets (Appendix A.2). Table A1 notes how frequently each code was mentioned across the 35 interviews and how it appeared in the final set of items included in the survey, if applicable.

After sorting, combining, and prioritizing these 81 items, a concise list of 45 items was created (Table 2). These 45 items were later included in the quantitative survey, so participants could

Table 1: Demographic breakdown of the 35 interviewees

Group	Number Interviewed	Gender
Faculty and Staff	13	5 M, 6 F, 2 O
Current Students	5	0 M, 4 F, 1 O
Alumni	14	8 M, 4 F, 2 O
Employers	3	1 M, 2 F, 0 O

answer questions about how these specific items were used in their current careers and how they perceived to have developed them at Olin College. For analysis purposes (not for the survey design), these 45 items were grouped into four subgroups: High-Level Thinking, Technical Skills, Interpersonal Skills, and Mindsets.

Table 2: The final list of 45 skills used in the survey presented and their subgroup.

High-level thinking	Technical skills	Interpersonal skills	Mindsets
HL1: Breaking large problems into manageable ones HL2: Problem solving HL3: Design processes HL4: Designing for a specific group of people HL5: Teaching yourself new content HL6: Interdisciplinary thinking HL7: Entrepreneurial thinking HL8: Ethics HL9: Creativity HL10: Your professional Identity HL11: Personal and professional reflection	T1: Engineering systems T2: Energy and power T3: Circuits and signals T4: Measurement and control T5: Material properties T6: First-order analysis and estimation T7: Data analysis T8: Computational analysis (e.g., FEA, Topology, CFD) T9: Coding fundamentals T10: Using visual design tools (e.g., CAD, circuit diagrams) T11: Fabrication and machining skills T12: Underlying math T13: Underlying science	I1: Teamwork I2: Leadership I3: Project management I4: Relationship building I5: Networking strategies I6: Ability to influence the direction of your team I7: Written communication I8: Oral communication (to coworkers, clients/customers, supervisors, etc.) I9: Presentation skills (to an audience) I10: Storytelling I11: Understanding others' thoughts and ideas	M1: Desire for your work to have an impact M2: Comfort with and learning from failure M3: Comfort in ambiguous/uncertain contexts M4: Comfort with working alone M5: Comfort in high-pressure scenarios M6: Passion for work and projects M7: Confidence in your decisions and work M8: Recognizing that your knowledge about a problem is incomplete M9: Healthy skepticism M10: Harmony between work life and personal life

Further, in defining what aspects of Olin College create the College experience, the team found that it could be explored in four aspects: courses, engineering extracurriculars (e.g., Formula SAE, student-run technical research labs), humanities/social-based extracurriculars (e.g., theatre, cultural groups), and the community. Of all aspects of Olin College, the "community" was the most-mentioned across all interviews.

4.2 Quantitative results from the survey

Sixty-two participants responded to the survey, providing an average response rate of 19.0% (Table 3). The total class size of Olin College has increased since the early 2000s, which is reflected in the participant numbers from cohort-to-cohort. The 62 represented a number of different backgrounds and experiences with respect to gender (39% M, 54% F, 7% O), race (58% White, 15% Asian, 15% Mixed, 5% Hispanic, 2% Jewish, 5% Undisclosed), first generation status (85% Non-First Generation Students, 12% First Generation Students, 3% Undisclosed), and the international student status (88% US, 10% International, 2% Undisclosed).

Table 3: Response rates according to each class and the total.

Time since graduation (years)	**n=**	**Rate**
15	13	21.0%
10	14	16.7%
5	13	16.7%
0.5	22	21.6%
Total	**62**	**19.0%**

Figure 1 shows the correlation between how frequently alumni claim to use each item in their current careers and how much they reported developing it while enrolled at Olin. Each point represents one of the 45 items, with the point positions determined by the average response of all survey respondents. Table 4 presents the Pearson correlation for all items and for each subgroup. It is notable that there is an overall positive trend ($r = 0.55$), showing a correlation between development and usage. Figure 2 highlights the specific items within each of the four subgroups.

Table 4: Pearson correlation coefficients for all items and for each subgroup.

Item subgroup	$r =$
Overall	0.55
High-level thinking	0.56
Technical skills	0.72
Interpersonal skills	0.67
Mindsets	0.12

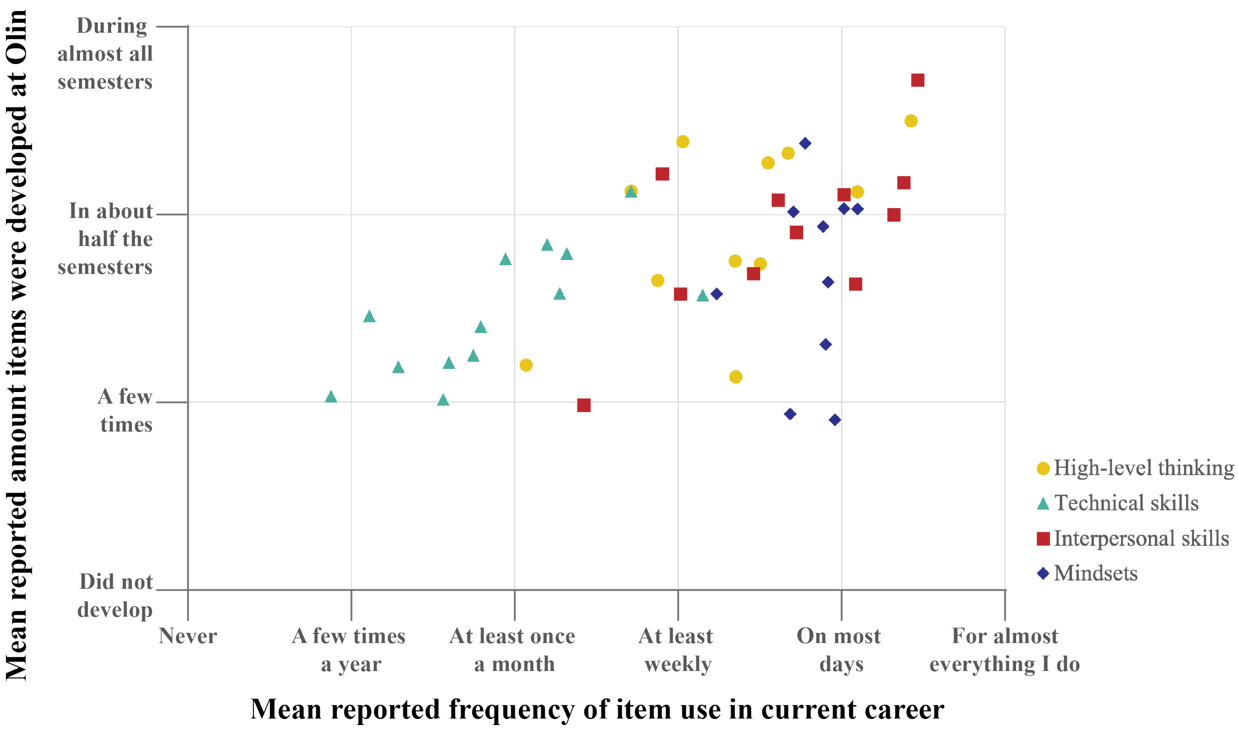
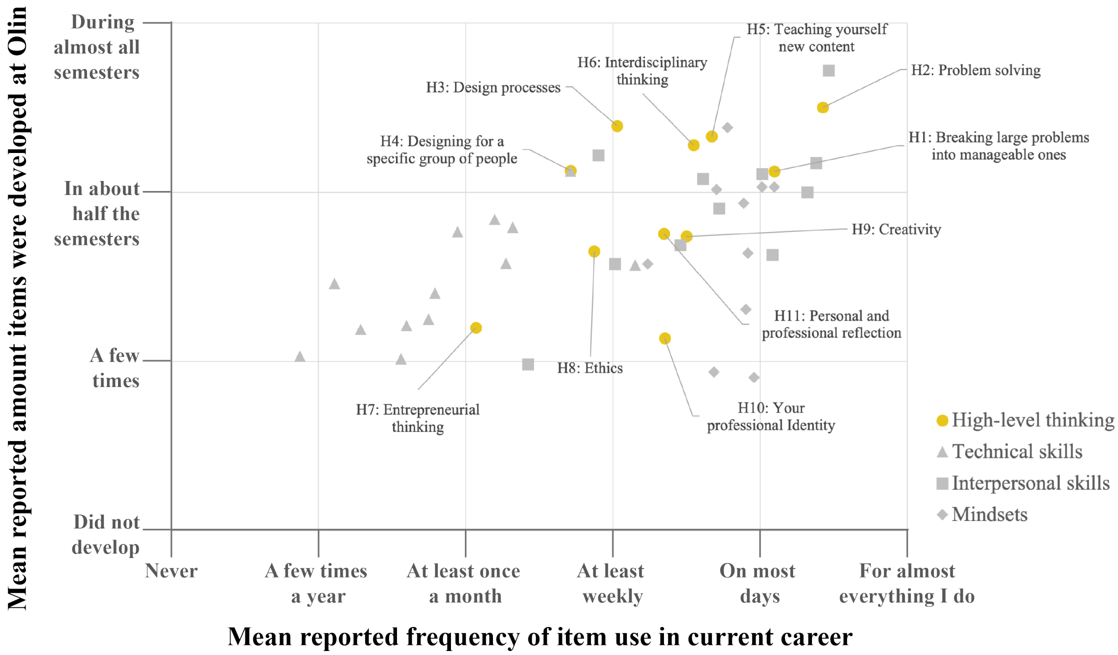
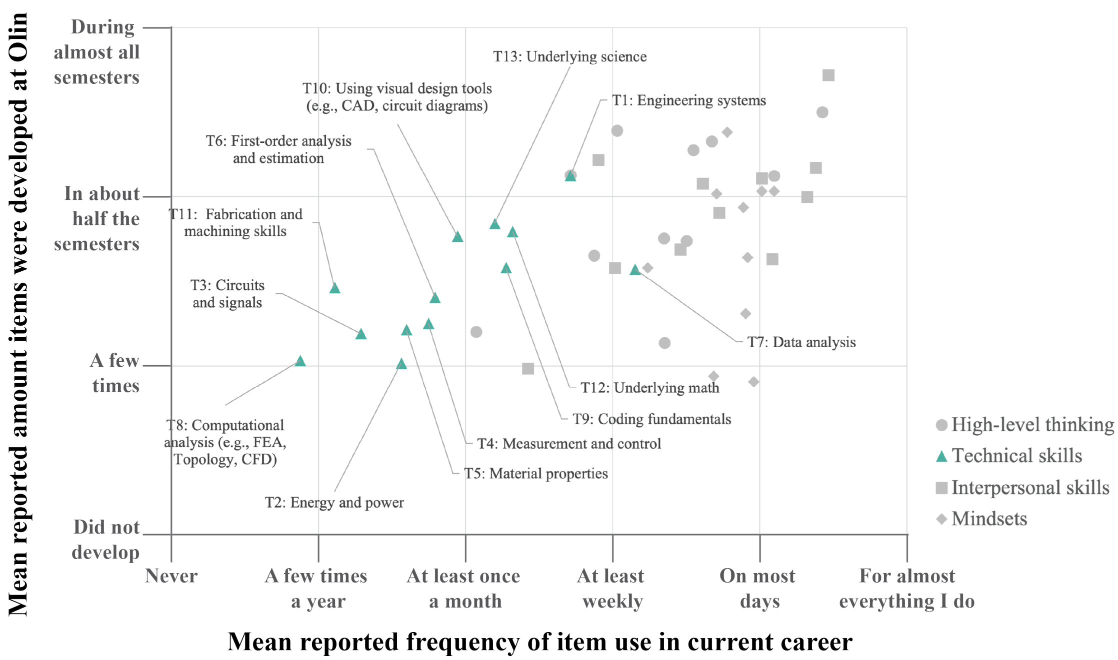


Figure 1: Mean average of the 45 items' frequency of use in alumni' current careers compared to how much they developed the items in their undergraduate program at Olin College. The overall positive correlation ($r = 0.55$) suggests that Olin's program prepared graduates well for the items they would frequently use in their careers.

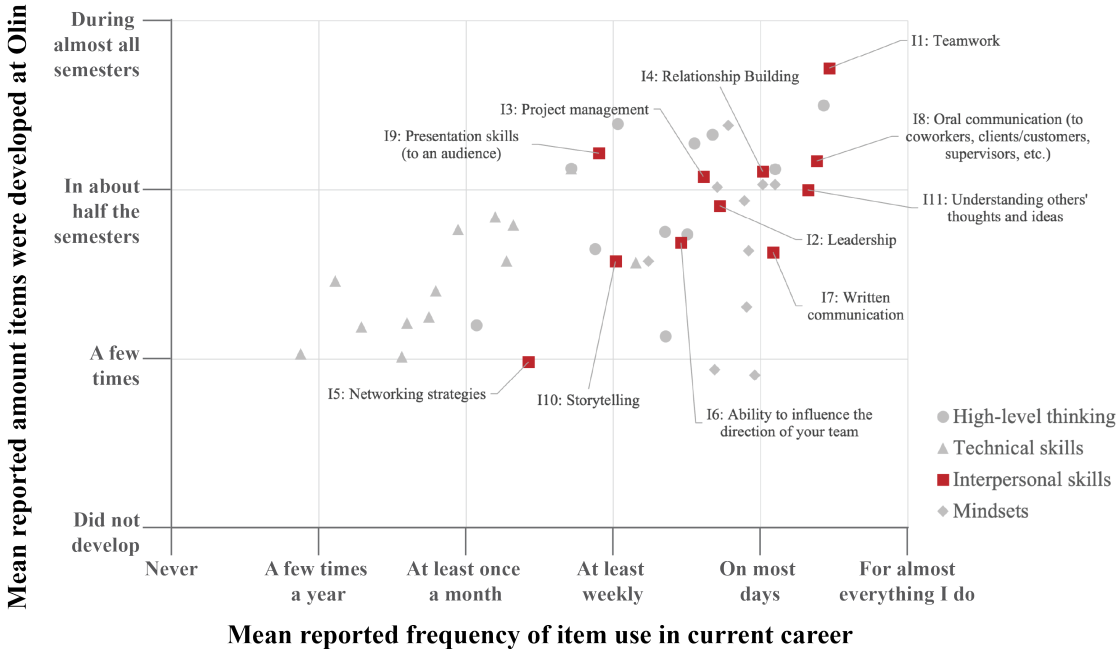


(a) High-level thinking items

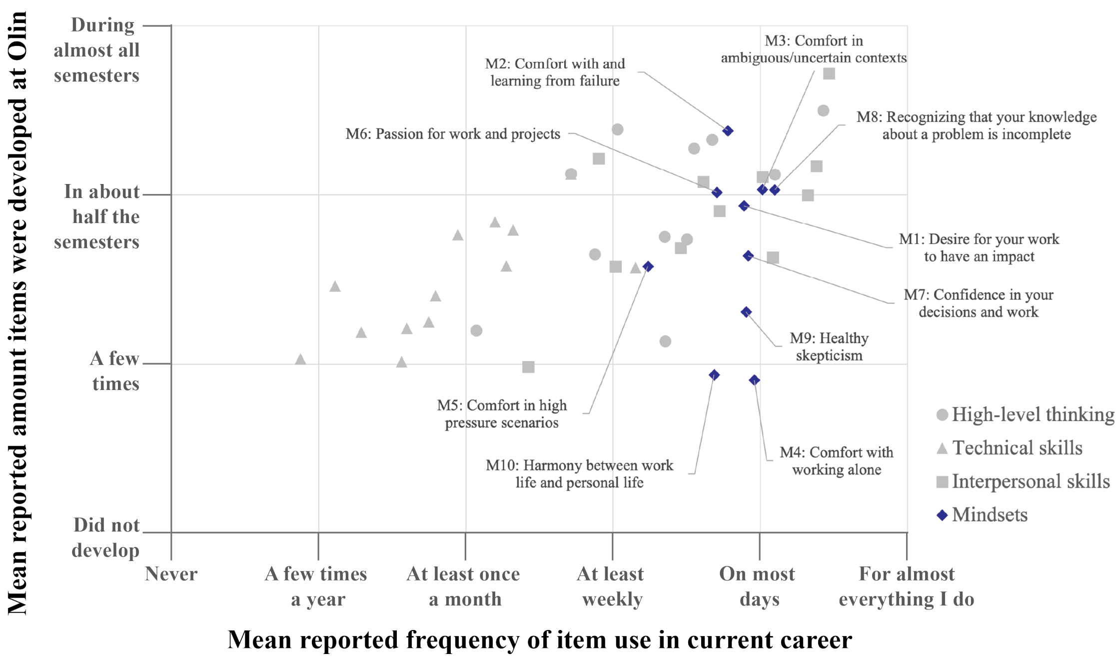


(b) Technical skill items

Figure 2: Figure 1 broken out to show the four subgroups and individual items. Continued on next page.



(c) Interpersonal skill items



(d) Mindset items

Figure 2: Figure 2 continued. Items that are highly used in current careers (e.g., ‘I7: Written communication’ and ‘M4: Comfort with working alone’) and not developed much at Olin College are ones that could be evaluated for strengthening in the curriculum.

There are several takeaways to note from Figure 2. First, as shown in Figure 2a, of all High-Level Thinking items at Olin College, ‘H10: Your professional identity’ was developed the least yet was reported as being used quite frequently in current work. In Figure 2b, the Technical Skills were the lowest recorded subgroup in terms of development at Olin and current use. In Figure 2c, while ‘I1: Teamwork’ and ‘I8: Oral communication’ were two of the strongest data points of all items, ‘I7: Written communication’ was developed much less at Olin. On a similar note, alumni reported developing ‘M4: Comfort with working alone,’ ‘M10: Harmony between work and life,’ and ‘M9: Healthy skepticism’ very little at Olin College, as seen in Figure 2d. However, these items are currently used as frequently as other mindsets. The mindset subgroup has a notably weak correlation ($r = 0.12$) relative to other subgroups. Items that are used frequently in current careers but not developed at Olin are ones that could be considered as opportunities to strengthen in the current curriculum. Overall, it is important to note that no items clearly fall in the top left area of any plot. Items in this space could be ones developed too much in the program relative to how much they are used in later careers, implying that Olin’s program does not focus on developing items that are not used in careers.

Table 5 shows a matrix of respondents’ answers to two questions: (1) their perceived relative strength between enduring and technical skills and (2) their reported career satisfaction ratings. There is an observable correlation between career satisfaction and strength in enduring skills, with 60.% being satisfied in their careers and having felt stronger in their enduring skills upon graduation.

Table 5: Perceived relative strength in enduring and technical skills compared with career satisfaction rating. For the former, participants were prompted with, *“Olin strives to teach its students a wide variety of both technical skills (e.g., underlying math skills, coding, CAD, machining) and enduring skills (e.g., teamwork, communication, leadership). Right after graduating from Olin, did you feel stronger in your technical skills or your enduring skills?”* Each number represents a single respondent’s answers, and the darker hues represent a higher number of answers.

		How satisfied are you with your post-Olin career?				
		Unhappy	.	.	.	Satisfied
After graduation, I felt…	Strongest in enduring skills	2	2	3	10	9
	A bit stronger in enduring skills than technical skills	0	1	3	7	11
	Equally strong in technical and enduring skills	1	1	1	4	1
	A bit stronger in technical skills than enduring skills	0	1	2	0	2
	Strongest in technical skills	0	0	0	1	0

5 Discussion

The first objective of this work was to develop a list of items that engineering alumni of Olin College find important in their post-baccalaureate careers. An exhaustive list of items is available in Table A1, and Table 2 provides a concise list. A majority of these items are hallmarks of a liberal education, especially the High-Level Thinking, Interpersonal, and Mindset items. Moreover, several items align specifically with the need to bridge the socio-technical divide in engineering programs (e.g., 'HL4: Designing for a specific group of people,' 'HL6: Interdisciplinary thinking,' and 'I11: Understanding others' thoughts and ideas'). This result aligns with the literature highlighting the importance of enduring skills introduced in Section 2.1. Further, some items may prove to be more latent in engineering education programs (e.g., 'M9: Healthy skepticism'); additional studies that involve other programs are needed to confirm this. Overall, for Olin's alumni, both the non-technical items and the technical items are important.

The second objective of this work was to use the list of identified items to assess Olin College's program and identify areas of strength and potential improvement. Table 5 suggests that engineering graduates who graduate with a stronger self-perceived set of enduring skills can lead fulfilling, satisfying careers. This result has the potential to ease the minds of engineering students who are worried their technical skills may not be developed enough to find career satisfaction. Figure 1 and Table 4 show the correlation between the mean reported amount items were developed at Olin College and the mean reported frequency of item use in graduate's current careers. Overall, a positive correlation exists ($R = 0.55$), showing that Olin's socio-technical program successfully prepares graduates for their careers, according to this one metric of success. Figure 2's caption identifies individual items that correlate strongly (i.e., areas of strength) and ones with weaker correlations (i.e., areas of *potential* weakness). We emphasize that the results of this study alone cannot fully conclude whether any items should certainly be improved within Olin College's program or not.

While the results of this study can inform curricular change efforts at Olin College, the research team does not believe that this study alone provides a holistic enough understanding to make specific change recommendations. To this end, the research team shared the results with the on-campus Olin community in a workshop format designed to guide participants through interpreting the results from their unique positionings. All faculty, students, staff, and administration were invited to two 90-minute workshops. Each workshop began with a presentation that introduced the project objectives, motivation, methods, qualitative and quantitative results, and high-level takeaways from the quantitative results. It was important to only include high-level, non-committal takeaways (e.g., "there exists a potential opportunity to evaluate how students develop their professional identity at Olin") because more specific takeaways and action items should be community-driven to have greater impact[33,34]. The second stage of the workshops entailed small group discussions. Groups were given hard copies of the results, including Figure 1, Figure 2, and Table 5. For each result, groups were asked a series of questions designed to provoke conversation: *What surprises you? What excites you? What do you wish were different about the result? Why?* At the end of this stage, small groups were asked to submit a two-sentence statement to bring to the full group. Each workshop concluded with a forum-style discussion with all attendees. The two-sentence statements were read, and community members responded to these statements or other points made during the discussion. Because the institution is comprised of many unique perspectives, these perspectives must be accounted for in how the results may shape the College. This workshop format was designed to do just this. A key group of perspectives missing from this exercise was Olin College alumni. A workshop designed for them is planned for the future.

The final objective of this work is to discuss how the methods used to assess Olin College's program and the resulting findings could inform other engineering programs. First, as engineering programs implement institutional changes to address 21st-century needs and integrate more sociotechnical learning into their curriculum, they can look to the results of this study. Table 5 shows that 60.% of Olin College's engineering graduates felt more confident in their enduring skills (versus technical skills) upon graduation *and* were satisfied with the careers that follow. Figure 1 shows that, on average, alumni of Olin College use high-level thinking items, interpersonal skills, and mindsets more frequently than they use technical skills in their post-baccalaureate careers. While these results represent one institution, it is likely that engineering graduates of other programs would exhibit some similar patterns. These results can motivate other engineering programs to adopt more liberal education practices and sociotechnical integration into their curricula.

Second, as institutions consider or undergo significant changes, they can adopt the assessment methods outlined in this paper to evaluate their own programs. The methods are outlined such that others can directly adopt the survey tool used in this study, but we recommend revisiting the items listed in Table 2. Many of these items are relevant to all higher education and engineering programs. However, some of the listed items may be unique to Olin College, and there are certainly unlisted items that are important to other programs. Interviewing alumni and other constituents, as outlined in Section 3.1, can inform which items to retain from, add to, or drop from Table 2's list. To enable a positive, community-driven response and buy-in to any change efforts that may arise from this work, we recommend involving faculty, staff, students, administration, and alumni in the process. Two ways we approached this were to interview community members to elucidate the items most important to assess and to host community workshops to co-analyze the results.

5.1 Limitations

This study has several limitations. First, survey data captures participants' perceived development of their skills and mindsets, which does not always reflect an individual's true development. Overall, interviewed alumni of Olin College, especially early career alumni, claimed that their technical skills were far less developed than those of their peers. The perception of a technical skill deficit was far more common in the interviews than a perceived lack of skill of enduring skills. Beyond observations of this study, other studies have shown that compared to their peers, gender and racial minority students are known to perceive their development to be less than it is in practice[35,36,37]. Because our participant pool included a significant number of minority-identifying individuals, it is expected that the reported development is deflated. This tendency may also be evident for participants who are more removed from their undergraduate experience; many older alumni who were interviewed (10 or more years from graduation) often claimed they did not remember the finer details of their time at Olin. Likely, participants in the older cohorts (10 and 15 years from graduation) have a difference in their perceived skill development from those in the younger cohorts (0.5 and five years from graduation).

A second limitation is that the survey asked participants to report the frequency of skill/mindset use in their current careers. Frequency of use is one factor that contributes to an item's overall importance, but there are other key factors that contribute as well, which we did not measure. Alumni may have developed an essential but rarely used item (e.g., interview skills). So, while these items are extremely important to alumni' careers, their importance is not reflected in our survey results. Frequency was chosen as the metric to measure in this study because it is easily recalled accurately by participants.

A third identified limitation is that, in analysis, we list all skills and mindsets together, but not all items can be compared in a one-to-one manner. For example, technical skills and other skills have very different levels of versatility and applicability that have changed how frequently they appear in the results. Another important consideration is that our survey gathered data from all engineering majors and included some items that were expected to be more applicable to graduates of one major and less used by others. For example, 'T3: Circuits and Signals' was expected to be used by Electrical and Computer Engineering graduates significantly more than Mechanical Engineering graduates.

Fourth, like all institutions of higher education, Olin College has several purposes in its graduates' lives, including career preparation, identity exploration, and psychological and behavioral maturation. While these purposes are all pertinent and intersect in complex ways, the scope of this study was to evaluate Olin's role in preparing students for their diverse career paths in technical, technical-adjacent, and non-technical fields. Future, complementary work could explore how Olin College's approach to a liberal engineering education satisfies these other purposes.

Lastly, results may inspire the question: "Do alumni frequently use certain items in their careers precisely because that is what they developed most in their undergraduate program?" There is likely a causation effect; graduates will find it more difficult to get a job for which they lack the specific skills than one for which they can easily demonstrate the skills. However, understanding the causation of what items are used in careers is outside the scope of this work; only correlation was assessed.

6 Conclusion

This work evaluated a socio-technical engineering program that was launched two decades ago at Olin College of Engineering by assessing how it has prepared its graduates for their careers. Through 33 semi-structured interviews with alumni, faculty, staff, employers of alumni, and current students, a list of 81 skills, mindsets, behaviors, practices, and knowledge were found to be import to Olin graduates (Table A1). Sorting and categorizing the list of 81 items led to a concise list of 45 items divided into four subgroups: 11 high-level thinking items, 13 technical skills, 11 interpersonal skills, and 10 mindsets (Table 2). The 13 technical skills are engineering-specific, and the other 32 items are ones that align with liberal education practices. Then, these 45 items were included in a survey sent to four graduated classes of Olin College. We found that on average, the technical skill items were used less frequently in alumni' current careers compared to items in the other subgroups. Overall, the amount alumni claim to use the 45 items in their current work correlates with how much they claimed to have developed them at Olin College, suggesting that Olin's approach to a liberal engineering education prepared them well for their post-baccalaureate careers. Significant items to note are ones that are used highly in alumni' current work but were not significantly developed at Olin College, including 'H10: Your professional identity,' 'I7: Written communication,' 'M4: Comfort with working alone,' 'M9: Healthy skepticism,' and 'M10: Harmony between work life and personal life.' Finally, 60.% of survey respondents reported being satisfied with their careers *and* having felt stronger in their enduring skills (compared to technical skills) upon graduation. These findings motivate the increase of socio-technical integration and liberal engineering approaches in engineering programs throughout the nation and globally.

The results from this work spark many questions for future research. Many interviewees noted that elements of Olin College beyond courses (e.g., extracurriculars and the community) were important ways they developed, so future work could investigate which items are developed in which areas. Future investigation could understand if any trends exist with respect to graduation year, gender, race, first-generation college status, or US Citizen/international student status. Each of the 45 items could also be explored in depth and contextualized with the breath of literature studying these items. Further, this project could be expanded to include a complementary survey tool that asks employers of Olin graduates how they perform on the 45 items compared to their peers. Employers provide a unique perspective because they observe graduates from various programs and disciplinary backgrounds. Finally, this type of assessment method can be brought to other engineering programs to understand the impact of the changes they make as they respond to 21st-century challenges. If programs share their findings with each other, all institutions can learn together about how graduates are being prepared for their diverse career paths.

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A Appendix

A.1 Interview questions

A.1.1 Questions for Current Students

1. Why did you choose to come to Olin College?
2. What is your current/intended major? Why?
3. What is the most memorable or impactful part of your Olin experience so far? *Note for the interviewer: memorable parts of the Olin experience can be anything from huge moments to small things that happen every day*
4. What are the most important skills you think you have developed so far at Olin? Why are these important? More generally, how have you grown as an engineer during your time at Olin? *Note for the interviewer: Summarize and ask if they have anything else*
5. Where did you learn those experiences (e.g., courses, project teams, dorm life)?
6. What are some skills you hope to develop more while at Olin College?
7. Transition to next Question: What would you give up to learn those skills?
8. What are some of the skills you have developed so far at Olin that you think were not as important? Why are those less important?
9. What are your goals before graduating from Olin?
10. What are your goals for after graduating?

For students with work experiences:

1. What work experiences have you had during your time at Olin College so far? What did these experiences entail, and what organizations?
2. What skills did you use most frequently in these jobs?
3. What did you find you were well-prepared to do? Unprepared?
4. What did you have trouble learning how to do? What did you find you were easily able to learn?

Following completion of interview conversation above:

1. Is there anything else you want to add?
2. Do you have any questions for us or about this research study?
3. How did you feel about the flow of this interview? Is there anything you would change?
4. Do you know anyone you think we should contact to interview?

A.1.2 Questions for Alumni

Current position

1. Please describe your current role and how that fits into your organization.
2. What skills do you use most frequently in your job?
3. What skills did you think you might need but have used less than expected?
4. What skills are you continuing to build? How are you doing that?

Post-Olin College career path

1. Please describe any previous positions you've held since graduating Olin and the organizations.
2. What skills did you use or need in those positions?
3. What did you find you were well-prepared to do? Un-prepared?
4. What did you have trouble learning how to do?
5. In your early positions, how do you think your answers might differ from peers who didn't attend Olin College?

Olin experience

1. Why did you choose to come to Olin?
2. What do you remember most from your Olin experience?
3. What are the most important skills you think you developed at Olin? Why are these important? More generally, how did you grow as an engineer during your time at Olin?
4. Where did you learn these skills (e.g., courses, project teams, dorm life)?
5. What are some of the skills you developed at Olin that you think were not as important? Why are those less important?
6. What were some skills you wish you had developed more while at Olin?

Following completion of interview conversation above:

1. Is there anything else you want to add?
2. Do you have any questions for us or about this research study?
3. How did you feel about the flow of this interview? Is there anything you would change?
4. Do you know anyone you think we should contact to interview?

A.1.3 Questions for Olin Faculty/Staff

Regarding a course or program that the interviewee runs or participates in.

1. Please describe how you interface with Olin students.
2. What skills are you intentionally developing in the course/program you run? Why are these the skills you chose to include? More broadly, how are you using your program to develop Olin College students as engineers?
3. What skills are you intentionally not developing? Why not?
4. How do you decide which skills to include and exclude?
5. What were some skills you would like to see students develop more in your course/program?

Regarding the overall Olin experience

1. What skills do many Olin students come to campus with before their first year?
2. What skills do they develop most strongly during their time at Olin? Least?
3. What parts of the Olin experience do you think have the most impact on this skill development? (e.g., courses, dorm life, co-curricular activities)
4. Biggest difference between first-years vs seniors?

Following completion of interview conversation above:

1. Is there anything else you want to add?
2. Do you have any questions for us or about this research study?
3. How did you feel about the flow of this interview? Is there anything you would change?
4. Do you know anyone you think we should contact to interview?

A.1.4 Questions for Employers

Hiring process

1. Please describe your current role and organization.
2. Please describe your organization's hiring process for new employees from technical backgrounds. How are you personally involved with this process?
3. What skills do you look for in the hiring process?
4. What skills are difficult to find in the hiring process?

Employee management and personal development

1. Once employees join your organization, please describe the management structure and what opportunities employees have for career development.
2. How would you define success for someone in a technical position?
3. What skills do employees use most frequently in their jobs? Least frequently?
4. What skills do employees often have to develop while they're working here?
5. What skills do you wish more employees had?
6. Are there areas where new hires are often overqualified?

Observations of Olin graduates

1. When an Olin graduate joins your company, what skills do you notice are well-developed? Less-developed?
2. How well do Olin graduates continue developing the skills they need to be successful at your organization?

Following completion of interview conversation above:

1. Is there anything else you want to add?
2. Do you have any questions for us or about this research study?
3. How did you feel about the flow of this interview? Is there anything you would change?
4. Do you know anyone you think we should contact to interview?

A.2 All interview codes

Table A1: Codes from qualitative analysis of the 33 interview transcripts and the items they became after sorting, ordered by how often they appeared in interviews.

Code	Number of occurrences in 33 interviews	In final list of 45 items (Table 2), this item became:
Teamwork	25	I1: Teamwork
Communicate Effectively	19	I7: Written Communication and I8: Oral Communication
Learning how to Learn	18	HL5: Teaching yourself new content
Leadership	16	I2: Leadership
Communication with Teammates	15	I7: Written Communication and I8: Oral Communication
Creativity and Problem Solving Skills	14	HL9: Creativity and HL2: Problem Solving
Centering design around a specific group's needs	13	HL4: Designing for a specific group of people
Ability to Handle Openness and Ambiguity	13	M3: Comfort in ambiguous/uncertain contexts

Table A1: Codes from qualitative analysis of the 33 interviews (continued).

Code	**Number of occurrences in 33 interviews**	**In the final list of 45 items (Table 2), this item became:**
Design Process	13	HL3: Design Processes
Manufacturing/ Machine Operation Knowledge	12	T11: Fabrication and machining skills
Class-Specifc Technical Content	12	Became no specific item but integrated into technical subgroup
Working with/understanding a variety of people	12	I6: Ability to influence the direction of your team, I1: Teamwork
Project Management	11	I3: Project Management
Coding	11	T9: Coding Fundamentals
Comfort with and growth from Failure	10	M2: Comfort with and learning from failure
CAD	10	T10: Using visual design tools (e.g., CAD, circuit diagrams)
Engineering with an Impact	9	M1: Desire for your work to have an impact
Asking for help	9	M8: Recognizing that your knowledge about a problem is incomplete, M2: Comfort in ambiguous/uncertain contexts
Creative expression and freedom outside of engineering	8	HL9: Creativity, M10: Harmony between work life and personal life
Work-Life Balance	7	M10: Harmony between work life and personal life
Epistemic Humility	7	M8: Recognizing that your knowledge about a problem is incomplete
Self Care	6	M10: Harmony between work life and personal life
Confidence in one’s own ability and knowledge	6	M7: Confidence in your decisions and work
Time Management	6	M10: Harmony between work life and personal life
Understanding Expectations	6	I11: Understanding others’ thoughts and ideas
Storytelling	6	I10: Storytelling
Ability to break down problems	6	HL1: Breaking large problems into manageable ones

Table A1: Codes from qualitative analysis of the 33 interviews (continued).

Code	Number of occurrences in 33 interviews	In the final list of 45 items (Table 2), this item became:
Wide breadth of engineering	5	HL6: Interdisciplinary Thinking
Personal Reflection	5	HL11: Personal and professional reflection
Formation of One's Identity	5	HL10: Your professional Identity
Prototyping	5	HL3: Design Processes
Self-organization	5	M4: Comfort with working alone, I3: Project Management
Knowing how you learn best	5	HL5: Teaching yourself new content
Ethics in Engineering	5	M9: Healthy Skepticism, M1: Desire for your work to have an impact
Analytical Ability	5	T6: First-order analysis and estimation
Writing	5	I7: Written Communication
Presentation Skills	5	I8: Oral Communication, I9: Presentation skills (to an audience)
Underlying Math	5	T12: Underlying Math
Intersectionality in Engineering	5	HL6: Interdisciplinary Thinking
Self-directed Learning	4	M6: Passion for Work and Projects, HL5: Teaching yourself new content
Data literacy	4	T7: Data Analysis
Calmness Under Pressure	4	M5: Comfort in high-pressure scenarios
Understanding the system of a project/company/machine	4	T1: Engineering systems
Continual learning from results	3	HL5: Teaching yourself new content
Communication with Superiors	3	I7: Written Communication, I8: Oral Communication
Providing support for others	3	I2: Leadership, I3: Project Management
Interview Skills	3	HL10: Your Professional identity
Self Advocacy	3	M7: Confidence in your decisions and work
Software Design	3	T9: Coding Fundamentals

Table A1: Codes from qualitative analysis of the 33 interviews (continued).

Code	Number of occurrences in 33 interviews	In the final list of 45 items (Table 2), this item became:
Creating a Development Plan	3	I3:Project Management
Ability to let go of ideas	2	M7: Confidence in your decisions and work, I11: Understanding others' thoughts and ideas
Creating and defending an argument	2	I10: Storytelling, I9: Presentation skills (to an audience)
Persistence	2	M7: Confidence in your decisions and work
Lab/Research Procedures	2	T1: Engineering Systems, T7: Data Analysis
Professional Skills	2	HL10: Your Personal identity
Google/Microsoft Suite	2	T10: Using visual design tools (e.g., CAD, circuit diagrams)
Flexibility in abilities	2	HL6: Interdisciplinary Thinking
FEA	2	T8: Computational analysis
Computer Literacy	2	T9: Coding Fundamentals
Forming a Network and Valuable Relationships	2	I4: Relationship Building, I5: Network Building
Joint decision making	1	I3: Project Management, I6: Ability to influence the direction of your team
Topology	1	T8: Computational analysis
Career Growth	1	Networking Strategies
Quickly Obtaining new Skills	1	HL5: Teaching yourself new content
Healthy Skepticism	1	M9: Healthy Skepticism
Active Listening	1	11: Understanding others' thoughts and ideas
Spatial Reasoning and Understanding	1	T10: Using visual Design tools (e.g., CAD, circuit diagrams)
CFD	1	T8: Computational analysis
Data Science	1	T7: Data Analysis
Personal Autonomy	1	M10: Harmony between work life and personal life, M7: Confidence in your decisions and work

Table A1: Codes from qualitative analysis of the 33 interviews (continued).

Code	**Number of occurrences in 33 interviews**	**In the final list of 45 items (Table 2), this item became:**
Drawing	1	T10: Using visual design tools (e.g.,CAD, circuit diagrams)
Hands-On Learning	1	HL5: Teaching yourself new content
Reading Comprehension	1	I11: Understanding others' thoughts and ideas
Having a Creative Outlet / Having Fun!	1	M10: Harmony between work life and personal life
Implementing Feedback	1	I11: Understanding others' thoughts and ideas
Synthesizing different fields of engineering	1	HL6: Interdisciplinary Thinking
Asking good questions	1	M8: Recognizing that your knowledge about a problem is incomplete
Mechanical Design	1	T10: Using visual design tools (e.g., CAD, circuit diagrams), HL3: Design Processes
Circuit Design/ Maintenance	1	T3: Circuits and Signals
Knowing where to find information	1	HL5: Teaching yourself new content