# The Power of Connections: A Mixed Methods Approach to Understanding Social Capital's Influence on Engineering Students' Professional Skills


## Abstract

*Background:* Providing engineering students with the non-technical professional skills they will need in the workforce, including communication, teamwork, and leadership, requires repeated, contextually embedded development opportunities. Yet, limited research has explored how such opportunities vary by institutional type and academic year, or how students gain access to them. This study examines the relationship between engineering students' social capital and their access to professional skill development, focusing on variation across institution types (e.g., research-intensive, minority-serving institutions) and school years.

*Results:* We employed an explanatory sequential mixed methods design using a probabilistic stratified cluster sampling strategy. A total of 1,234 undergraduate engineering students across 13 institutions completed two assessment instruments, and 20 students were selected for follow-up interviews. Quantitative analysis using linear mixed models revealed that instrumental social capital significantly predicted access to professional skill development. Qualitative findings elaborated how students utilize relationships with faculty, instructors, advisors, and organizational peers to practice problem-solving, communication, and leadership skills. These interactions served as key enablers of access.

*Conclusions*: Social capital plays a pivotal role in facilitating engineering students' access to professional skill-building opportunities. Faculty, academic advisors, and student organization leaders should foster relationship building and mentor networks to support students' professional growth throughout their academic journey.

**Key words:** *multi-institutional, professional skills, social capital, mixed methods*

## Introduction

Engineering undergraduates increasingly need professional skills to complement their technical skills if they are to navigate the collaborative, interdisciplinary realities of modern engineering practice. Accrediting bodies such as the Accreditation Board for Engineering and Technology, Inc. (ABET) and the UK's Engineering Council as well as groups such as the National Academies of Sciences, Engineering, and Medicine (NASEM) have long emphasized that professional competencies (e.g., communication, leadership, teamwork, and ethical responsibility) are necessary in the workforce (ABET, 2021; NASEM, 2016, National Academy of Engineering, 2005; Volkwein et al., 2004). This imperative is strengthened by a rapidly changing technological landscape and the increasingly complex and interdisciplinary nature of contemporary engineering problems.

Despite broad recognition of their importance, the opportunities to develop professional skills are not evenly woven into the fabric of undergraduate curricula. Certainly, accreditation bodies require that degree programs provide curricular evidence of student learning inclusive of professional skills (ABET, 2021; NAE, 2005), but institutional and departmental curriculum committees do not tend to think about students' professional skill learning progression with the same rigor as engineering, mathematics, and science content (Shuman et al., 2005). Some engineering programs incorporate professional skill-building through design courses (e.g., Sperling et al., 2024) or structured internships (e.g., Dym et al., 2005) or even throughout the curriculum (e.g., Mitchell et al., 2019), but many do not implement a deliberate, program-wide strategy for embedding these competencies across the curriculum.

Many students instead rely on developing professional competencies through activities outside of the classroom such as student organizations, undergraduate research, or industry cooperative education (“co-ops”; Hinkle & Koretsky, 2019; Martin et al., 2015; Coyle et al., 2005; Dalrymple & Evangelou, 2006; Garrett et al., 2021; Simmons et al., 2018; Winberg et al., 2020). Traditional models of skill development often center on individual traits or perceived competencies and perhaps optimistically assume a level playing field, but this framing neglects the critical influence of social systems and institutional structures. Access to cocurricular and extracurricular experiences often hinges on students’ social networks and institutional support structures (Millunchick et al., 2021). Social ties with peers, faculty, and mentors often act as essential gateways to skill-building experiences (e.g., professional societies and cocurricular programs; Martin et al., 2016; Moreira et al., 2019) and skill-building roles (e.g., leaderships roles in cocurricular programs and undergraduate researcher positions; Martin et al., 2014; Revelo & Baber, 2018).

Relying on social networks to access opportunities for professional formation thus compounds societal inequities. Among engineering students, students of lower academic standing, who are first generation college attending, of Color, and/or are at institutions with lower levels of research activity may have less access to opportunities to practice professional skills than their peers (Martin et al., 2020; Skvoretz, et al., 2020; Li et al., 2023). This raises important equity questions in terms of who gets the chance to practice professional skills, who is inadvertently left behind, and how can we ensure all students have opportunities to develop these skills.

Disruptions brought on by the COVID-19 pandemic potentially deepened the disparities in opportunities to practice professional skills by disrupting students' access to critical relationship-based and experiential-learning contexts. Students who began their undergraduate programs remotely due to the pandemic missed foundational opportunities to form social ties with peers, faculty, and mentors (Martin et al., 2022; Wiggins et al., 2022). Students relied on intentional instructional decisions in remote learning, such as pre-recorded videos, virtual teamwork assignments, and online discussion boards; however, these supports may not be as impactful to building social capital compared to pre-pandemic opportunities (e.g., in-person socialization during class time, hands-on laboratories; Emberley et al., 2022), and it is unknown how the loss of in-person connections during lockdowns affected students' opportunities to practice professional skills. These conditions have left lasting questions about the importance of social capital's role in providing students with opportunities to practice professional skills and the degree to which personal and institutional characteristics influence students' access to these skill-building opportunities.

This study uses Lin's (2001) network theory of social capital, which posits that a person's network of relationships mediates their access to resources. Here, we suggest that students' networks mediate their access to knowledge about skill-building opportunities and the support to pursue those opportunities. Prior research has shown that engineering students' social capital from peer and faculty networks supports their persistence in the major and identity formation (Martin et al., 2014; Renata & Baber, 2017). Thus, this study examines how students' relationships shape their ability to engage in opportunities for skill development. We also incorporate Dall'Alba's (2009) ontological perspective on professional learning, which moves beyond the notion of skill “acquisition” to view development as a process of becoming that is deeply embedded in practice and identity. Together, these frameworks shift the focus from studying students’ professional skills competencies to understanding how students access opportunities to practice professional skills, and what those opportunities look like.

We present a sequential explanatory mixed methods study to examine how engineering students’ social capital predicts and enables access to opportunities to practice professional skills, addressing a notable gap in the literature. While prior research has established that social capital influences student persistence, belonging, and identity in engineering (e.g., Martin et al., 2014; Skvoretz et al., 2020), fewer studies have directly modeled the relationship between students’ networks and their access to professional skill development opportunities. Moreover, little is known about how these relationships vary across institution types and academic progression.

Our study integrates Lin’s (2001) social capital theory with Dall’Alba’s (2009) ontological framework to conceptualize access to skill-building not merely as an individual achievement, but as a relational process shaped by institutional and network contexts. In the quantitative phase, we analyze how well students’ expressive and instrumental support predict their opportunities to practice professional skills and the extent that institution type and school year indirectly influence those opportunities. In the qualitative phase, we explore students’ experiences leveraging social networks to access these opportunities. To address potential variation in campus experiences due to the COVID-19 pandemic, we collected data from a diverse sample across institution types and academic levels, enabling nuanced group comparisons.

Four research questions guided this study. The first two we answer primarily through quantitative research: RQ #1) *To what extent does engineering students' social capital predict their opportunities for practicing professional skills?* and RQ #2) *To what extent do student's institution type and their year in school mediate the relationship between social capital and opportunities to practice professional skills?* The latter two we explored qualitatively through in-depth interviews with engineering students focused on how they used their social networks to access opportunities to practice professional skills: RQ #3) *Where and through whom do students describe opportunities for practicing professional skills across their undergraduate experiences?* and RQ #4) *How do students use social capital to practice professional skills across school year and institution type?*

## Literature Review

### Engineering Students' Professional Skill Attainment

Engineering students' acquisition of professional skills has become a central concern in higher education research as programs strive to prepare graduates for dynamic, collaborative work environments. Researchers have used a variety of methods and instruments, including self-reports, assessments of reasoning, and third-party evaluations, to gauge competencies such as teamwork, creativity, and ethical decision-making (e.g., Avec and Savec, 2019; Zhu et al., 2014; Hundhausen et al., 2022). While these different approaches offer valuable insights, the inconsistency in constructs and measurement techniques complicates efforts to draw general conclusions about the state of professional skill education.

Nonetheless, there are apparent reasons for concern about engineering programs' success in imparting professional skills education, as well as researchers' ability to consistently measure those professional skills. Researchers are finding that engineering students often exhibit lower levels of professional skills than their non-engineering peers. For example, using the Creative Engineering Design Assessment, Charyton and Merrill (2009) and Avsec and Savec (2019) found that non-engineering students—such as pre-service teachers and chemistry majors—outperformed engineering students by approximately 10%. In line with accreditation requirements, engineering programs provide targeted ethics instruction to their students (Feister et al., 2014; Zhu et al., 2014), but a study using the Engineering Ethical Reasoning Instrument reported no significant differences in ethical decision-making between engineering students and students from other majors who do not typically have targeted ethical instruction (Zhu et al., 2014).

Moreover, the evidence that engineering students progressively develop professional skills over the course of their degree program is less robust than expected. Multiple studies using the Comprehensive Assessment of Team Member Effectiveness (Ohland et al., 2012) have reported that class standing (e.g., first-year vs. fourth-year) does not predict higher teamwork scores, potentially suggesting that students do not increase their teamwork skills over their undergraduate years, although the measure's reliance on peer evaluation complicates our understanding of these results (Hundhausen et al., 2022; Pejcinovic et al., 2018; Vasquez et al., 2020). When comparing findings from Zhu et al. (2014) and other studies utilizing the Engineering Ethical Reasoning Instrument, we found first-year engineering students scores were not statistically different than their first-year peers in non-engineering majors in Cimino et al.'s (2024) study across three institutions. Moreover, both undergraduate groups reported higher levels of ethical reasoning engineering graduate students (Hess, Beever et al., 2019; Hess, Kisselburgh et al., 2016). These findings underscore the difficulty of evaluating professional skills such as ethical behavior, where progression in ethical reasoning is not clearly tied to degree progress. One interpretation of these discrepancies may be that institutional factors, demographics, and access to learning opportunities can significantly shape attainment of these skills.

**Social Capital as a Mechanism to Access Professional Skill Opportunities**

To get a clear picture of engineering students' access to professional development, we need to ask how, where, and through whom the opportunities to build those skills arise. Social capital theory gives us a lens to examine the "how" of access. Lin (2001) defines social capital as the set of resources embedded in social networks that individuals can mobilize toward their goals. These networks, comprised of peers, institutional actors, and members of organizations, have been linked to student outcomes ranging from persistence to well-being and college enrollment (Martin et al., 2020; Puccia et al., 2021; Glass, 2023; Skvoretz et al., 2020). Lin's theory distinguishes between strong ties (such as with family, close mentors, and close friends) and weak ties (such as with more casual acquaintances or distant contacts). Both types of ties help engineering students to navigate both academic and professional challenges. While strong ties can offer sustained emotional support and identity reinforcement, weak ties are often critical for uncovering new opportunities—they bridge gaps between social circles and open doors that students may not otherwise know exist (Granovetter, 1973; Lin, 2001). Both strong and weak ties are essential in mapping how students navigate professional learning landscapes.

Peers serve as strong ties for STEM students, helping each other navigate course requirements, build belonging, and overcome microaggressions, fostering both academic and emotional resilience (Campbell-Montalvo et al., 2022a, 2022b; Mondisa, 2020; Smith et al., 2021). Peers act as mentors and cultural guides, shaping students' academic and professional decision-making (Beard, 2021; Brouwer et al., 2016). Meanwhile, institutional actors such as faculty and advisors may play a more crucial role in expanding students' professional access as either strong or weak ties. Faculty connect students to opportunities like research positions, scholarships, and leadership roles while also providing motivational support and mentorship (Henderson et al., 2023, Martin et al., 2020; Sausner et al., 2024). These relationships often serve as pivotal enablers of professional identity and career exploration, particularly for students from marginalized backgrounds (Salazar et al., 2020).

Social capital is further accumulated through involvement in cocurricular (i.e., out-of-class activities that complement engineering coursework) and extracurricular (i.e., out-of-class activities not related to engineering coursework) organizations, where students can grow their personal and professional networks. Participation in cocurricular groups like the Society of Women Engineers or National Society of Black Engineers offers students access to both peer mentorship and industry-facing events (Garrett et al., 2021; Martin et al., 2016; Smith et al., 2021). Such organizations foster emotional engagement and boost self-efficacy (Wilson et al., 2014), enabling students to access high-impact learning experiences (e.g., applying theories learned in coursework to hands on projects, developing leadership skills, and connecting with industry professionals; Olewnik et al., 2023).

Despite growing interest, relatively few studies directly examine the link between social capital and access opportunities to practice professional skills. Some research highlights that cocurricular engagement promotes both social bonding and skill acquisition (Buckley & Lee, 2021; Garrett et al., 2021), while others shows that social capital and participation in organizations enhances students' leadership and professional growth, respectively (Gholami et al., 2020; Volpe et al. 2023). Our study builds on these findings to investigate how engineering students' expressive and instrumental social capital predicts and enables access to professional skill opportunities across diverse institutional contexts.

## Theoretical Framework

Social capital theory offers a promising framework to explain disparities in access to professional skill-building opportunities among engineering students. Lin's (2001) network theory of social capital positions individuals (egos) within a web of supportive relationships (alters), which provide both expressive (emotional, psychological) and instrumental (goal and career-oriented) support. Through a lens of social capital, researchers can identify how and why certain students gain easier access to leadership roles, internships, or other developmental learning experiences than their peers. For example, in the context of engineering education, students have been found to mobilize the resources in their network, such as leveraging information about employment opportunities or receiving invitations to participate in undergraduate research, to practice technical and professional skills and progress towards their professional goals (Martin et al., 2014; Volpe et al., 2023).

While Lin's framework helps us understand the mechanisms of access, Dall'Alba's (2009) "ways of being" framework explains why access matters in a deeper sense. Rather than viewing it as a process that culminates in a static collection of skills, Dall'Alba frames students' development of professional competence as an ontological process—a way of becoming that unfolds through situated engagement in professional practice. In this view, learning professional skills is not simply the internalization of content but a transformation of identity, shaped by participation in meaningful, real-world contexts. Thus, access is not just an equity issue; it is a prerequisite for becoming an engineer in any full and authentic sense.

Together, social capital theory and Dall'Alba's "ways of being" framework underscore that professional skills are not simply about what students know or can do—it is about whether they have had the opportunity to participate, reflect, and grow in ways that are socially and contextually meaningful. This study aligns with and builds upon the professional skills opportunities framework (Author et al., under review), which seeks to capture the richness of students' actual opportunities to engage in core practices like teamwork, leadership, and communication. By bringing together a relational model of access and an ontological view of learning, our approach surfaces the often-invisible structures that shape who gets to learn, how, and under what conditions.

## Methods

Reflecting our disciplinary backgrounds, identities, and institutional affiliations, our positionality inevitably influences our research choices, methods, and interpretations (Secules et al., 2021). Our team includes one PhD student, two postdoctoral scholars, two tenured faculty, and one professor of practice with backgrounds spanning three engineering subfields (i.e., materials science, mechanical, and chemical), engineering education, and educational psychology. All faculty and postdocs have taught engineering courses with professional skill-building components, which informed our design of interview protocols and deepened our interpretive engagement with students' experiences.

Our research questions reflect the convergence of our expertise in social capital, professional skill development, and mixed methods approaches (e.g., Authors, 2011, 2022, 2024). While senior team members brought established knowledge in these areas, research trainees developed expertise through collaborative engagement on this project. For example, senior members of the team mentored the early career researchers in conducting mixed method research designs, performing thematic analyses, and disseminating the findings through multiple avenues (e.g., conferences, journals, workshops, and infographics). Both our institutional positions and our diverse gender identities (two nonbinary individuals, three women, and one man) shaped our methodological decisions, including survey item design and sampling. Thus, our survey intentionally provided inclusive options for self-identification, and we interviewed nonbinary engineering students.

As researchers based at highly intensive research institutions, we recognize that our experiences may shape our assumptions about students' access to resources and networks. To avoid a myopic focus on students familiar to our own context, we recruited a representative sample of engineering students from a range of institutional types (e.g., research institutions, undergraduate institutions, HSI/MSIs, and HBCUs). We also utilized a probabilistic sampling approach, rather than relying on our on social capital to recruit participating institutions. We were also mindful of the extractive nature of academic research and committed to reciprocity, which we fulfilled by providing all participating institutions with individualized reports offering specific, actionable, and timely feedback tailored to their results (Author, 2020). These reports allowed institutions to benchmark their own outcomes against peer institutions and develop strategies to expand access to professional skill-building opportunities for their students.

**Overall Study Design**

To answer our research questions, we employed a sequential explanatory mixed methods design (Creswell & Clark, 2017), where we first used quantitative methods to establish whether social capital predicts access to professional skill practice opportunities (see Figure 1). This phase addressed RQ1 and RQ2, which focused on whether and to what extent social capital, particularly instrumental support, was associated with students' opportunities across institution type and academic year. The qualitative phase was then designed to answer RQ3 and RQ4, which asked how students use social capital to access these opportunities. Because our goal in the qualitative phase was to explain the mechanisms of access, we purposefully sampled students based on their levels of social capital, not on their level of opportunity. This design allowed us to explore the ways students with high or low social capital utilize their networks to access opportunities, building conceptual depth around the predictive patterns found in the quantitative model.

In our study design and implementation, we addressed measures of quality for the quantitative methods, qualitative methods, and sequential explanatory method (Creswell & Guetterman, 2019). We used a well-defined methodological framework (sequential explanatory mixed methods) and theoretical framework (Lin's network theory of social capital, 2001) to guide each phase of the study. Our study followed the order and focus specified by the sequential explanatory method—that is, the collection and analyses of the quantitative data then qualitative data with a focus on the qualitative portion. Additionally, our work applied rigorous methods for each phase and addressed the quality of each phase separately (specified in their following respective sections).

**Figure 1**

*Visual model of mixed methods research design*

| **Phase** | **Procedure** | **Product** |
|---|---|---|
| Quantitative Data Collection | • Undergraduate Social Support & Professional Skills Opportunities survey (*n* = 1,234) | • Numeric data |
| Quantitative Data Analysis | • Data screening and fitness<br>• Null linear model<br>• Linear mixed model | • Descriptive statistics, normality<br>• Nested relationship between groups<br>• Estimates, intraclass coefficient, conditional $R^2$<br>• Analysis used to answer RQ1 and RQ2 |
| Participant Selection; Interview Protocol Development | • Purposefully selected participants from each group (*n* = 4) with low and high levels of measured variables<br>• Developing interview questions based PSO responses | • 20 interview participants<br>• Interview protocol |
| Qualitative Data Collection | • In-depth interviews with 20 participants across four institution types | • Transcription data |
| Qualitative Data Analysis | • Coding and thematic analysis<br>• Within group and across group thematic analysis | • Codes and themes<br>• Similar and different themes across groups<br>• Analysis used to answer RQ3 and RQ4 |
| Integration of the Quantitative & Qualitative Results | • Examination of relationship between factors (quantitative results)<br>• Explanation of mechanism between factors (qualitative results) | • Discussion<br>• Recommendations |

A crucial aspect of mixed methods quality is in the integration of the quantitative and qualitative data. Using results from the Undergraduate Social Support survey (USS; quantitative phase), we selected interview participants based on (1) their reported level of instrumental and expressive support (low or high) and (2) equal representation from each institution type. We then tailored the interview guide for each participant based on their responses to both the USS and the Professional Skills Opportunities survey (PSO) to capture rich context and nuance about their quantitative responses. Lastly, we used the qualitative findings as additional evidence for our interpretation of the quantitative findings and reported the meaning of integrated results.

## Quantitative Phase

### ***Measures Used***

In spring of 2022, we distributed the USS and PSO and collected demographic data, including students' year in school, gender, and racial demographic information.

*Undergraduate Student Support Survey*

The USS instrument (Author et al., under review) consists of three distinct yet interconnected scales that capture different dimensions of students' social capital: *Expressive Support*, *Instrumental Support*, and *Accessed Support*. The *Expressive Support* and *Instrumental Support* scales are scored out of five, where a zero indicates that no alters have provided support and five indicates that five unique alters have provided support. The validation study reports strong internal consistency for each subscale, with Cronbach's alpha coefficients greater than $\alpha > 0.80$, indicating that the items effectively capture their intended skill domains (Author et al., under review).

The *Expressive Support* scale focuses on identifying students' close relationships—what Lin (2001) refers to as *strong ties*—and the emotional or relational supports these individuals provide. This includes dimensions such as mentorship and advice, personal well-being, and outreach behaviors. To gather this information, the section employs a *name generator* technique, asking participants to list individuals who provide them with various types of supports. This section comprises 15 items.

The *Instrumental Support* scale, comprising seven items, explores the extent to which students' strong ties offer assistance directly related to academic and career objectives. This includes supports such as help with finding internships, securing employment, and accessing professional opportunities. These questions follow up on the named strong ties from the previous section, focusing on tangible outcomes facilitated by those relationships.

The third section*, Accessed Support*, contains 13 items designed to measure the instrumental benefits students receive from their broader social network—specifically, *weak ties* (Lin, 2001). These more casual or acquaintance-level connections often serve as important conduits for information, opportunities, and access to professional resources, even if they lack the emotional intimacy of strong ties. This portion of the survey draws on a *resource generator* methodology, asking respondents to indicate the nature of these relationships and the resources made accessible through them. The categories covered in this section include academic guidance, scholarship information, and pathways to professional growth.

According to exploratory and confirmatory analyses, the USS has strong evidence of validity for assessing students' social capital (Authors, 2024). It also has strong evidence of fairness and can be used to assess social capital fairly across gender, race, ethnicity and students' year in school. For more information on the items and factor structure, see Authors (2024).

*Professional Skills and Opportunities Survey*

The PSO survey is designed to assess undergraduate engineering students' opportunities to practice professional skills across curricular, cocurricular, and extracurricular contexts. It includes four subscales: (1) shared leadership, (2) business management, (3) problem-solving, and (4) communication, measured on a 7-point Likert scale from "do not practice at all" to "practice very frequently." These four skill domains were selected based on a thorough review of the literature and prevailing frameworks for professional competencies in engineering education, including ABET (2021), the National Academies (NASEM, 2016), and key empirical studies (Authors, 2022). The goal was to capture skills that are both broadly emphasized in professional formation and feasibly measurable through student-reported opportunity contexts. While we initially intended to include ethical decision-making as a fifth domain, psychometric analysis during validation did not support its inclusion at the time of this study. The validation study reports strong internal consistency for each subscale, with Cronbach's alpha coefficients ranging from $\alpha = 0.73$ to $\alpha = 0.87$, indicating that the items effectively capture their intended skill domains (Authors et al., 2022; Authors et al., under review).

The PSO remains, to our knowledge, the only published instrument focused specifically on measuring *opportunities* for professional skill practice, rather than skill attainment or perception of skill attainment, and does so from a developmental and theoretically grounded lens. It is supported by strong validity evidence from expert review, cognitive interviews (Authors et al., 2022), exploratory and confirmatory factor analysis, and measurement invariance testing (Authors, 2024). For our purposes, the PSO was appropriate because it aligned with our focus on how access is shaped, rather than what students have already achieved. When used alongside the USS, the PSO provides a robust, empirically supported lens into the relational and developmental aspects of professional formation in engineering education.

***Research Setting & Data Collection***

To address our research questions and make claims about engineering students attending ABET-accredited schools in the United States, we sought to obtain a representative cross-section through a probabilistic stratified cluster sampling approach as described by Blair et al. (2014). We used the 2021 Carnegie Classification (Indiana University Center for Postsecondary Research, n.d.) to classify ABET-accredited schools into four categories of sampling strata. (While Carnegie updated the classification system in 2025, our study was already underway at the time of their publication.) The classification definitions from Carnegie 2021 are as follows:

- Research—doctoral universities with very high research profiles
- Undergraduate—teaching-focused, exclusively or very high undergraduate populations
- Hispanic serving and minority serving institutions (HSI/MSIs)—institutions with at least 25% Hispanic enrollment
- Historically Black colleges and universities (HBCUs)—institutions founded with a mission to educate students of African American descent

The strata are not necessarily mutually exclusive (e.g., some research institutions are also MSI/HSIs).

Cluster sampling is particularly effective for achieving cost-effective, probabilistic samples when the researcher has a list of clusters (here, ABET-accredited programs), but not a list of individuals (Blair et al., 2014). We strove for approximately equal sample sizes between groups of students located within each of the four strata. The universities that fall into two or more strata were placed in the smallest stratum it falls under in terms of number of institutions (thus a research institution that is also an HSI/MSI was classified as the latter). From each stratum, we randomly selected three institutions (clusters) to recruit from to achieve approximately equal sample sizes in each stratum. We reached out to the associate dean for undergraduate engineering education (or equivalent) at the selected institutions and asked if they would be willing to have their institution participate. We obtained institutional review board approval to recruit institutions who would then email the advertisement for the survey to their undergraduates.

We determined the minimum sample size based on expected standard deviation in our outcome variables of interest (social capital and professional skill opportunities) and population sizes of each stratum (Blair, et al., 2014). There is typically greater variance within larger strata than in smaller ones in terms of size of institution (Blair et al., 2014); thus, the minimum sample size for each stratum was based on achieving a representative sample for the largest strata and oversampling if smaller strata (e.g., HBCUs) to create equal sample sizes across types of institutions. Our previous work using a sample of 1,613 undergraduate students at a large research institution found a standard deviation of 8.39 in scores on the USS (Authors, 2020). To achieve a 95% confidence interval of +/- 1 from the true mean with largest standard deviation of 10, we estimated we needed 384 samples from each stratum (Blair, et al., 2014 p. 157). Based on our previous survey research and that of others (Kost & da Rosa, 2018), we anticipated that compensation of $10 would result in an approximately 50% response rate and would support a diversity of respondents.

While our strategy was effective for research, undergraduate, and MSI/HSI institutions, the initial round of data collection from HBCUs was far lower than the desired sample size. Therefore, we recruited from an additional institution and increased compensation to $20 for survey completion for all HBCU students. In total, we collected 2,246 student responses from 13 institutions.

### *Data Preprocessing*

Prior to data analysis, we performed data preprocessing to ensure data quality based on three criteria, following Meade and Craig (2012): completion rate, filter question response (asking respondents to select "Not at all"), and cohort information. We eliminated 658 responses with a completion rate of less than 50% and 354 responses based on the filter question. Our finalized sample, then, was 1,234. Table 1 contains the demographic information for the respondents included in our finalized dataset.

### *Data characteristics*

We considered multiple factors, such as normality and the nested relationship between groups, when selecting a model for our dataset. Linear mixed models, a special case of generalized mixed models, are ideal for understanding the linear relationship between multiple variables while considering the effect of normally distributed random effects (Fox et al., 2015). Thus, we performed checks for normality on the response variable, opportunities to practice professional skills, to determine suitability. The PSO dataset was within range for normally distributed data with a slight negative skew (*Skew* = -0.72, *Kurt* = 1.01), making our data ideal for a linear mixed model. Additionally, random effects, sometimes called conditional modes, are ideal for modeling the underlying effects of group membership. As we were interested in modeling the main effects and the effects of collecting data at different sites (institutions) and populations (students across differing school years), our data was an ideal fit for a mixed model.

**Table 1**

*Demographic information and descriptive statistics for research participants*

| Measure | n | % |
|---|---|---|
| Gender | | |
| Women | 522 | 42 |
| Men | 678 | 55 |
| Other[a] | 34 | 3 |
| Race/Ethnicity | | |
| White | 648 | 52 |
| Asian | 206 | 17 |
| African American | 123 | 10 |
| Hispanic/Latino | 172 | 14 |
| Other[b] | 85 | 7 |
| Strata | | |
| Research | 460 | 37 |
| Undergraduate | 336 | 27 |
| MSI/HSI | 310 | 26 |
| HBCU | 128 | 10 |
| Year in School | | |
| First-Year | 317 | 26 |
| Second-Year | 239 | 19 |
| Third-Year | 305 | 25 |
| Fourth-Year | 273 | 22 |
| Fourth-Year+ and up | 93 | 8 |

*Note.* $n$ = 1,227. Demographics were collected through self-identified responses in surveys.

[a] Other gender includes students who selected non-binary or N/A as their responses.

[b] Other race/ethnicity includes students who selected multi-racial, Native Americans, Pacific Islanders, Arabic/Middle Eastern, or other.

***Linear Mixed Model Methods***

We performed a linear mixed model to examine the relationship between students' instrumental and expressive support and their opportunities to practice professional skills.

Mixed models have two parts: fixed effects and random effects. The former model the linear relationship between the response variable and the explanatory variable, and the latter model the unmeasured, underlying effects controlled for by group membership (Fox et al., 2015). In this study, the fixed effects are the linear relationship between students' expressive and instrumental support, the predictor variables, and their opportunities to practice professional skills, the response variable. The random effects are expressed in a hierarchical, nested structure with the first group being the year they entered college (i.e., year in school) and the second group being students' university classification (i.e., research, undergraduate, HBCU, MSI/HSI). This created 20 intersectional groups: four from the Carnegie classification and five from year in school. The random effects illustrate how far that intersectional population varies from the group mean (the intercept; Fox et al., 2015). For this study, we allowed for random intercepts to show how the group varies from the population mean, where positive random effect intercepts are that much above the population average.

We conducted multiple linear mixed models with increasing levels of specification in R-4.3.3 using the *lme4* and *nlme* packages. By performing multiple models with increasing levels of specification, we are able to compare model fit and thus quality of the models. We first performed a null model, a linear mixed model without fixed effects, to determine the portion of variance the random effects capture (Nakagawa et al., 2017). From the null model, we found that strata and year nested captured approximately 3% of the random effects variance. Next, we conducted a linear mixed model with fixed effects being the relationship between students' opportunities to practice professional skills and their expressive and instrumental support and random effects being the nested relationship between students' university strata and their year in school. We assessed the model based on model fit with a conditional $R^2$ value and proportion of variance captured with the intraclass correlation coefficient (ICC). Model fit was acceptable: the $R^2$ value was 0.102, indicating fixed and random effects explain 10% of the model. The random effects model fit was small but relevant to our study with the nested relationship between strata and school year, explaining approximately 4% of the random effects model.

## Qualitative Phase

### *Quality considerations*

We adhered to Walther et al.'s (2013) "quality in qualitative interpretive research" ($Q^3$) management typology, a well-recognized measure of quality in engineering education research, to ensure quality and robustness in all aspects of our work. We particularly addressed three types of validation (Walther et al., 2013, p.641): theoretical (the fit between the social reality under investigation and the theory produced), procedural (which suggests incorporating features into the research design to improve this fit), and communicative (which accounts for co-construction of knowledge in the social context under investigation as well as within the research community). We addressed theoretical validation through purposeful sampling of participants based on school year, institution type, and level of social capital. Our research team further supported communicative validation of the work by tailoring interview prompts to student survey responses, inductive coding, and peer debriefing.

We also addressed procedural validation through the use of critical incident technique and negative case analysis. In addition to identifying critical instances where participants described accessing social capital (e.g., strengthened relationships or resource sharing), we also actively searched for accounts where social capital was hindered, diminished, or inaccessible.

These negative cases highlighted actions and conditions that undermined access to professional skill practice opportunities, which allowed us to refine our analysis with nuance and identify interactions and practices that facilitate social capital accumulation but also those that may inadvertently harm it. Throughout the qualitative methods section we parenthetically describe how we attended to each type of validity.

***Participant Recruitment***

We used purposeful sampling aligned with our explanatory sequential mixed methods design for participant recruitment. Because the goal of this phase was to explore how social capital serves to provide access to opportunities to practice professional skills (RQ3 and RQ4), we selected participants based on their levels of instrumental and expressive social capital as reported in the USS survey. This approach allowed us to obtain rich, explanatory data from students who had utilized their social networks for opportunity access. While the quantitative model established that social capital significantly predicts opportunities, it does not account for all variance, meaning students with high opportunity scores may not necessarily have relied on social capital to access them. Therefore, selecting interviewees based on social capital (rather than PSO scores) was critical for investigating our central mechanism of interest. Nonetheless, our interview participants did have a variety of PSO scores (shown in Table 2).

To ensure variation in context, we also stratified participants by institution type and academic year, including students who began college during the COVID-19 pandemic. We used each participant's PSO responses to tailor interview protocols, focusing on the three professional skills they reported most frequently practicing. This approach allowed us to center the interview on specific lived experiences while preserving our focus on social capital as the primary lens. Because students reported more frequent opportunities in communication and shared leadership, these skills were emphasized more heavily in the interviews than less commonly practiced areas like business management. Table 2 displays the demographics of the interviewees, who selected their own pseudonyms and pronouns.

**Table 2**

*Participant demographic information*

| Pseudonym | Pronouns | School Year | Institution Type | Expressive Social Capital[a] | Instrumental Social Capital[a] | Total PSO[b] |
|---|---|---|---|---|---|---|
| Olin | He/him | 1 | HBCU | Low | Low | Medium |
| Nathaniel | He/him | 2 | HBCU | Low | Low | Medium |
| Eeyore | She/her | 3 | HBCU | High | Low | Medium |
| Frank | He/him | 3 | HBCU | Low | High | High |
| Ingrid | He/him | 3 | HBCU | High | High | High |
| Doria | She/her | 4 | HBCU | High | Low | Low |
| Samantha | She/her | 1 | MSI/HSI | High | Low | Medium |
| Rachel | She/her | 2 | MSI/HSI | Low | Low | High |
| Tamara | She/her | 2 | MSI/HSI | Low | Low | High |
| Pennelope | She/her | 3 | MSI/HSI | High | High | High |
| Mariana | She/her | 1 | Research | Low | Low | High |
| Bennett | She/her | 2 | Research | High | High | High |
| Christina | She/her | 3 | Research | Low | Low | Low |
| Garry | He/him | 4 | Research | Low | High | High |
| Quinn | He/him | 4 | Research | High | High | High |
| Heather | She/her | 5 | Research | High | Low | High |
| Katie | She/her | 1 | Undergraduate | Low | High | Medium |
| Lucas | He/him | 2 | Undergraduate | Low | Low | High |
| Albert | He/him | 2 | Undergraduate | High | High | High |
| Jackelob | He/him | 5 | Undergraduate | Low | High | Medium |

[a] Low social capital was operationalized as having an expressive or instrumental support score of less than 2.5 alters and high social capital was operationalized as having more than 2.5 alters providing expressive or instrumental support.

[b] Low PSO total score ranges from 4-13.99, medium PSO total score ranges from 14-21.99, and a high PSO total score ranges from 22 to 28. Scoring is based on frequency of opportunities to practice professional skills. See Authors (2024) for additional information on score interpretation.

***Data collection***

Each interview guide was tailored to participants' responses on the USS and PSO instruments, allowing us to align questions with their reported levels of social capital and opportunities to practice specific professional skills (procedural, theoretical, and communicative validation). We conducted and recorded semi-structured interviews via Zoom (Version 5.11.0), with participant consent. A member of our research team designed the protocol with guidance from the second author, who has extensive qualitative research experience. Interviews were conducted with an ethic of care, using accessible, student-friendly language and avoiding jargon related to social capital to ensure clarity and comfort for participants.

The interview consisted of two sections: the first focused on opportunities to practice professional skills and the second on access to those opportunities through students' social networks. We used the critical incident technique (Flanagan, 1954; Simmons & Trenor, 2010) to prompt participants to recall specific instances where they practiced professional skills they had rated highly in the PSO survey (procedural, communicative validation). We asked participants to recall instances where they were able to practice certain professional skills which they had reported practicing through the USS and PSO surveys. Our prompts focused on the top-rated skills from their survey to explore how opportunities manifested in practice.

In the second section, we asked participants to reflect on individuals they named in the USS survey's name generator, exploring how those alters provided access to skill-building opportunities. This portion adapted elements from prior protocols (e.g., Authors, 2020) and enabled us to examine how different forms of instrumental and expressive support facilitated access across settings (procedural and communicative validation). Table 3 provides a summary of the interview structure and examples.

**Table 3**

*Overview of interview protocol including sample questions for each section*

| **Topic** | **Sample Questions** |
|---|---|
| Professional skills: critical incidents [a] | In the survey, you indicated that you had many opportunities to develop communication skills, such as adapting your communication to fit different audiences. Can you tell me about a particular time where you felt that skill was being enhanced? What was the context of this situation? Who was involved in your learning experience? |
| Name generator critical incidents: professional skills | In the survey you mentioned that [Name of alter listed] has supported you in school. Can you tell me about how they contributed to your professional skills development? |
| Name generator critical incidents: general engineering studies | Tell me about how [Name of alter listed] has helped you be successful in your major or persist in engineering. Can you think of a specific time when [Name of alter listed] said or did something that contributed to your success or persistence? |

[a] This question was repeated to elicit critical incidents for other skills that were also highly rated, tailored to each participant's survey responses.

We used Zoom audio transcription function to generate transcripts. Members of our research team verified each interview transcript for accuracy and cleaned them to remove any potentially identifying information that could compromise participant identity (procedural and communicative validation).

***Data analysis***

We analyzed our qualitative data in two distinct phases using a coding scheme (Table 4) with Dedoose 9.2.12. We employed first and second cycle coding, as described by Saldaña (2013), to capture thematic instances of social capital and professional skill opportunities (first cycle) and the connection between their social capital and opportunities to practice professional skills across institution types and school years (second cycle). We coded these two cycles using deductive codes directly aligned with social capital theory and the PSO factors and inductive coding emergent from the data (theoretical, communicative, procedural, and pragmatic validation). The team met regularly to discuss ongoing analysis, findings, and implications (process reliability).

The first cycle focused on coding participants' actions to utilize their social capital and practice their professional skills. We deductively coded each instance of accessed social capital as instrumental or expressive support (Lin, 2001) and then inductively coded how instrumental and expressive support was accessed (e.g., expressive support: encouraging to persist). We used emergent coding to define subcodes for both instrumental and expressive support to help us capture actions specific to this context. For each instance of support, we also coded who provided the support (i.e., alter; faculty) and the setting where the support was accessed (e.g., cocurricular; Simmons et al., 2017). We followed a similar process for coding instances of opportunities to practice professional skill by deductively using the four professional skills assessed by the PSO (Authors, 2024) and inductively coding how students practiced these skills (e.g., shared leadership: considering others).

In the second cycle, we analyzed the coded excerpts for trends across institution type and school year separately. We categorically analyzed interview transcripts by school year and institution type and wrote memos during each coding session, identifying major overarching themes across both school year and institution type (procedural validation). Lastly, we deductively coded the setting where the support was accessed or skill was practiced using Simmons et al.'s (2017) definitions for curricular, cocurricular or extra-curricular.

**Table 4**

*Interview Coding Structure*

| **Phase** | Accessed Social Capital | | Opportunities to Practice Professional Skills | |
|---|---|---|---|---|
| **Alter** | Professors<br>Faculty Advisors<br>Teaching Assistant<br>Peer/Friends<br>Family | | | |
| **Process** | *Instrumental support* (Lin, 2001) | Involving in activities<br>Helping with assignments<br>Instilling curiosity in engineering | *Problem-solving* (Authors, 2024) | Problem-solving<br>Generating ideas to solve problems<br>Optimizing design<br>Evaluating feasibility |
| | | | *Shared Leadership* (Authors, 2024) | Managing teams<br>Considering others<br>Supporting others<br>Accepting responsibility<br>Being professional |
| | *Expressive support* (Lin, 2001) | Encouraging to persist<br>Supporting during challenges | | |
| | | | *Communication* (Authors, 2024) | Communicating effectively |
| **Setting**[a] | *Curricular*: Activities in the classroom<br>*Cocurricular*: Activities outside of the classroom related to engineering coursework<br>*Extracurricular*: Activities outside of the classroom not related to engineering coursework | | | |

[a] Codes are derived from definitions by Simmons et al. (2017). See publication for complete definitions.

## Results

### Social capital and prediction of professional skill opportunities (RQ#1)

The linear mixed model revealed that instrumental support ($\beta$ = 1.2*, t* = 5.0*, p < 0.005*) was a significant main effect in predicting students' opportunities to practice professional skills, but expressive support was not (see Table 5). As well, the fixed effect size of instrumental and expressive support was 0.13 and 0.04, respectively (Table 5). The averages for each scale and subscale reflect positive relationships between instrumental support and opportunities to practice professional skills, meaning increases affected total average and each individual professional skill (see Table 6). The finding is unsurprising as instrumental support tends to offer actionable and professionally focused resources, such as opportunities for professional development, whereas expressive supports are more focused on support for emotional health and well-being (Martin et al., 2020).

**Table 5**

*Results from final linear mixed model*

| **Fixed Effects** | | | |
|---|---|---|---|
| *Predictors* | *Estimates (β)* | *p* | *Fixed Effect Size* |
| Intercept ($b_o$) | 23.18 | **<0.001** | 4.77 |
| Expressive SC | 0.35 | 0.081 | 0.04 |
| Instrumental SC | 1.24 | **<0.001** | 0.13 |
| **Random Effects** | | | |
| $\sigma^2$ | 26.29 | | |
| $\tau_{Strata:Year}$ | 0.96 | | |
| $N_{Strata}$ | 4 | | |
| $N_{Year}$ | 5 | | |

| | |
|---|---|
| ICC | 0.04 |
| Conditional $R^2$ | 0.102 |

**Table 6**

*Relationship between instrumental support average and average for each professional skill and PSO total score*

| Quantiles | Instrument. support avg. | PSO avg | Shared leadership avg. | Business avg. | Problem-solving avg. | Com. avg. |
|---|---|---|---|---|---|---|
| 0% | 0 | 23.6 | 4.9 | 3.7 | 5.1 | 5.4 |
| 25% | 0.5 | 24.2 | 5.2 | 3.7 | 5.1 | 5.5 |
| 50% | 1 | 25.3 | 5.3 | 4.2 | 5.4 | 5.6 |
| 75% | 1.66 | 26.9 | 5.6 | 4.5 | 5.7 | 5.9 |
| 100% | 5 | 30.2 | 6.1 | 6.0 | 6.1 | 6.0 |

*Note.* Sample sizes for each quartile differ: 0 % quartile ($n$ = 267), 25% quartile ($n$ = 303), 50% quartile ($n$ = 361), 75% quartile ($n$ = 301) and 100% quartile ($n$ = 2).

**Potential mediators of social capital and professional skill opportunities? (RQ #2)**

We examined the random effects to explore how institution type and school year, both independently and in combination, contribute to students' access to opportunities to practice professional skills.  While random effects do not test statistical significance directly, they highlight patterns of variation that may inform the model's structure and interpretation.

When modeled independently, institution type showed little variation in mean from the population mean. For instance, research institutions had a group-level intercept of $b_o = 0.002$, while undergraduate institutions were slightly below the mean ($b_o = -0.013$), with a total range of only 0.03. These small differences suggest that institution type alone does not meaningfully affect access to opportunities. In contrast, when we examined nested groups—students grouped by both institution type and school year—more meaningful differences emerged. The lowest opportunities were observed among first-year students at undergraduate institutions ($b_0$ *= -1.33*), while the highest were among fifth-year and above students at research institutions ($b_0$ *= 1.78*). Notably, across institution types, first-year students consistently reported lower access than more advanced peers. Additionally, students in their second or third year at HBCUs or HSIs/MSIs often had means below the population mean (e.g., second-year HBCU students: $b_0$ *= -0.89*), whereas students in their later years (fourth year and beyond) showed positive intercepts across all institution types indicating means above the population mean.

These results suggest that access to opportunities to practice professional skills increases over time, especially at research institutions, and support the mediating role of school year and institution type identified in our model. Appendix A provides the full list of the intercept values across nested groups.

**How students use social capital to access opportunities to practice professional skills across school year and institution type (RQ#3) and how students describe those opportunities (RQ#4)**

To answer RQ#3 and RQ#4 qualitatively, we first address how the data reflect differences between expressive and instrumental supports and how students use their social capital to access opportunities to practice professional skills. We then summarize student descriptions of the opportunities they used to practice professional skills in curricular, cocurricular, and extracurricular settings, facilitated by different individuals in their networks.

***Expressive Supports***

Participants described utilizing expressive support—that is, supports that encourage emotional, physical, and mental health—from strong ties (e.g., friends, family; Lin, 2001) to bolster their persistence in engineering. Students did not rely on expressive support to create or access opportunities to practice their professional skills. Although no participants related expressive support to their ability to practice professional skills, our findings suggest that these supports may more generally contribute to the decision to persist in practicing professional skills when difficulties arise.

### ***Instrumental Supports***

Students described a variety of alters in their social networks who provided opportunities to practice professional skills through instrumental supports across school years and institution types (Table 7). They utilized relationships with professors, advisors, and peers to access a multitude of opportunities to practice professional skills in curricular, cocurricular, and extracurricular contexts (Table 8).

**Table 7**

*Sources of students' instrumental support leading to professional skill opportunities*

| Alter | Type of Instrumental Support | Context |
|---|---|---|
| Professors | Involving in activities<br>Introducing to connections | Curricular cocurricular |
| Advisors | Involving in activities<br>Introducing to connections<br>Supporting with resources | Cocurricular |
| Peers | Involving in activities | Cocurricular, extracurricular |

**Table 8**

*Students' social capital accessed to practice different professional skills*

| Source of support (alter) | Professional skill | Context |
|---|---|---|
| Professors, peers | Shared leadership (leadership and teamworking) | Curricular, cocurricular |
| Professors, advisors, peers | Communication | Cocurricular |
| Professors, advisors | Problem-solving | Curricular, cocurricular |

### ***Curricular Settings***

*Professors in curricular contexts*

Students' access to professional skill opportunities in curricular contexts was primarily dependent on leveraging weak ties with the instructors teaching their courses. Students reported that many of their opportunities to practice professional skills came through their professors, whose teaching provided such opportunities. These reports came more frequently from first- and second-year students as well as students at undergraduate institutions who relied on curricular opportunities, especially in their introductory level (i.e., first and second year) engineering courses to practice professional skills. As the examples students provided were often in required courses, curricular opportunities provided easy access to professional skill practice opportunities at early points in students' academic careers.

Students across all institutions and across school years reported utilizing engineering design coursework to improve their problem-solving skills. While some participants discussed practicing other professional skills, such as communication and shared leadership skills, in curricular contexts they often described these other skills in direct relation to problem-solving skill practice. For example, Bennett, a second-year student at a research university, recalled that in a design course,

> we had to design a robot to complete some tasks involving sorting different size balls.… [The task] involved a lot of problem-solving in terms of weight constraints [and] having to use the right motors.… [It] was really fun for problem-solving [and] working in a team.

Bennett's experience illustrates the interrelation of technical expertise and problem-solving skills, which aligns with the simultaneous practice of these skills in engineering course contexts (Litzinger et al., 2011).

Participants from undergraduate institutions in particular relied on curricular context for professional skill practice and attributed many of their opportunities to practice those skills in a curricular context to stronger relationships and higher frequency of interaction between students and faculty due to small class sizes (Beattie & Thiele, 2016). Jackelob, a student at an undergraduate institution, recalled how his senior design professor spent time with him to overcome and reflect on a teamwork issue, and that the professor "was helpful with the disagreements" that arose in Jackelob's senior design project team.

> [T]hat was something I was able to go into his office and we spent a decent amount of time unpacking that, trying to figure out what had happened, what had really gone on there. That type of his perspective was very valuable in those types of things.

As well, a professor from another class provided invaluable feedback throughout Jackelob's senior design experience "even though he had no obligation to do so, he wasn't our advisor or anything, he still spent a lot of time working with us and discussing." These stronger connections from more frequent interactions may contribute to stronger social networks and increased interaction frequency between professors and students at these institutions than others.

At the same time, curricular contexts were most important for professional skill practice in the first and second years of college, and students reported relying on curricular contexts less heavily in their third and fourth years as their social capital grew. Pennelope, a student at an HSI/MSI institution, recalled a teamwork experience that helped practice professional skills from her first year in college, two years earlier, thus:

> [W]e had to develop a prototype of a prosthetic for my biomedical engineering class.… It was a group project, and I don't really know the people I was in a group with. Everybody's going to have their own idea of things. In those situations, I think it's important to do my fundamental research and then, hear people out, give my own input, and then, try to decide. If someone says, "Oh, we should make it out of this material," I have to look at that and be like, "Okay, is that durable? Is that going to hold? Is that cost efficient? Is this going to work?" If not, then you get to say, "No, let's find something else."… [W]hen judging feasibility of different ideas, it's important to relate it back to your main goal over and over again.

According to her account, Pennelope had the opportunity to practice problem-solving skills in her first year throughout the team project by evaluating multiple designs under the engineering constraints of the assignment. This experience related to Pennelope's first year, and our data shows that students rely less on structured curricular contexts to practice professional skills as they develop broader social networks.

### ***Cocurricular Settings***

*Faculty advisors and professors in cocurricular contexts*

Students reported practicing their professional skills through cocurricular opportunities—that is, opportunities that complement what students are learning in their engineering courses but are not directly connected to their coursework—such as teaching assistantship opportunities and undergraduate research with faculty (Simmons et al., 2017). These contexts allowed them to practice leadership and communication skills, sometimes with high levels of autonomy.

Participants frequently discussed discovering undergraduate research opportunities through professors and faculty advisors who directed them to meet faculty conducting research in the participant's area of interest. Frank described how his relationship with one faculty in his engineering department led him to make connections with other faculty in the department that ultimately led to the research opportunity he was working on at the time of the interview. Thus, for multiple participants, instrumental support led to opportunities to practice professional skills in participating in research opportunities. Disseminating and presenting their research findings in conference proceedings and journals became an opportunity to practice communication skills, and the research process itself posed challenges that became opportunities to practice professional skills.

A few first- and second-year students had already started practicing professional skills in undergraduate research. Olin, a first-year student at an HBCU, described generating ideas to meet a research goal of creating experimental module kits for all engineering fields as part of his undergraduate research position. Olin highlighted the autonomy he had to set objectives within that goal and manage the tasks associated with it. In this way he had practiced problem-solving skills, shared leadership (i.e., being a teammate and a leader), and communication skills through the deliverables he was assigned to create.

The difference in the opportunities of students of higher class standing like Heather and those of lower class standing like Olin demonstrate how social capital is not a static entity and changes over time, increasing involvement in research efforts and providing more intellectual contribution to the work. Heather's experience undertaking research at a research university as a fourth-year student was common amongst third and fourth year students. She described how her professor encouraged her to write a journal manuscript about her experiences in undergraduate research and took her to a professional conference in biomedical engineering. Her interactions with professors at schools where she was applying to attend graduate school were very encouraging. All of these experiences amounted to opportunities to practice written and oral communication skills for Heather, and such experiences were typical for students later in their college years. The close working relationships that students in their third and fourth years developed with professors generally led to opportunities to practice high level professional skills.

Teaching assistantships, while less commonly mentioned, also provided valuable opportunities to practice professional skills, specifically leadership and communication skills. For example Heather said this about serving as a teaching assistant for a statistics class for second-year students:

> [The students] were not only struggling with the class, but they were struggling with their career paths. So, I was there, even though I was already in my major, I was there to redirect them.… This girl was in materials science, but she wanted to do research [in]

> bioengineering and I'm like, "Why are you in materials science if you want to do [something else]? Here, I'll help you. Jump in my office hours. We'll go over your resumé [and] get you into the bioengineering field."… Even in harsh times I was able to help her pursue her dreams.

Heather's description demonstrates how she practiced her leadership skills, through "redirecting" other students, and communication skills, through advising and giving feedback. She also served as a source of social capital to second-year students.

Students who accessed teaching assistantships earlier in their college trajectory also described benefits of those opportunities to practice professional skills. Bennett, a second-year student, said that seeing how she could "hel[p] other students" through her teaching assistantship had helped "develo[p] [her] confidence and skill sets, and also encourag[ed] [her] to keep researching, keep learning so that [she could] help other people better." The professor who was in charge of Bennett's teaching assistantship also provided instrumental supports, such as help with her resumé and writing recommendation letters for her.

*Industry professionals in cocurricular settings*

Other cocurricular activities students mentioned included industry internships and co-ops, which offered opportunities for students to further their communication skills (encompassing writing, presentations, and phone conversations) and expand their professional networks. Ingrid, a third-year student at an HBCU, described how his boss went over emails with him that were intended for the client and they edited them together. He said that this helped him understand "how to email teachers and other students, and putting the information I needed in there so that everybody could understand."

*Friends and peers in cocurricular settings*

Students across all school years and institution types accessed cocurricular opportunities—such as engineering clubs and student chapters of engineering professional societies—through entry points made available by peers. These student-driven cocurricular activities were available to students at all academic levels and were more varied in terms of professional skills practiced (e.g., communication, leadership, and problem-solving skills) than those associated with curricular and cocurricular supports from faculty and advisors. However, there were fewer instances of student-driven cocurricular activities than faculty-provided curricular and cocurricular opportunities (e.g., teaching assistantships).

Samantha, a first-year student at an HSI/MSI institution, was among those who referenced student-driven cocurricular activities. More senior students invited Samantha to participate in a make-a-thon event that required that every team include a first- or second-year member, and this gave her experience practicing problem-solving skills. She said of the team:

> They all worked [together] really nicely. So there was leadership and critical thinking and there was the creative part of the project. It was kind of nice to see each part of the project and how they complement each other. And I think that kind of influenced me to learn a little bit about [leadership, critical thinking, and creativity] and apply it on my own project later on.

Samantha’s experience of accessing opportunities through her social capital aligns with past research showing that more advanced peers often have greater access to resources (Martin et al., 2020) and can use these resources to provide opportunities to younger students. Rachel, a second-year student at an HSI/MSI institution, also accessed a cocurricular opportunity because of a peer; a friend of hers contacted her over the summer and asked her to join the executive board of her school's chapter of the National Society of Black Engineers. Rachel said that she experienced "a lot of growth" through serving as treasurer, including "develop[ing] more public speaking skills, learning how to speak to a large crowd." She had also developed her leadership skills by running meetings of 20 to 50 people.

### ***Extracurricular Settings***

#### *Peers in Extracurricular Settings*

Most students participated in extracurriculars that were related to their engineering identity in some way but did not necessarily supplement their course work. For example, Samantha served as a representative on her university's student government as a representative for the College of Engineering. A few were involved in activities unrelated to their engineering coursework. These students shared their reason for participation as having little to do with professional skill growth and instead focused on social activities and employment opportunities. For example, Christina attributed her involvement in the Japanese student association to social opportunities, and Olin was paid to work as committee member for the university.

## Discussion

### Social capital as a predictor (RQ#1)

Our quantitative results showed that students' social capital—in the form of instrumental supports—is strongly predictive of their opportunities to practice professional skills, explaining approximately 10% of the variance in skill levels. While expressive supports are crucial to engineering students' persistence and well-being in their majors (Puccia et al., 2021), our findings differ in that it is instrumental supports that are the most crucial for professional skill opportunities. The value of instrumental support in providing access to professional skill development opportunities aligns with prior research on agricultural students, which found that participation in cocurricular activities offering instrumental resources—such as major-specific organizations and networks linked to professional associations—accounted for a significant portion (33%) of students' professional skill development (Gholami et al., 2020).

When analyzing the qualitative findings in light of the quantitative results, we explored social capital as a mechanism to access opportunities to practice professional skills. Similar to the quantitative findings, the qualitative findings produced little to no evidence of engineering students using expressive supports to access opportunities to practice professional skills. Instead, we found evidence of students mobilizing instrumental supports from weak ties with faculty who taught their courses to access professional opportunities. Students also reported instrumental supports from faculty advisors, professors, industry professionals, and peers in cocurricular settings. These findings illustrate the strength of an explanatory mixed methods research design, where our quantitative results found a significant relationship between instrumental supports and opportunities to practice professional skills, and our qualitative findings shed light on how engineering students mobilized these instrumental supports to practice professional skills.

While we found that instrumental social capital was predictive of opportunities to practice professional skills, some interview participants with low levels of instrumental social capital still shared rich opportunities to practice professional skills (see Table 2). These instances were less common than students who had high levels of instrumental social capital and professional skill practice opportunities but still highlighted that methods of accessing opportunities for professional skill practice can come from outside of one's social capital. These findings opens potential future work on holistic understandings of how engineering students access opportunities to practice professional skills.

**Role of institution type and year in school (RQ#2)**

The nested relationship between institution type and school year played a modest but meaningful role in predicting students' opportunities to practice professional skills. Because data were collected in 2022, we anticipated that students' entry year relative to the COVID-19 pandemic might affect their access. During the early phases of the pandemic, instructors struggled to recreate pedagogical environments conducive to collaboration and skill development in online formats (Emberley et al., 2022). These disruptions may partially explain why school year accounted for most of the observed random effects, with more advanced students (i.e., those in their fourth and fifth years) reporting greater access to professional skill opportunities across all institution types.

However, these findings are consistent with our qualitative results and existing literature suggesting that undergraduate engineering students' social capital is temporal, that is, it builds over time. Prior work has shown that students both retain early ties (e.g., family, K–12 peers) and gradually expand their networks through academic and cocurricular engagement (Martin et al., 2020; Puccia et al., 2021). Our qualitative data similarly indicated that students' later academic years involved more intentional leveraging of faculty, research mentors, and peer networks.

While institution type alone showed limited predictive power, differences became clearer when considered in combination with school year. First-, second-, and third-year students at HBCUs, HSIs/MSIs, and undergraduate institutions consistently reported below-average access, while students at research institutions reported above-average access after their first year. This pattern may reflect structural disparities in institutional resources, as research-intensive universities typically offer greater access to research programs, faculty networks, and funding for professional development (Williams et al., 2019; Fletcher et al., 2024).

These findings carry important implications for engineering programs committed to expanding equitable access to skill-building opportunities. The lower access reported by early-career students, especially at less-resourced institutions, underscores the need for intentional scaffolding of professional learning from the outset of students' academic journeys. In contrast, the relatively higher access seen in later years and at research institutions points to the cumulative advantages of structured environments and strong support networks. Taken together, these results suggest that equitable access is not automatic—it must be cultivated through both institutional investment and proactive mentoring, particularly in students' early years.

**Accessing curricular activities (RQ#3 and RQ#4)**

In pursuing a deeper understanding of our quantitative results, we qualitatively explored how students across varying institution types and school years accessed support that led to professional skill development. While coursework does not fit within the traditional conceptualization of resources being accessed through individuals' social networks (i.e., as a source of social capital; Mishra, 2020), we found that students accessed opportunities to practice problem-solving skills through weak ties with faculty and the engineering coursework assigned. Students in their first and second years of their engineering major, as well as students at undergraduate institutions, relied more heavily on curricular professional skill opportunities than other students. For first- and second-year students, this reflected their nascent social networks; for students at undergraduate institutions, it reflected lower access to undergraduate research and teaching assistantship opportunities (Dahlberg et al., 2021). Additionally, course work provided a rich but narrow variety of opportunities to practice professional skills, limited primarily to problem-solving skills.

**Accessing cocurricular activities (RQ#3 and RQ#4)**

Our qualitative results demonstrated that student access to cocurricular activities varied heavily depending on their institution type and school year. Literature shows that underrepresented and minoritized engineering undergraduate students often find support in cocurricular spaces, such as professional organizations, that bolsters their sense of belonging and persistence in their engineering studies (Campbell-Montalvo et al., 2022a, 2022b; Skvoretz et al., 2020; Smith et al., 2021). More broadly, we found in our qualitative data that students from undergraduate institutions were less likely to access cocurricular opportunities to practice professional skills than their peers at HBCU, HSI/MSI, and research institutions. This is a novel finding and could be partially attributed to the high teaching and service loads that faculty at many undergraduate institutions carry. When combined with the documented tendency for these institutions to have fewer graduate assistants to assist faculty or lead research labs, these higher teaching and service loads could be reducing faculty's availability to mentor undergraduate researchers and teaching assistants at the same rate as their peers at highly research-intensive institutions (Dahlberg et al., 2021). Faculty play crucial roles in aiding engineering students' engineering identity, persistence in their majors, and career development; without these supports, the retention and well-being of marginalized students may be particularly at risk (Sausner et al., 2024).

In interviews, students in their third and fourth year and students at research institutions described leveraging support from faculty advisors and professors to become involved in undergraduate research and teaching assistantships, where they practiced a diverse set of professional skills such as communication, shared leadership, and problem-solving. Our findings align with those of Martin et al. (2021), who found faculty provided career development support in the form of research opportunities. From students' descriptions of diverse professional skill development opportunities through undergraduate research and teaching assistantships, we concluded that students rely on cocurricular supports to develop the diverse array of professional skills they need to thrive in modern engineering workplaces.

Our interviews also revealed that first- and second-year students seldom accessed cocurricular opportunities compared to their third- and fourth-year peers. Social ties can grow over time with prolonged engagement between individuals (Granovetter, 1973), and the number of social ties is likely to increase in environments where individuals frequently engage (Corbin et al., 2023). As a result, we found that students' social networks expanded over the course of their undergraduate degree to include more professors in their field with whom they may interact in smaller, field-specific courses. Our finding is consistent with other literature that discusses the temporal nature of social capital, where students develop engineering-related social networks over time, and therefore can access opportunities from a larger number of alters as their network grows (Martin et al., 2020; Puccia et al., 2021).

In investigating the peer-to-peer social networks as described in participants' survey responses and interviews, we found that students accessed instrumental supports from friends and peers through cocurricular activities, in line with previous literature (Garrett et al., 2021; Martin et al., 2020). Cocurricular opportunities such as student-led engineering clubs and professional societies provided opportunities for students to practice practicing problem-solving, communication, and shared leadership.

The role of friends and peers in accessing cocurricular opportunities showed no discernable differences across institution type or school year in the qualitative findings. Likewise, institution type did not affect how students reported accessing professional skill opportunities from friends and peers. However, in the few situations where first- and second-year students shared that they accessed support through cocurricular organizations, their roles differed from those of their more advanced peers. Less advanced students described being assisted and guided by their peers to access professional development opportunities through their organizations, while more advanced students described taking active and leadership roles in organizations and clubs, creating deeper and rich opportunities to refine their communication and leadership skills.

## Limitations

Our findings should be interpreted with awareness of the context in which data were collected, particularly the varying impacts of the COVID-19 pandemic. Students' educational experiences differed based on their year in school and their institution's pandemic response.

While we expected disruptions during students' first year to influence access to social capital, especially for second- and third-year students, our findings did not indicate this was a major source of variance. Another limitation relates to the fact that our sampling focused on variation across institution type and school year, which limited our ability to examine differences in social capital and opportunity access by race, gender, or other intersecting identities. Future studies should explore these dimensions to better understand structural inequities in access to professional skill development.

Despite intentional recruitment efforts, students from HBCUs were underrepresented in our sample. We mitigated this by oversampling and conducting careful data validation, resulting in comparable variance in social capital scores between HBCU and research institutions. Nonetheless, future research should focus more deeply on HBCU contexts to better understand student experiences and opportunity structures. Finally, student-reported opportunities to develop business management skills were lower than for other professional skills, which limited the emphasis on this area in interviews. Future work should examine why this gap exists and how to expand access to these less commonly practiced, but equally important, skill areas.

Additionally, our study is limited to understanding the relationship between social capital and opportunities for practicing professional skills and how social capital serves to provide access to those opportunities. Future research should explore how students are afforded those opportunities through means other than their social capital.

## Conclusion and Future Work

Engineering undergraduate students need access to opportunities to foster their development of professional skills that are essential for their growth as engineering professionals. This study provides a significant contribution to understanding how engineering students gain access to professional skill development opportunities by identifying where these opportunities exist and then examining how social capital enables access to them. By combining predictive modeling with qualitative analysis, we demonstrate that instrumental social capital is a key mechanism through which students engage in professional development.

Our results show that engineering students draw on relationships with professors, faculty advisors, and peers to access opportunities in curricular and cocurricular spaces, particularly for practicing communication, leadership, and problem-solving skills. We also found that access is not uniform. Students' ability to access social capital to practice professional skills varies by institution type and academic year, with more advanced students and those at research-intensive institutions reporting greater opportunities. This work thus moves beyond prior studies focused on belonging or persistence to provide empirical and conceptual clarity on the relationship between social capital and access to professional learning.

By identifying the mechanisms through which students access professional development opportunities, this study offers actionable insights for faculty, advisors, and institutional leaders aiming to promote equitable access. Supporting the cultivation of instrumental social capital, particularly for early-year students and those at smaller or lower-resourced campuses, can help close opportunity gaps and better prepare all students for the demands of engineering practice. Faculty can play a vital role by connecting students to research, teaching assistantships, tutoring roles, and cocurricular activities such as engineering clubs or professional societies. At teaching-focused institutions, faculty may also guide students toward external opportunities, such as summer undergraduate research programs at research-intensive universities or participation in international exchanges, that can broaden access to social capital beyond local constraints. Extracurricular spaces like student government offer further avenues for practicing communication and leadership skills, and peer encouragement remains an important catalyst in helping students navigate and pursue these opportunities.

In sum, this study provides empirical and conceptual clarity on how engineering students' social capital functions as a gateway to professional skill development opportunities. By identifying instrumental support as a key predictor of access, and revealing how students mobilize these networks across institutional and developmental contexts, we illuminate a pathway that is often overlooked in engineering education. As professional formation is deeply relational and unevenly distributed, expanding access to supportive networks must become a priority for institutions committed to equity. Future work should continue to explore how social capital evolves over time and intersects with students' identities to shape their professional trajectories.

## Declarations

### *Human ethics and consent to participate*

This work was approved by [blinded for review] Institutional Review Board under protocol number [blinded for review].

### *Availability of data and materials*

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

### *Competing interests*

The authors declare that they have no competing interests.

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***Authors' contributions***

Author 1 (A1), A2, and A5 made substantial contributions to the conception, design, and supervision of this work. A3 analyzed and interpreted the quantitative dataset. A4 analyzed and interpreted the interview data along with A3 and A6. A3 and A4 were major contributors in writing and editing the manuscript; A6, A2, A5, and A1 substantially edited and reviewed this manuscript. All authors read and approved the final manuscript.

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***Consent to Publish Declaration***

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## Appendix A

**Table A**

*Random effects intercepts—interpreted as variations from the population mean—for each nested group.*

| School year | Institution type | Random Effects Intercepts |
|---|---|---|
| - | Research | 0.022 |
| - | Undergraduate | -0.013 |
| - | HSI/MSI | -0.011 |
| - | HBCU | 0.00059 |
| 1 | Research | -0.64 |
| 1 | Undergraduate | -1.33 |
| 1 | HSI/MSI | -1.19 |
| 1 | HBCU | -0.46 |
| 2 | Research | 0.0063 |
| 2 | Undergraduate | -0.41 |
| 2 | HSI/MSI | -0.89 |
| 2 | HBCU | -0.22 |
| 3 | Research | 0.95 |
| 3 | Undergraduate | -0.37 |
| 3 | HSI/MSI | -0.59 |
| 3 | HBCU | -0.17 |
| 4 | Research | 0.31 |
| 4 | Undergraduate | 0.64 |
| 4 | HSI/MSI | 0.95 |
| 4 | HBCU | 0.42 |
| 5 | Research | 1.78 |
| 5 | Undergraduate | 0.14 |
| 5 | HSI/MSI | 0.57 |
| 5 | HBCU | 0.49 |