Research Article

From Academy to Workplace: Perceptions of Engineering Communication Skills

—Eva R. Brumberger and Allison J. T. Ellsworth

***Abstract*—Background:** *Practitioners, academics, and accrediting boards all recognize the importance of communication to the work of engineers, but ensuring that engineering students graduate with effective communication skills continues to be a challenge for programs. Our project examines this problem within our institutional context, with the goal of serving local needs while extending the literature on engineering communication.* **Literature review:** *Prior research identifies communication skill gaps, examines the effectiveness of various approaches to teaching engineering communication, and highlights issues of knowledge transfer. Few studies collect both academic and practitioner perspectives.* **Research questions:** *1. How effectively does the required first-year course provide students with foundational engineering communication skills? 2. How much do students' communication abilities improve by the time they complete the engineering capstone course in their final semester? 3. To what extent are engineering students graduating with the communication skills they will need to succeed professionally?* **Research methodology:** *This study involved technical and professional communication instructors' analysis of student communication work from two courses: 1. first-year engineering communication and 2. the engineering capstone. The study also included surveys of and follow-up interviews with engineering practitioners regarding the communication skills of capstone students and recent engineering graduates more generally.* **Results:** *Student work from the first-year engineering communication course was weak; communication work from the capstone was not substantially stronger, even though students were provided with a detailed template for each assignment. The survey and interviews suggest that practitioners tended to view capstone students' communication skills favorably but found the skills of new hires who were recent graduates to be weaker.* **Conclusions:** *The data emphasize the shortcomings of stand-alone communication courses, issues with knowledge transfer, and the role of institutional contexts.*

Index Terms*—Curriculum design, engineering communication, industry communication practices, industry partnerships, pedagogy.*

Engineering practitioners, academics, and accrediting boards alike acknowledge the importance of communication to the work of engineers. Yet, ensuring that engineering students graduate with the communication abilities they will need for workplace success continues to be a challenge. The project that we discuss here examines this problem within our institutional context, with the dual goal of better serving local needs and adding to the body of literature on engineering communication.

Although the Accreditation Board for Engineering and Technology (ABET) criteria specify that students should graduate with the ability to "communicate effectively with a range of audiences" [1], that statement is sufficiently vague that simply incorporating some level of communication instruction may seem, at least on the surface, to meet the requirement. However, engineering faculty typically have neither the training nor the interest in teaching communication skills on top of the engineering material they are already teaching.

Alternative models exist for incorporating communication instruction that is typically provided by technical/professional communication (TPC) faculty rather than engineering faculty. There is wide variation in these initiatives, ranging from programs like that at Cornell, with dedicated faculty members and courses, to communication labs like those at MIT, to singular communication courses (sometimes engineering-specific, sometimes more general) taught by faculty from technical communication or other communication-centric programs.

Arguably, the most common strategy entails simply requiring students to complete a technical communication "service" course offered by the institution's TPC or similar program. Although this is certainly the simplest approach and the most cost-effective in purely monetary terms, it is

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Practitioner Takeaway

- TPC faculty found that first-year and final-year engineering students did not differ substantially in their communication abilities.
- Engineering practitioners indicated that new hires who are recent graduates are not very strong in any communication areas and are only adequate in developing content that demonstrates consideration of user needs.
- The academic and practitioner perspectives suggest strongly that engineering students still are not graduating with the communication skills needed for the engineering workplace and point to the need for large-scale collaborative studies both within the academy and between faculty and practitioners to address this longstanding issue.

arguably also the least effective, since such a course typically serves students from multiple majors; the course content will not necessarily be matched to the communication work expected of junior engineers.

Having embedded TPC faculty teach alongside engineering faculty in key courses throughout the curriculum seems to be a more effective, although less common, solution. There are logistical challenges with this approach, including, among others, issues of scheduling and accounting for cotaught courses, as well as the differential pay scales for TPC and engineering faculty. In addition, even these cotaught courses need to be approached carefully to avoid a perception that communication skills are secondary to the engineering content.

In between these two extremes is a third option: adding dedicated engineering communication courses to the curriculum. A key issue here is that most undergraduate engineering curricula are already so extensive that many students struggle to graduate in four years, so adding nonengineering courses—even courses vital to professional success—is extremely difficult. Some programs do require a dedicated communication course—typically later in the curriculum—but even when such courses are added, the situation is still complex. The courses are typically taught by TPC faculty who have the expertise to teach communication courses. However, TPC faculty most often do not have academic backgrounds or professional experience in an engineering field.

In addition, most faculty teaching these courses—whether they are embedded within an engineering program or, more commonly, have their academic home within a TPC program outside of engineering—typically hold nontenure-line positions with heavy teaching loads. This makes it difficult to conduct research in engineering communication practices. Still, having TPC faculty teach engineering communication courses is often the most feasible approach, particularly with appropriate support from and effective collaboration with engineering partners. It is this approach that serves as the starting point for our project.

In the sections that follow, we provide a brief overview of the existing literature; introduce the structure, research questions, and methodology of our project; and discuss what we found, along with implications and directions for future research. Although the project by necessity focuses on our local context, it should prove helpful for technical communication faculty at other institutions who are tasked with addressing engineering communication needs.

Literature Review

Numerous scholars have investigated and identified patterns in engineering communication, from discipline-specific patterns to patterns in engineering students' writing that differentiate their communication from that of practitioners. For example, de Souza Almeida and Becker [2] explore engineering communication in four industry sectors: high-tech, automotive, aerospace, and manufacturing. Communication was considered critical and tied to career advancement across all sectors. Key aspects of communication, irrespective of industry, included clarity, concision, and audience awareness. Engineers across industries communicated with multiple types of audiences and stakeholders through a range of genres. Other scholars have identified some of these same areas as weaknesses among engineering students. For instance, Conrad [3], [4] explores stylistic issues (e.g., indiscriminate use of passive voice, wordiness, overly complicated sentence structures,

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etc.) that reflect students' misconceptions about what constitutes effective communication in civil engineering. Similarly, Li et al. [5] identify important communication areas that seem especially difficult for students (particularly audience awareness and visual communication) and raise a key point: simultaneously learning complex engineering content and learning how to communicate that content may make the latter especially challenging. These findings seem to echo the work reported by Leydens [6], who found that students and practitioners differ from one another in their recognition and understanding of the role and impact of rhetoric in engineering communication.

Of course, identifying the skill gaps is only the first step, albeit a critical one. Ultimately, we need to figure out how best to address those gaps, so that students enter the workforce with a foundation in communication skills that will enable them to succeed as junior engineers and to advance in their careers. Scholars have explored various approaches to improving the effectiveness of engineering communication instruction. These include bottom–up pedagogical strategies developed by individual instructions for use within their courses, such as incorporating game-based techniques to increase student engagement [7] and adding explicit instruction on grammar and mechanics [8]. Although these efforts may improve the outcomes for specific courses, they are less successful at shifting communication from its position as a "marginal activity" [9, p. 175]—an add-on that students see as "downstream" of and distinct from the engineering work in the curriculum [9, p. 169].

Multiple studies have examined the benefits of incorporating communication instruction into engineering classes. At the least, this more extensive top–down approach provides students with increased opportunities to practice engineering communication, which improves students' confidence, as well as their skills [10]. A systematic approach involving engineering faculty training in addition to communication outcomes and assignments that are distributed and scaffolded throughout the curriculum may have considerable impact, although such an effort requires buy-in from both the engineering leadership and a core of committed faculty [11], [12].

Beyond improvement in students' communication outcomes within specific courses is a second and, in the long term, perhaps more critical benefit of an integrated approach. Many engineering students approach communication with the preconceived notion that they are strong in math and weak in writing [5] and that communication assignments interrupt and even interfere with their engineering work. A situated-learning approach, in which rhetorical work is embedded within the context of engineering, may help to address these ideas [13] and may also help to confront the technical/social dualism prevalent within engineering curricula, which positions nontechnical work as separate and subordinate [14]. In short, an integrated, situated-learning approach may encourage students to think about communication as integral to engineering and to their identity as engineers [15].

The transfer of knowledge is perhaps the most crucial aspect of closing the communication skill gap. As Boiarsky [16] explains, learning strategies, such as audience awareness, organization for different purposes, and so on, are only the first step; students then need to learn to apply that knowledge to new communication tasks and contexts, a process that takes place both unconsciously and through conscious behavior based on prior experience. This process depends upon helping students see writing as part of engineering and on helping them understand the connections between what they have already learned and new communication situations. If students do not recognize the similarities among writing tasks across different contexts, transfer of rhetorical strategies is less successful [17]. For example, Ford [17] found that some students did not see the connections between rhetorical strategies taught in a technical writing course and the writing in their senior-level industrial engineering course. The rhetorical knowledge that they transferred was typically more tangible (e.g., genre awareness); they also recognized and applied the idea that writing is a process—a concept familiar to them from their engineering work. However, they were less successful at transferring more abstract rhetorical knowledge (e.g., audience and purpose). The exceptions were students who had practice utilizing rhetorical strategies in professional engineering settings, such as internships and co-ops. These experiences led the students to see writing as a higher-stakes activity, one with professional impacts.

As Kim and Olson [18] report, crafting a pedagogical approach that focuses explicitly on the transfer of rhetorical knowledge can have positive outcomes. They designed a transfer-focused module for use in gateway lab courses,

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re-introducing important concepts from the students' first-year writing course, including an emphasis on audience and style. They found that using a transfer-focused approach to teaching engineering lab reports led not only to better quality work from students, but also to their improved understanding of the rhetorical aspects of engineering communication and of lab reports as discipline-specific.

The transfer process is vital to building students' communication knowledge from course to course, but it is even more critical for knowledge transfer from the academy to the workplace. No matter how outstanding the instructional strategies and academic outcomes, if students do not apply their learning in their professional positions, all that work is essentially lost. Here, again, the literature emphasizes the importance of connecting the unfamiliar to the familiar [12].

In a study investigating new engineers' first three months on the job, Ford et al. [19] found that virtually all participants reported challenges related to teamwork and communication. Some of these challenges were due to navigating communication situations that were unfamiliar. They involved far more complexity than communication requirements encountered as a student, in large part because of much greater audience diversity in age, expertise, and discipline. The authors describe communication and teamwork as being among the most "foreign" and "complex" aspects of students' transition to the workplace [19, pp. 2002] and emphasize the value of engineering capstone courses that not only integrate prior knowledge but also foster self-directed learning, so that students are prepared to transfer this knowledge successfully to new situations.

Reporting on the same study, Ford et al. [20] similarly highlight the challenges that new engineers face due to the complexity and context-dependence of the communication required in the workplace compared to that in school. They emphasize that the gap is a context gap rather than a content gap and suggest that educators may be able to reduce it by helping students understand not only the genres common in engineering communication but also the situations to which those genres typically respond and the ways in which the two are connected. They also point to the need for students to recognize the importance of flexibility in adapting to new communication contexts.

Finally, one of the key findings from the literature on transfer, and one that likewise is visible in the literature on integrating communication into engineering curricula, is the importance of partnerships. For example, Ford and Riley [21] highlight numerous collaborations between communication and engineering programs that have resulted in a range of positive impacts for students. Similarly, Li et al. [5] emphasize the ways in which such collaborations, their own included, benefit not only the students but also the faculty themselves. The collaboration relies on the expertise of both groups, and ultimately, both groups acquire knowledge that can help them be more effective in the classroom. Again, such partnerships require the leadership and full support of administrators from both areas to be successful [11], [12].

Like cross-disciplinary collaborations, partnerships with industry practitioners can be beneficial in helping to bridge the gap in communication skills that persists between academic programs and workplace needs. For instance, Fries et al. [22] discuss the ways in which designing an engineering capstone course around industry-sponsored projects led to improved communication outcomes. Likewise, Ford et al. [20] suggest that involving industry partners in the engineering capstone can be beneficial to reducing the context gap between academic and workplace communication tasks.

Our project extends this body of literature through a two-pronged approach that collected both academic data and practitioner perspectives, the first through an examination of student communication work, and the second through a survey of and follow-up interviews with industry members who are closely connected to the engineering program on our campus.

Research Questions

A key goal of our project was to evaluate the effectiveness of the current model of engineering communication instruction within our local context, and, depending on the results of that exploration, to recommend potential approaches that might better serve student and program needs. Although the questions and resulting data are by necessity focused on our local context, our findings have implications for other institutional contexts as well. The following research questions drove our project.

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RQ1. How effectively does the required first-year course provide students with foundational engineering communication skills?

RQ2. How much do students' communication abilities improve by the time they complete the engineering capstone course in their final semester?

RQ3. To what extent are engineering students graduating with the communication skills they will need to succeed professionally?

Research Methodology

After considering the various strands of the literature discussed above, consulting with engineering communication faculty at other institutions, talking with members of the industry advisory board for the engineering school on our campus, and thinking carefully about the range of stakeholders (students, faculty, ABET, advisory boards, and future employers), we concluded that addressing our research questions required a multifaceted approach that would involve not only evaluating student work but also gathering practitioner perspectives. We opted to review student work from the first-year engineering communication course and from the second semester of the year-long program capstone because these two courses serve, in a sense, as bookends, allowing us to evaluate students' communication skills early in the program and just before graduation. To collect practitioner perspectives, we surveyed and conducted follow-up interviews with two groups of practitioners. We submitted each piece of the project for Institutional Review Board approval; all aspects were either approved or exempted.

Evaluating Students' Communication Work—First Year The initial step in our project involved evaluating the communication work of first-year students in the engineering program. The first-year course is the only required dedicated engineering communication course and, at the time we collected our data, served approximately 450 students each year. The course is intended specifically for engineering students, which the literature suggests should lead to better outcomes in terms of student attitudes toward communication than simply requiring a more general communication course [15]. At the request of the engineering school, the technical communication program had redesigned and taken over the teaching of the course in 2018. The reason for the requested change was that engineering faculty felt that they did not have the expertise necessary to teach the course, nor did they want to continue teaching it. At the same time, they acknowledged that students were weak in communication, particularly written and visual communication, and that students needed more effective instruction in that area.

The redesigned course is rhetorically focused, with particular emphasis on audience and purpose, including a brief introduction to user experience. The course includes instruction on basic principles of visual communication early on, and this is built upon and expanded in a later module focused on simple data visualization and incorporating visuals into documents. Throughout the term, students are asked to apply rhetorical concepts as they practice crafting typical genres of engineering communication, and they receive feedback on drafts of their work.

We collected two semesters of student work from multiple sections of the revised course. After removing all identifying information, we examined a combination of individual and team projects (n = 499), all of which were due in the second half of the course:

- Instructions (individual and team)
- Proposals (individual and team)
- Progress reports (individual)

Each assignment was scored on a scale of 1–4 (1 = limited, 2 = developing, 3 = competent, and 4 = proficient), which assessed developmental progress in six areas (see Table I):

- Audience/user focus
- Purpose
- Organization, flow, and coherence
- Language and style
- Visual communication
- Genre awareness

Following a norming process, each author reviewed every assignment independently. We subsequently reviewed and independently rescored assignments for which our evaluation scores differed by more than one point [23].

Evaluating Students' Communication Work—Final Year We followed a similar process for examining the capstone work of engineering students in their final semester, but with the support of a grant, we were able to involve four additional technical communication faculty in the evaluation process. The capstone is a project-based

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TABLE I
FACULTY EVALUATION OF STUDENT WORK—FIRST YEAR (1 = LIMITED, 2 = DEVELOPING, 3 = COMPETENT, 4 = PROFICIENT)

Assignment	Audience	Purpose	Organization	Language	Visual Communication	Genre Awareness
Individual Instructions	1.77	2.17	1.97	1.92	1.66	1.83
Team Instructions	3.79	3.81	3.60	3.25	3.02	3.33
Individual Proposals	1.78	1.87	1.74	1.78	1.56	1.72
Team Proposals	1.93	2.11	2.03	2.14	1.69	1.95
Individual Progress Reports	1.37	1.75	1.50	1.66	1.22	1.42

TABLE II
FACULTY EVALUATION OF STUDENT WORK—FINAL YEAR (1 = LIMITED, 2 = DEVELOPING, 3 = COMPETENT, 4 = PROFICIENT)

Assignment	Audience	Purpose	Organization	Language	Visual Communication	Genre Awareness
Critical Design Review	2.13	2.14	2.18	2.34	1.93	2.43
Project Plan	2.07	2.12	2.20	2.16	1.73	2.25
Briefing	2.32	2.28	2.24	2.08	2.00	2.29
Individual Status Report	2.54	2.52	2.53	2.38	2.81	2.76
Team Status Report	2.43	2.39	2.30	2.14	2.16	2.55
Poster	1.82	1.90	1.71	1.93	1.67	1.71
Final Report	2.24	2.75	2.33	2.47	2.14	2.50

course in which teams of students work with an industry partner on projects sponsored by that partner's organization. The course is taught by engineering faculty; no technical communication faculty are involved. We collected 300 student artifacts from the capstone; we also collected the instructions for each of the seven assignments that generated those artifacts (see Table II):

- Critical design review (team)
- Project plan (team)
- Project briefing (team)
- Status report (one team, one individual)
- Poster (team)
- Final report (team)

Due to nondisclosure agreements with some of the industry partners sponsoring projects, we had to omit eight of the artifacts from the review, leaving a total of 292, of which 179 were collaborative and 113 were individual. Following an extensive norming session, each artifact was reviewed independently by two faculty members, using the same rubric that was used for the first-year course. The authors individually rescored assignments for which the first two reviews differed by more than one point on any of the rubric areas.

Collecting Practitioner Perspectives The goal of the practitioner surveys was to better understand practitioner viewpoints regarding communication needs in their industry contexts and whether new graduates are coming to the workplace with the communication skills they will need for professional success. Engineering practitioners are unlikely to have the TPC faculty's rhetorical training and framework for evaluating communication, which may lead the practitioners to label things differently or focus on more concrete aspects of communication (e.g., grammatical correctness). Still, they can provide insights that academics, particularly those who are not themselves engineers or do not have experience in the engineering workplace, may not be able to provide.

We conducted surveys of two groups of practitioners: 1. The 27 practitioners who comprise the industry advisory board for the engineering

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school and 2. the 29 industry partners who serve as mentors for the engineering capstone course and therefore have first-hand experience with both graduating students and the workplace. Both surveys included a combination of Likert scale, ranking, and open-ended questions. (The surveys may be obtained by contacting the corresponding author.) The two surveys shared a core of detailed questions about the communication demands and priorities of the engineering workplace, with particular attention to the work of junior engineers. These core questions focused on rhetorical strategies (e.g., tailoring content and style to intended users) as well as issues of clarity, conciseness, correctness, and so on. Both surveys also asked participants to comment on changes that they have seen in the communication needs of their organization over the past two years, as well as changes that they anticipate over the next 5–10 years.

In addition to these shared questions, we asked the 27 industry advisory board members about the communication abilities of new hires who had recently completed an undergraduate engineering program. Although the companies represented by the advisory board members do hire from our program, they also hire widely from numerous other programs; thus, these survey results offer a more general benchmark. The survey of the 29 capstone partners instead asked about the communication abilities of our local engineering capstone students specifically. For questions that asked about respondents' perceptions of communication abilities, we utilized a 5-point Likert scale (very strong, somewhat strong, adequate, somewhat weak, and very weak) to provide respondents with a neutral option, something we intentionally omitted from the TPC faculty's evaluation of students' actual coursework.

Each survey was administered via a recruitment email with a link to the appropriate Qualtrics survey. Each survey took approximately 10 minutes to complete. The small size of each group of practitioners precluded in-depth statistical analysis, but we used descriptive statistics to identify patterns in the responses.

We conducted follow-up interviews with respondents from both practitioner groups who indicated their willingness to participate further. Most of the interview questions were designed to elicit more in-depth responses to areas asked about on the survey, such as their perceptions of new engineers' most significant communication shortcomings. We also wanted to learn more about patterns regarding communication in participants' workplaces (e.g., the use of templates in crafting documents and presentations) as well as the career trajectory of engineers in their field who do not communicate well.

Results and Discussion

Students' Communication Abilities Students in the first-year course were not consistently competent (a score of 3+) on any of the categories in the evaluation rubric (see Table I). As one might expect, the outcomes were somewhat stronger for the team-based assignments. In fact, the only assignment on which all categories received a 3+ was the team instructions project; the difference between the individual and team instructions project was substantial. In this case, however, topic differences for the projects almost certainly played a significant role. The team instructions were rarely engineering-specific and were often obviously sequential in nature (e.g., how to get from one location on campus to another), while the individual instructions were typically more engineering-related and more technical in their focus (e.g., how to build an LED light siren with a breadboard, Arduino, resistors, etc.). Thus, a significant portion of the stronger outcomes for the team instructions could be the result of the topics chosen rather than the collaborative nature of the project. Notably, the difference between the individual and team proposals was far less pronounced, and the team proposal did not demonstrate competence in any of the outcome areas.

Across all assignments, students' weakest area was visual communication, followed by audience awareness, although the pattern varied slightly for the different genres. Overall, the patterns in the data indicate that students struggled to communicate effectively and would have benefitted from more engineering communication instruction.

Certainly, by their final year in the program, students have gotten more practice in engineering communication, and we therefore hoped to see that their communication work from the engineering capstone course was substantially stronger, even without instruction focused explicitly on communication. In addition, the capstone course centers on industry-sponsored projects and involves the industry partners at each step of those projects, which the literature suggests should lead

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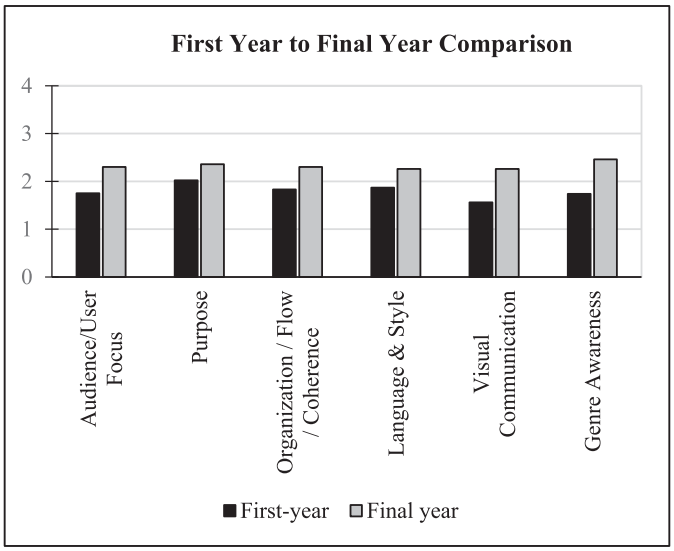

Fig. 1. Change in communication skill.

to improved communication outcomes [22]. However, the work from the capstone revealed similar patterns to that from the first-year course. TPC faculty found that students in the second semester of their final year still were not competent (a score of 3+) in any category (see Table II).

Although there was only one individual project, it shows an interesting reversal from the first-year course: student work on the individual status report was slightly stronger than the work on the team status report. Otherwise, students' communication abilities were roughly comparable across genres, with one notable exception: the poster was substantially weaker than the other assignments.

Overall, the artifacts suggest that students' communication abilities had developed only modestly by the end of the program (see Fig. 1). The most notable improvements were in visual communication and genre awareness.

However, there were critical differences between the two courses that almost certainly accounted for a significant portion of the changes observed. The first-year course is taught by TPC faculty, and its focus is entirely on communication. The course foregrounds the rhetorical elements of audience, purpose, and context, and asks students to use these as the basis for decision making about all other aspects of communication (style, organization, etc.). As such, the course takes a problem-solving approach to engineering communication rather than a prescriptive approach. Assignment instructions remind students to consider the aspects of the rhetorical situation as they determine what information to include, how to organize it, what visual elements are important, etc., a thinking process scaffolded throughout the course.

Not surprisingly, the primary focus of the capstone course is the engineering projects; the communication work is secondary and is not taught by the engineering faculty in any explicit way that we know of. In addition, rather than asking students to think critically about how best to craft their communication artifacts, the assignment instructions are detailed and prescriptive, providing students with the purpose for the assignment and including detailed lists of the items and information to be included. Students are also provided a template for each assignment that dictates the overall layout and organization. Most of the assignments must be completed as PowerPoint slides, an approach that introduces its own set of rhetorical constraints, and, in some cases, the actual number of slides (and what should go on each slide) is specified in the instructions. Finally, for all assignments save the poster, the primary audience is the industry partner.

Unlike the other capstone assignments, the poster requires a significant level of rhetorical problem-solving. The posters are presented at an Innovation Showcase on campus at the end of the semester. The instructions for the assignment are very brief—only half a page. They indicate that the Showcase is intended to appeal to "a general audience"; its goal is to celebrate students' accomplishments with all the other teams, industry partners, and the students' "friends and relatives, and anyone else [they] might want to invite." Beyond that, the instructions specify that the poster should summarize students' work on the project and must use one of the PowerPoint templates provided. The reduced specificity and the much broader audience of both engineers and laypersons make this assignment rhetorically challenging. Although posters are unquestionably a difficult genre under the best of circumstances, it is noteworthy that this one assignment, which demanded rhetorical problem-solving not evident in any of the other assignments, had markedly weaker outcomes.

In the end, the way that the communication assignments are approached in the capstone raises

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questions regarding the communication improvements that we observed. It is probably safe to conclude that the improvement in genre awareness was due to the templates provided to students. We are unable to say with certainty whether the changes in the remaining areas are the result of the "fill-in-the-blank" nature of the capstone work, whether they are related to the more abbreviated writing style prevalent in PowerPoint, whether they reflect some actual improvement in students' communication abilities or some combination thereof. In any case, the data suggest that any improvement is modest at best.

Ultimately, then, the evaluation of student work from both the first-year and capstone courses addressed our first two research questions.

RQ1. The required first-year course, by itself, is not effective at providing students with foundational skills in engineering communication.

RQ2. It does not appear that students have developed substantially stronger communication abilities by the second semester of senior year.

The evaluation of student work from the capstone also begins to address our final research question.

RQ3. From our perspective as technical communication instructors, students do not appear to be graduating with the communication skills they will need to succeed in the engineering workplace.

The practitioner survey and interview results offer a nonacademic perspective on this question, a perspective that is critical if programs are to better prepare students for the communication needs of the future workplaces.

Practitioner Perspectives Nine of the 27 advisory board members (33%) completed the entire survey; one additional board member completed Parts I and II of the survey—we have included that participant's data where appropriate. In total, 17 of the 29 capstone partners (59%) completed the entire survey. On average, advisory board participants had worked as engineers for 21–25 years, while capstone partners averaged 16–20 years. The average company size for both groups of respondents was 1000–5000 employees. Survey respondents represented a broad range of engineering specialties. We were able to conduct follow-up interviews with five survey participants (four advisory board members and one capstone mentor).

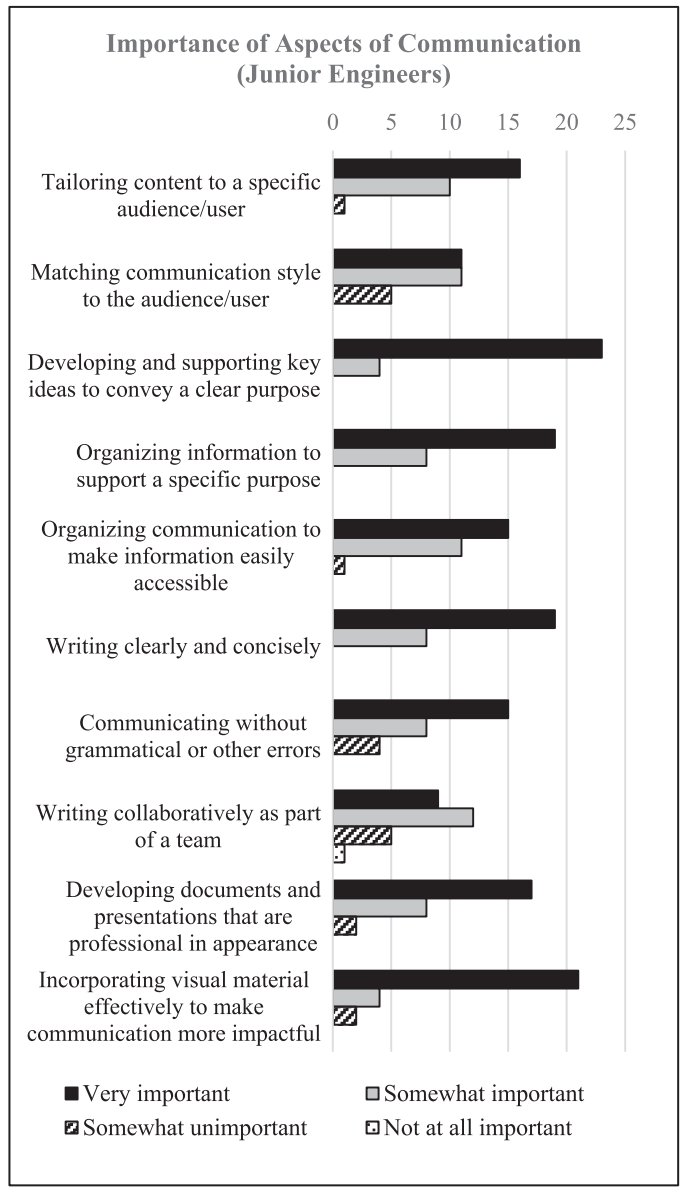

Fig. 2. Importance to communication work of junior engineers.

For the questions that appeared on both surveys, the pattern of responses was comparable across the two participant groups, so we discuss those results as an aggregate (participant $n = 27$). Both groups of practitioners indicated that written, oral, and visual communication all play an important role in their organizations and that their engineers communicate via a broad range of genres (reports, proposals, presentations, etc.).

We asked participants about the importance of several aspects of communication to the work of junior engineers (see Fig. 2). With two exceptions, each aspect that we asked about was seen as very

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important by well over half (58% or more) of the participants. The exceptions were writing collaboratively and matching style to the audience.

Although they noted that much of the communication work is collaborative, only 35% of participants indicated that writing collaboratively as part of a team is a very important skill for junior engineers. One explanation for this apparent contradiction could be that practitioners may see collaboration as being less about the writing itself and more about the overall team communication or team process. The interview data reinforced this idea. Every participant spoke about the importance of collaboration in producing documents, but the nature and scope of the collaboration varied. For example, one interviewee estimated that "eighty-percent of our documents are to some extent collaborative," noting that all their proposals and reports are written collaboratively, with multiple engineers contributing content that is "merged together" (I1). Meanwhile, although multiple engineers contribute slides for presentations, the team lead ultimately crafts the presentation. Another interviewee described collaboration as a blend of writing and "a very robust peer review system" (I3). A third offered the following, which seems to sum up the role of collaboration in each of the interviewee workplaces: "It's pretty rare for one person's document to go from beginning to end without having some review or collaboration with our peers or their managers" (I4).

Surprisingly, only 42% of participants found matching style to the audience to be very important for junior engineers, although 62% said that tailoring content to specific audiences was very important. Again, these results seem somewhat contradictory. However, participants did indicate that most of the communication at the junior engineering level is internal, with only a limited amount directed at lay audiences. This may contribute to the perception that, at this level, style is less important.

Meanwhile, developing and supporting key ideas was identified as very important by the greatest number of participants (88%). Incorporating visual material effectively was a close second, seen as very important by 81% of participants. Almost three-quarters (73%) of participants said that writing clearly and concisely and organizing information to support a specific purpose were both very important.

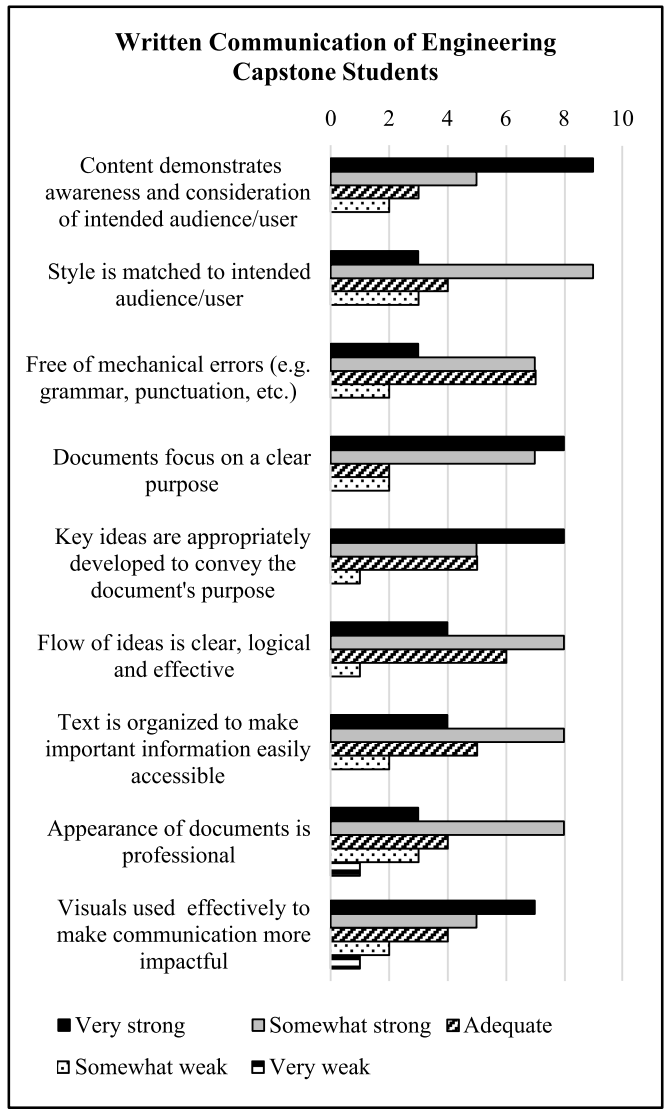

Fig. 3. Communication abilities of capstone students.

Do practitioners think that capstone students who are about to graduate—and engineers who have recently graduated—exhibit the requisite communication abilities? The survey responses were mixed, with the responses regarding our capstone students differing rather sharply from the responses regarding recent graduates more generally. Again, a 5-point Likert scale was used for these questions, allowing respondents to evaluate abilities as very strong, somewhat strong, adequate, somewhat weak, or very weak.

The capstone partners ($n = 17$) evaluated students' communication abilities quite favorably (see Fig. 3). Almost half (47%) of the industry partners found that the capstone students were very strong in

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developing content that demonstrates awareness and consideration of the intended audience/user, focusing on a clear purpose (42%), and developing key ideas to support the purpose (42%). Participants tended to find the students stronger at considering audience and purpose in oral communication than in written communication.

More than one-third (37%) of the capstone partners felt that the students were very strong at using visuals effectively, and 37% or more of respondents found that the capstone students were somewhat strong in the remaining communication areas.

Given our own evaluation of the capstone students' communication work, we were rather surprised by these results. It is possible that, as Fries et al. [22] suggest, students' communication was stronger in their direct interactions with the industry partners, which may have colored the partners' responses. It is also possible that the capstone partners' perceptions were shaped somewhat by the way the course is structured. As the partners build mentoring relationships with their student teams, the focus is on the engineering, not the communication. The partners do not provide mentoring about communication; rather, the completed communication work is presented to them via templates designed specifically to meet the mentors' needs. It may be that the mentors evaluate the written work less stringently because it is presented to them orally as well.

Meanwhile, advisory board survey participants ($n = 9$) were much less enthusiastic about the communication abilities of new hires who had recently completed an engineering degree. Again, these data reflect recent graduates in general, not new hires who are graduates of the local program, specifically. Advisory board respondents indicated that recent graduates are not very strong in any of the previously mentioned aspects of communication (see Fig. 4).

More than half (56%) of participants said that recent graduates are somewhat strong in their ability to develop key ideas, while 44% found recent graduates somewhat strong in their ability to produce documents that focus on a clear purpose. In addition, 44% indicated that recent graduate new hires are somewhat strong in crafting documents free of mechanical errors (e.g., grammar, punctuation, etc.).

However, 78% of advisory board participants found recent graduates to be only adequate in developing

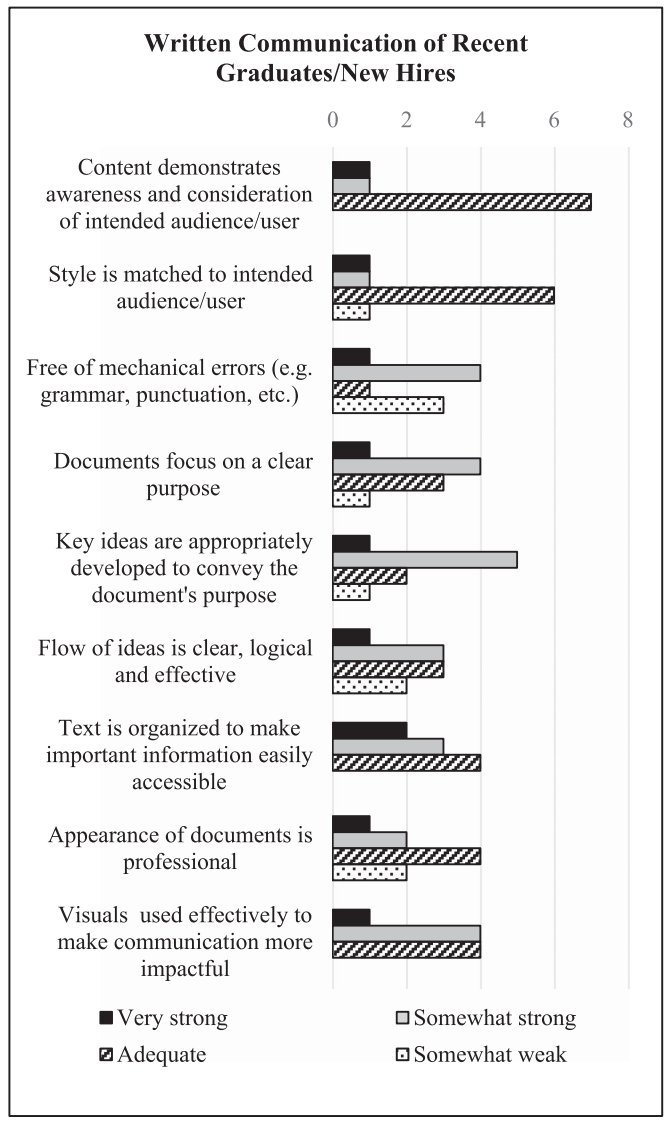

Fig. 4. Communication abilities of recent graduates/new hires.

content that demonstrates awareness and consideration of audience needs. Interview responses reinforced this finding, consistently identifying aspects of audience/user awareness as the most significant shortcomings in the written and oral communication of new engineers. For example, interviewees noted that "understanding what is truly relevant" (I4) and getting to that information quickly was a key difficulty for new engineers when communicating with other engineers. As one interviewee put it, "Being concise and getting to the point instead of going on a kind of a journey to explain something. Just give me the things I care about" (I1). Similarly, interviewees indicated that new engineers tend to assume "that the person knows things" (I1) when communicating with nonengineers.

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Practitioners' evaluation of new graduates' visual communication abilities was mixed: 44% of survey participants said that new graduates are somewhat strong at incorporating visuals effectively, but an equal number said that new graduates are only adequate in this area. Similarly, 44% indicated that new graduates are only adequate at creating documents that are professional in appearance. An interesting finding regarding visual communication emerged during the interviews. We asked participants what types of visual communication new engineers struggle with (or succeed with) most. We included a list of examples with the question: "graphs, charts, image use, document design …." Typical responses were, "A lot of that comes with technology, and they're usually pretty good at it … with those types of visual tools, they seem to do pretty well" (I3) and "They come with good digital skills" (I2). As these comments suggest, responses focused almost entirely on software tools (e.g., Excel and CAD), with little to no mention of the rhetorical aspects of visual communication. This was the one area in which we saw a very clear disconnect between engineering practitioners' and our own framework for evaluating communication.

Taken all together, the practitioner perspectives suggest that engineering students continue to graduate with communication skills that are insufficient for the needs of the workplace. The capstone partner survey responses seem to suggest that local students may be graduating with the communication skills they need. However, this finding does not align with our evaluation of those students' work. The advisory board responses regarding recent graduates more broadly strongly suggest that our evaluation is more reliable and not limited to the local context. The interviews—including that with a capstone mentor—generally aligned with the advisory board survey responses.

In addition, the practitioners who participated in the study agreed unequivocally that communication skills become even more important when considering career advancement. Capstone mentors and advisory board members alike noted that communication becomes increasingly outward-facing as an engineer moves forward from the junior level. Like observations made by Leydens [6], participants indicated that with increasing seniority, the communication work is characterized by more interaction with clients and lay persons, meaning that audience and style considerations in particular become more important.

Both groups of practitioners emphasized that poor communication skills negatively impact career advancement. Interview participants described the career trajectory of engineers with poor communication skills as limited, lacking in opportunities, and even "flat to down" (I5). Interviewees emphasized that facility with both oral and written communication is critical for advancement. It seems reasonable that engineers may develop some of this on the job, but that development rests on the foundation of communication skills that they should be acquiring as students.

The interviews provided one additional finding related to the final research question. Given the approach taken for assignments in the capstone course, we asked interviewees about the use of templates within their workplaces. Responses suggested that, as one would expect, organizational style guides are prevalent. Interviewees noted that the guides often include information about document structure and sections that might be included, particularly for documents that need to meet regulatory or certification standards. But, as one interviewee explained, "There's notes in there about whether you should … take [a section] out or leave it in" (I1). The engineers and project teams need to determine what structure and content will best fit each situation. In short, although the guides function to ensure consistency and compliance with standards, they still demand some level of what we would term "rhetorical problem-solving."

Conclusion

The academic and practitioner data that we collected answer our research questions and reinforce several key points from the engineering communication literature. It is important to keep in mind, however, that this project reflects student work from only one institution and the perspective of practitioners who are closely connected to that institution. The survey data reflect practitioners' perceptions of our engineering capstone students, not engineering capstone students in general. Meanwhile, the advisory board survey captures practitioner perceptions of recent graduates more generally, although some of those new hires certainly come from our institution.

In addition, there are a limited number of capstone mentors and advisory board members, which, in turn, limited the number of study participants.

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These limitations notwithstanding, the project contributes insights to the engineering communication conversation and raises numerous questions that point to opportunities for additional research that could be beneficial across institutional contexts.

Curricular Outcomes Our examination of student work from the first-year course strongly reinforces the idea that isolated courses are insufficient in preparing students for the communication needs of the engineering workplace. Although we certainly did not expect that a single freshman-level course would prepare students for the communication demands of the workplace, we did hope that it would at least provide a solid starting point. However, these data clearly indicate that students are not leaving the course with a strong foundation on which to build additional engineering communication skills, even though the course is designed to do exactly that.

We strongly suspect that the course would be more effective if it were positioned later in the engineering curriculum. Currently, students take it in their first year in the program, typically at the same time as they complete the second semester of the freshman composition requirement. This means that they come to the engineering communication course having had very limited instruction and experience in both engineering and writing, which may make the course especially challenging for them [5].

Moving the foundational communication course to the sophomore year would help to address this problem, presumably leading to better outcomes. However, even if the sequencing constraints of engineering courses allowed for this change, which they currently do not, it would not address other crucial issues highlighted by the literature [15], [16] because the course would still be separate from the "real" engineering curriculum and would still lack the situational embeddedness that could lead students to approach it differently.

Engineering students do not take any additional communication courses between the first-year course and the capstone, nor is communication foregrounded in their engineering courses, and this too is problematic in terms of both knowledge transfer and outcomes [10], [17]. There is no mechanism within the program like that described by Harichandran et al. [11] that would ensure explicit communication instruction with scaffolded outcomes leading up to the work produced in the capstone. Again, without some sort of embedded progression that situates communication within engineering, there is no process in place to reduce the likelihood of students seeing communication work as distinct and less important [9], [14] from engineering work.

Ultimately, even though the capstone is built around industry-sponsored projects and involves extensive interaction with practitioners, which the literature suggests should lead to better outcomes [20], [22], the students' work did not indicate to us that they had developed effective communication skills. We expect that if we examined student work from the junior-level project course, we would see very similar patterns.

However, the industry partners working with the capstone course saw students' communication skills much more positively than we did. This finding raises several questions that set the stage for further research. We were only able to review the written products from the class. If we were instead able to sit in on the meetings between the students and the industry partners, as well as the student presentations for those partners, would that alter our assessment of students' communication abilities? Would we see the students performing better orally than in writing, as the capstone partners suggest? If so, is the difference in performance linked to the communication context [13]? That is, might students perceive the written work as being a class exercise for the teacher (particularly given the detailed instructions and templates) and the oral work as being part of the actual engineering context?

Knowledge Gaps If we set aside our more critical evaluation of the students' capstone work for a moment, and accept the perceptions of the capstone mentors, then engineering students would appear—at least on the surface—to be graduating with the communication skills that they will need to succeed professionally. But then, the next question we need to ask is, why do the survey responses regarding the abilities of recent graduates more generally differ so strongly from those regarding the abilities of the local capstone students? Might the differing survey results from the capstone mentors and the advisory board members indicate a lack of knowledge transfer, where students have developed a level of communication knowledge while they are in school (reflected in the capstone partner responses), but

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then are unable to apply that knowledge in the workplace (reflected in the advisory board responses)? The literature suggests that this could well be the case [20]. If it is, to what extent would structuring the capstone communication assignments differently, with a greater emphasis on rhetorical problem solving and "learning to learn" [16, p. 252], lead to greater knowledge transfer? And would this one change be sufficient to offset the lack of embedded communication instruction through the rest of the curriculum?

Or might the data instead point to a different type of gap, one that potentially reflects a disconnect between engineering curricula and engineering workplaces? Is it possible that the communication knowledge does not transfer because it was never really acquired in the academy? In other words, if students receive only very limited instruction in communication and instead are consistently provided with detailed templates for their communication work within engineering courses, what knowledge about communication are they acquiring? Such an approach seems to reinforce the misconception that communication is about right and wrong (e.g., does the document include everything listed in the template?) or about simply conveying information accurately [6], instead of helping students develop the rhetorical strategies and flexibility needed for communication in the workplace. In short, the template approach may not lead to the emergence of what Leydens calls "a continuum of rhetorical awareness" [6, p. 251], and that awareness is crucial for further development and transfer.

Our findings regarding the local capstone course again suggest areas in which additional research may be useful. How prevalent is heavy reliance on templates for communication work in undergraduate engineering programs? How do the communication outcomes and knowledge transfer compare for programs that do and do not use a template-based approach? It would also be valuable to examine the impact of involving students in the development of the templates, because, as Ford [12] argues, such involvement may help to build students' rhetorical problem-solving and genre awareness.

The capstone and interview data also raise the question of what typical workplace practices are regarding the use of templates. How common is it for junior engineers in the workplace to be provided with detailed templates for their communication work? Learning more about the use of communication templates in engineering practice could support more effective approaches within undergraduate programs.

Institutional Contexts The initial goal of our project was to address local needs regarding engineering communication. We set out to examine the extent to which engineering students within our local context are developing the rhetorical skills needed for professional success. The engineering program leadership was very supportive of the project and enthusiastic about the idea of exploring new strategies for helping students develop stronger communication skills. In fact, we anticipated that our project might serve as a starting point for additional collaborations with the engineering program at our institution.

However, organizational and curricular changes at our institution have taken things in a very different direction. First, the university has put in place a new general studies structure that replaces the writing/literacy requirement with courses in other areas. This change means that the first-year engineering communication course no longer fulfills a general studies requirement. The engineering program needed to adjust its curriculum to ensure that students can still meet general studies requirements without additional credit hours, and to accomplish this, they have discontinued the sole engineering communication course. At the same time, although the program leadership recognizes the need for communication instruction, they cannot commit the resources that would be required to develop a more integrated approach. Similarly, organizational changes and revenue constraints within our own college and TPC program have shifted priorities away from collaboration with other colleges to focus on growing our own programs and majors.

Although we were of course disappointed by this turn of events, it, like other aspects of the project, highlights a crucial point made in the literature [11], [12]. Without ongoing and steadfast support of college and program administration, collaborations that may otherwise lead to improved outcomes are likely to encounter insurmountable structural obstacles.

Research into the prevalence of different models of engineering communication instruction across institutions could conceivably suggest solutions for at least some of these constraints. For example,

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our institution, like many others, often relies on peer institutions for programmatic comparisons. If collaboration between TPC and engineering were still viable in our context, our next step would be to research the pedagogical models for engineering communication that are in place at peer programs, because these data could serve as support for curricular changes locally. More important, although, when conducted on a larger scale across multiple programs (not just with peer institutions), such research would reveal the prevalence of effective models across institutions and could potentially identify specific factors that can make those models more feasible and make long-term collaborations between TPC and engineering programs more successful.

Summary Ultimately, the project reported here provides up-to-date data that reinforce the existing literature. At the same time, the project extends academics' understanding of engineering communication skill gaps as well as industry needs regarding engineering communication skills. Our project, like many that precede it, focuses primarily on one institutional context. The project's particular contribution is its multipronged approach that looks at one program from multiple angles while also considering practitioner perspectives that are not specific to the program. The project data thus offer insights that extend beyond the local context.

Our findings also raise numerous questions that highlight the need for additional engineering communication research in several related areas that may be especially relevant for faculty at other institutions who are striving to build a bridge between TPC and engineering programs. In addition to those already mentioned, studies that examine curricular outcomes across programs and institutions would be invaluable in providing larger data sets that could be used to more effectively codify patterns of strengths and weaknesses and connect those patterns to pedagogical approaches. Similarly, large-scale studies of communication practices in professional engineering contexts could provide academics with a more extensive data-driven understanding of the communication demands of engineering workplaces, which, in turn, could be used not only to strengthen pedagogy but also to make a compelling case for committing institutional resources to engineering communication initiatives.

The complexities of conducting such large-scale research would almost certainly demand a combined effort on the part of TPC and engineering faculty across multiple institutions. But this is the type of work needed to spark the sea change in engineering education that could address the communication challenges that academics and practitioners have grappled with for at least 25 years.

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