

Technical Communication Instruction for Graduate Students: The Communication Lab vs, A Course

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Samantha Dale Strasser aims to elucidate how cell signaling dysregulation contributes to disease, e.g., neurodegeneration and cancer, to advance therapeutics through development of predictive mathematical models. She is presently an Electrical Engineering and Computer Science (EECS) graduate student at MIT. Specializing in computational analyses, her Ph.D. research is supervised by Douglas Lauffenburger (Biological Engineering, Massachusetts Institute of Technology, MA) and Kevin Haigis (Harvard Medical School, MA). In 2011 she received B.S. degrees in Biomedical Engineering and Applied Mathematics from Northwestern University, IL, with a concentration in electromagnetics. During her undergraduate research in Backman's Biophotonics Laboratory she developed near-field penetrating optical microscopy (NPOM) to quantify the refractive indices of biological cells at nanoscale resolution. As a Churchill Scholar at the University of Cambridge, UK, she characterized the structure-property relationships of polymer materials for use in optoelectronic devices. A member of the Optoelectronics Group, Cavendish Laboratory, Department of Physics, she earned her Masters of Philosophy (MPhil) in Physics in 2012.

In addition to her studies at MIT, she serves as a communication advisor in the EECS Department Communication Lab providing peer-coaching on a variety of technical communication topics.

Dr. Alison F. Takemura, Massachusetts Institute of Technology

Alison loves wading into a good science story. Her first was her MIT doctoral thesis project, unlocking the gastronomical genome of a *Vibrio* bacterium. For some of the *Vibrio*'s meals, she collected seaweed from the rocky, Atlantic coastline at low tide. (Occasionally, its waves swept her off her feet.) During grad school, Alison was also a fellow in MIT's Biological Engineering Communication Lab. Helping students share their science with their instructors and peers, she began to crave the ability to tell the stories of other scientists, and the marvels they discover, to a broader audience. So after graduating in 2015 with a microbiology doctorate, she trekked to the Pacific coast to study science communication at the University of California, Santa Cruz. There, she learned how to interview people, write feature stories, create podcasts, shoot videos, and finally, drive. Her stories were about pesticide residues in children, HIV in South Africa, rainforests in Australia, calorie-burning brown fat, and what hide behind Jupiter's clouds. Alison graduated in 2016, and like a homing pigeon, has migrated back to MIT. Now the EECS Communication Lab manager, she's thrilled to support the learning and growing of early scientists—eager to share their own stories.

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Dirk Englund received his BS in Physics from Caltech in 2002. He earned an MS in electrical engineering and a PhD in Applied Physics in 2008, both from Stanford University. He was a postdoctoral fellow at Harvard University until 2010, when he started his group as Assistant Professor of Electrical Engineering and of Applied Physics at Columbia University. In 2013, he joined the faculty of MIT's Department of Electrical Engineering and Computer Science. Englund's research focuses on quantum technologies based on semiconductor and optical systems. Englund engages in developing new teaching methods for the STEM fields, for undergraduate and graduate students in engineering and engineering physics. Recent recognitions include the 2011 Presidential Early Career Award for Scientists and Engineers, the 2011 Sloan Research Fellowship in Physics, the 2012 DARPA Young Faculty Award, the 2012 IBM Faculty Award, an 2016 R&D100 Award, the OSA's 2017 Adolph Lomb Medal , and the 2017 ACS Photonics Young Investigator Award.

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Abstract

Communication skills are critical to engineers' success in both academia and industry. Nevertheless, a variety of factors keep engineering students from developing those skills while in school, leading to a skills gap between recent graduates' actual preparation and their expected performance. This gap can be especially pronounced with graduate students, yet relatively little research and innovation has targeted this key population. Here we present two initiatives to improve the communication skills of graduate students: a department-level "Communication Lab" using peer tutors, and a for-credit communication course. Each approach is analyzed for pedagogical advantages, resource intensiveness, and general utility to the department. We conclude that the Communication Lab model is an overall effective resource for reaching a large number of students in a way that is cost-effective per-student, pedagogically advantageous, and an efficient use of student time. With appropriate modifications, it may even supply some of the advantages that the communication course offered, namely explicit communication frameworks and peer feedback.

1 Importance of communication skills for engineers

The core emphasis of most degree programs in science, technology, engineering, and mathematics (STEM) is to develop "hard technical skills," often at the neglect of "soft skills" that are also essential.

This division is misaligned with the reality that engineering graduates report spending roughly 64% of their time on communication-intensive tasks [1]. Accreditation agencies recognize this importance, and both British [2] and US (Accreditation Board for Engineering and Technology, Inc., ABET) [3] agencies already have communication requirements. In addition, ABET introduced new language for 2016-17 requiring an ability to communicate effectively *with a range of audiences* [4], reflecting the fact that the communication demands of engineers are increasing in scope as well as intensity.

Recent graduates likewise recognize the importance of communication in their professional lives. A recent study of graduate opinion places communication as fourth out of twelve ABET requirements in terms of importance (related "teamwork" placed first) [5]. Nevertheless, graduates themselves have emphasized communication as a weakness [6], with most feeling insufficiently pre-

pared [1].¹ These findings suggest that communication is one of the most important skills for engineers, yet this skill is among the least developed for recent graduates [8].

This disparity is equally recognized by employers. Reports in the media [9–11] and academic research literature [12–15] almost universally show strong and widespread employer dissatisfaction with new graduates' communication skills.

We may hypothesize that the disparity between academic preparation and real-world expectation is even greater with postgraduate degree recipients. This hypothesis is based on a variety of factors:

1. Formal communication training typically slows during graduate school (and informal training varies enormously across advisors);
2. At the same time, graduate students' expertise becomes increasingly specialized and therefore abstruse;
3. Postgraduate degree recipients tend to be employed at higher levels of leadership with greater communication demands, including teaching.²

Therefore, for postgraduates (as opposed to undergraduates) the communication tasks are greater, the content more complex, but the training is still largely insufficient.

At the Massachusetts Institute of Technology (MIT), evidence for this hypothesis was found in the 2014 Institute-Wide Task Force on the Future of MIT Education [16]. One of the most common responses to an open-ended request for ways to improve MIT education was an emphasis on communication skills. When asked specifically about areas that students want more opportunities to improve, the top three responses for both doctoral and masters students were all communication-focused: grant proposal writing (doctoral students), negotiation (masters students), presentation skills (both), and written communication (both). By contrast, undergraduates sought these skills at a lower rate and more on par with technically-oriented skills like exposure to programming languages.

Overall, these facts led the task force to devote one of sixteen specific recommendations to communication skills. A graduate student focus group report presented to the visiting committee to the Electrical Engineering and Computer Science (EECS) department agreed with this recommendation, listing “resources to improve communication and presentation of ideas” as one of the two highest-priority needs within the department's graduate student community [17].

2 Current technical communication interventions and the research gap

The communication skills gap among graduates is not new [18, 19]. Universities have long recognized the importance of communication skills to well-educated graduates and have provided instruction through a few main avenues:

¹For an overview and additional primary references, see the introduction to [7].

²Indeed, the graduate population is of particular importance as the pool from which future university instructors will be selected, a feedback which presents both risk and opportunity.

1. Courses explicitly focused on communication tasks;
2. Communication tasks embedded in engineering courses and other Writing Across the Curriculum (WAC) approaches;
3. Online or written materials to be accessed and referred to on students' own time;
4. Writing centers or other consultant-client relationship structures for communication tutoring.

These approaches may not be equally useful when applied to technical communication, especially at the graduate level. For example, graduate students often take significantly fewer courses than undergraduates, potentially limiting the impact of course-based interventions.

A survey of the American Society for Engineering Education (ASEE) annual conference and the IEEE Frontiers in Education (FIE) conference for the years 2014–2016 reveals some patterns of recent emphasis within the engineering education community (see Table 1). Of 34 total papers with interventions for communication education, the vast majority tried to incorporate communication principles into students' coursework, either through dedicated courses or integration into technical courses. The same survey indicates that the majority effort has focused on undergraduate education, with only six total interventions targeting graduate students.

Particularly conspicuous is the absence of writing center research at ASEE and FIE for the past three years. This absence is consistent with the observation that writing center studies have received relatively little attention outside the Writing Center Journal (WCJ), even in written composition studies let alone engineering education [20, 21]. Keyword searches of WCJ articles show a similar dearth of publications on technical/engineering communication outside the useful debate regarding generalist versus specialist tutors (see Appendix A). Unfortunately, valuable research from various education communities appears to have difficulty “cross-pollinating.”

This, then, is the research gap:

The communication education of graduate students in STEM has been largely overlooked, and few comparisons have been made between course-centered interventions and other approaches (especially those modeled after writing centers).

3 Descriptions of the Communication Lab and the communication course

In response to the needs outlined in Sections 1–2, several initiatives were launched at MIT. One was the Communication Lab, a departmental writing and technical communication center staffed by peer tutors (graduate students and postdoctoral researchers). Communication Labs have been implemented in four departments, including Electrical Engineering and Computer Science (EECS). Another intervention was a graduate-level communication course, which the EECS Communication Lab helped design and operate.

The details of these two interventions are described in this section, followed by analysis and comparison in Section 4.

Approach	ASEE			FIE			Total	References
	2014	2015	2016	2014	2015	2016		
Course	0	2	4	3	2	2	13	[22–34]
Embedded	4	4	4	2	0	0	14	[6, 35–47]
Resources	0	2	0	0	0	0	2	[48, 49]
Writing Centers	0	0	0	0	0	0	0	—
Other	2	0	0	1	1	1	5	[50–54]
Total	6	8	8	6	3	3	34	—
(Graduate Focus)	0	0	2	2	2	0	6	[25, 26, 28, 29, 45, 53]

Table 1: Survey of conference papers in engineering education with interventions for building communication skills. Few interventions targeted graduate students directly, and most used coursework which in turn is less likely to impact graduate students. Of the papers surveyed, none used writing centers or similar approaches.

3.1 The Communication Lab

The Communication Lab organization is a *distributed* writing and technical communication center. It actually comprises a collection of largely independent Communication Labs, with one embedded in each participating department (Fig. 1). Though each is operated with some autonomy, the Labs are organized under a single umbrella administration at the institute level. This umbrella organization provides new-tutor and ongoing training and serves as a liaison with the university administration regarding funding, operations, policies, etc.

Each Communication Lab offers consulting appointments to help members of the department with technical/professional communication tasks (papers, presentations, CVs, etc.) as well as interactive, topic-specific workshops. The Communication Lab model uses *peer* tutors selected from the graduate student and postdoc population within each department. In this way, students are automatically matched with tutors of similar disciplinary expertise. This feature allows tutors to better understand their clients' work and assess it at a high level (see Section 4.1.1 and Appendix A).

In addition to the tutors, each Communication Lab has a part-time manager working 50% full time equivalent (FTE). Each manager works with the Communication Lab director and administrative assistant to achieve departmental goals as communicated by the corresponding department head.

3.1.1 The Communication Lab's operation

Before taking client sessions, the Lab's tutors are trained in peer coaching best practices and are given effective frameworks for a variety of technical communication genres. These fundamental principles are broadly applicable across departments and new-tutor training is efficiently adminis-

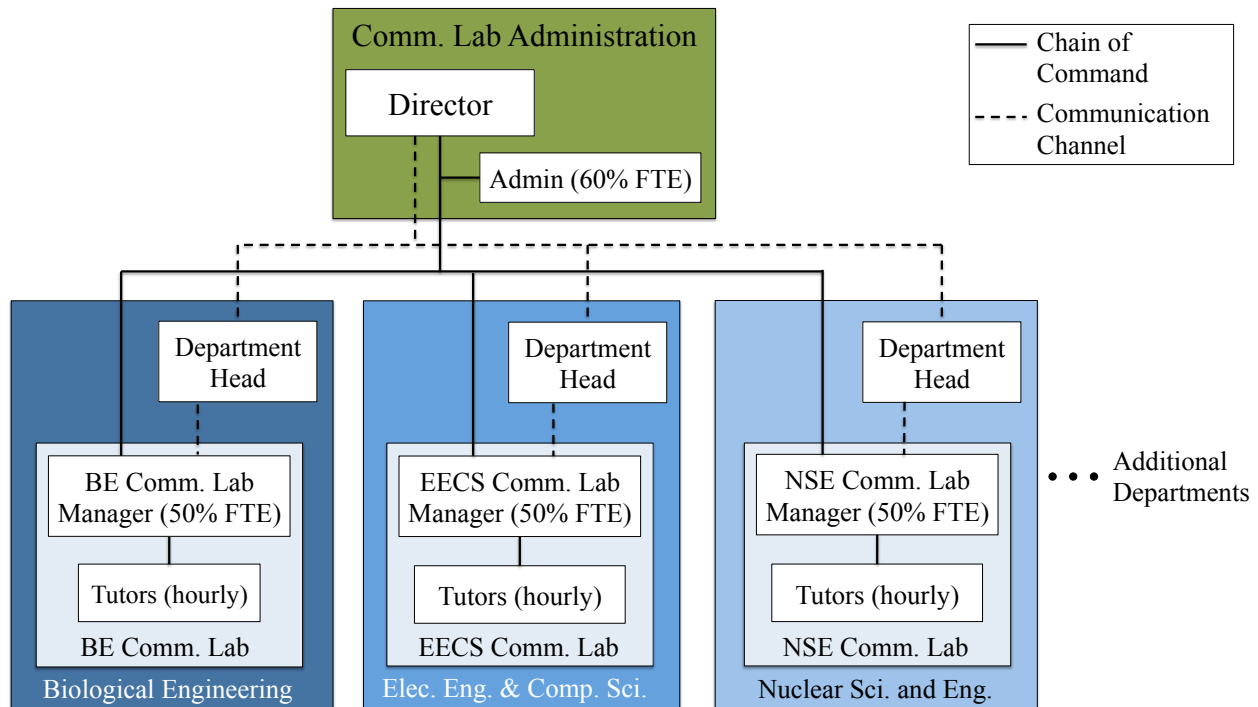


Figure 1: Communication Lab organization chart. Each Lab is embedded in a participating department and consists of a part-time manager and the tutors. An umbrella administration at the institute level supports and helps direct each department-level Lab. Department heads also have open channels of communication with their corresponding Lab manager as well as the Communication Lab administration for aligning the Lab’s operation with departmental goals.

tered at the institute level. Training for department-specific goals and culture are administered in the individual Communication Labs.

Once trained, tutors make themselves available to clients (students, postdocs, staff) for a few hours (typically 3-5) per week via an online scheduling system. Appointments are typically 30 minutes to 1 hour in duration. Tasks can be any form of technical communication, including: resumes, CVs, and cover letters; course-assigned papers, presentations, and lab reports; conference posters, papers, and presentations; journal manuscripts; and fellowship, grant, and faculty applications.

In each client appointment, the goals of the tutor are to quickly identify the portions or aspects of the piece needing the most refinement, to find representative examples of these deficiencies to serve as teaching opportunities for the client, and finally to coach the client with these specific examples in a way that promotes long-term learning and knowledge transfer.

In addition to one-on-one tutoring, the Communication Lab also holds workshops (run by department managers and peer tutors) and other teaching sessions. Workshops can frequently be designed and scheduled in conjunction with departmental deadlines, popular conferences, etc. The Lab can also partner with courses to make Communication Lab tutoring available for specific course assignments.

3.1.2 Profile of the Communication Labs at MIT

At MIT, the Communication Lab model started in the Biological Engineering (BE) department in March of 2013 and has since been implemented in Nuclear Science and Engineering (NSE), EECS, and the Broad Institute, a biomedical and genomics research center and institutional partner of MIT.

Table 2 provides high-level statistics (as of January 2017) of each department's Communication Lab's usage. Collectively, the Communication Labs have served over 1,000 unique clients over the course of 2,820 client visits. Almost 1,100 of these visits were made by graduate students. This impact is expected to increase as the (newer) graduate-centric Communication Labs of NSE and EECS continue to gain traction.

Department	Date Implemented	Total Number of Client Visits					Total (Unique)
		Undergrads	Grads	Postdocs	Others		
BE	Mar. 2013	1089	609	168	26	1892 (638)	
NSE	Sept. 2014	154	249	36	25	464 (158)	
EECS	Nov. 2015	88	210	17	3	318 (173)	
Broad	Mar. 2016	N/A	22	51	73	146 (74)	
All	—	1331	1090	272	127	2820 (1043)	

Table 2: Summary usage statistics (as of Jan. 2017) for the Communication Labs at MIT showing the number of client visits in each department by population. Additionally, the total number of visits are given in the far right column along with the number of unique clients in parentheses.

3.2 The interactive communication course

Within the EECS department, a for-credit graduate-level technical communication course was also designed and implemented by the Communication Lab Director and tutors from the EECS Communication Lab, together with the EECS Department Head and a faculty advisor. It provided an overview of relevant technical communication tasks, detailed below, facilitated by guest lectures and hands-on workshops.

3.2.1 The communication course's operation

The course consisted of a weekly, two-hour session. Topics covered a range of technical communication tasks, as outlined in Table 3. Typically each session began with an introductory guest lecture (~30 min), followed by small-group workshops run in parallel, in separate rooms, and led by Communication Lab tutors. Guest lecturers were selected based on (1) their example as good communicators and sometimes (2) as experts in a particular genre (e.g., a venture capitalist for the lecture on startup funding pitches). Workshops usually involved group analysis of the results of the

Week	Lecture	Workshop	Assignment
1	Course overview	—	Analyze a previous communication piece
2	Why communication matters in EECS	Effective feedback & intro to flash talks	Prepare flash talk
3	Conference talks	Flash talks and feedback	Revise flash talk
4	Journal papers and getting published	Abstracts and introductions	Prepare abstract and figure
5	Publishing ethics	Titles and figures	Revise abstract and figure
6	Venture capital pitches	Venture capital pitches	Prepare venture capital pitch
7	—	Venture capital pitch competition	Evaluate pitches
8	Writing for the press	Writing for a variety of audiences	Write article for popular press
9	Poster design	Poster best practices	Design and prepare poster
10	—	Poster feedback and portfolio preparation	Revise poster
11	—	Departmental poster session	Evaluate posters
12	Engaging the public	Portfolio assessment and final course feedback	Fine-tune one previous assignment

Table 3: Outline of sessions for the communication course showing the variety of writing genres covered and opportunities for feedback. Lectures and workshops were typically given back-to-back once per week; assignments are listed when they were assigned.

previous week’s homework, followed by interactive work as a starting point for the coming week’s homework.

Each homework assignment consisted of an example of a particular communication genre (e.g., journal papers, press release, startup pitch, etc.). Assignments were generally completed in two stages, with an original attempt followed by detailed feedback from both tutors and peers, and then a revision the following week. Thus, for many weeks, the assignment would consist of revising or evaluating the previous assignment while making a first attempt at a new one. Students were encouraged to use assignments as steps toward future authentic communication tasks and to incorporate works-in-progress from their research into course assignments.

Central to the course was a set of general principles that are applicable across a breadth of communication tasks (Fig. 2). During the course, these principles guided students through their homework assignments and were used as a grading rubric. The long term goal was to teach students how to apply this set of principles to their own communication tasks following the course.

WHY	<p>Strategic purpose Identified a strategic goal for your communication and achieved it</p>	HOW	<p>Organizational structure Chose an effective structure for your purpose and content</p>
WHO	<p>Audience Understood your audience's needs and optimized the "digestibility" of your message</p>		<p>Flow Developed smooth segues between ideas</p>
WHAT	<p>Context Included appropriate context for the problem you are addressing; explained who would care and why</p>		<p>Visual impact Designed visual elements that support your message without extraneous material</p>
	<p>Ideas Presented scientifically accurate information; clearly identified novel contribution</p>		<p>Synergy Created a streamlined yet effective redundancy of information</p>

Figure 2: Communication principles utilized across genres in the communication course, as presented to students. Specific recommendations varied across tasks, but principles were always presented in the consistent format of the listed headings.

3.2.2 Profile of the communication course

The course was run by the Communication Lab director, faculty advisor, five tutors and a teaching assistant (who also was a tutor in the EECS Communication Lab). A total of twenty students were enrolled in the course from a range of years in graduate school (see Fig. 3). The course attracted significantly more students at the beginning of the semester before settling on its final distribution; the implications of this are discussed further in Section 4.2.3.

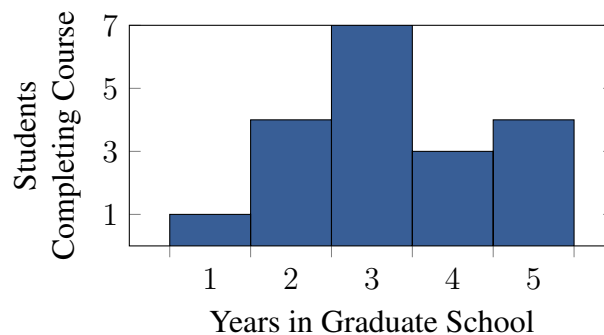


Figure 3: Histogram of students completing the communication course vs years in graduate school, showing relatively broad appeal. First-year students have other coursework commitments.

4 Analysis and comparison

The efficacy of the Communication Lab and the class are evaluated through the following sources of evidence:

1. Survey results from the BE and NSE Communication Labs. A variety of surveys were sent to clients, tutors, and faculty in the respective departments regarding Lab usage and the community's perceptions of its utility. At the time of writing, the EECS Communication Lab was too new to have analogous survey results.
2. Pre- and post-class self-assessment surveys from the graduate students involved in the EECS communication course.
3. Interview results from class participants. At the end of the course, each student had a short interview with their workshop leader (a Communication Lab tutor) with standardized questions.
4. Qualitative observations from students, faculty, and staff involved in the Communication Lab and the course.

This section is divided into two parts; Section 4.1 analyzes and compares the positive impacts or effectiveness of each intervention on a variety of metrics. Section 4.2 similarly analyzes the personnel costs, scalability, and student effort associated with each approach.

Since the effects/costs of any educational intervention can often be seen across several dimensions which do not easily admit of comparison or summation, this section simply reports those effects in relative isolation. Each effect/cost is compared between the Communication Lab and the course, but the value of each effect/cost is not compared to any other. Our summative assessment and subjective judgment for MIT is presented in Section 5.

4.1 Impacts and effectiveness

In analyzing and comparing the impacts and effectiveness provided by the Communication Lab and the course, we specifically considered several topics: the benefits of specialist tutors and workshop leaders and their ability to be an embedded resource; how the Communication Lab is adaptable to department needs; ways in which both interventions affect student confidence; and students' affinity for peer feedback.

4.1.1 Specialist tutors and workshop leaders are beneficial

Both the Communication Lab and the course had a design premise that tutors and instructors with content expertise (i.e. current or former engineers) would be more useful to the students. This was deemed especially important for teaching graduate students whose communication tasks tend to be at a higher technical level and therefore more difficult to improve by a generalist tutor. Research exists to support this conclusion, though it is also a matter of some disagreement; see Appendix A for further discussion.

Survey data from the Communication Labs show that students overwhelmingly preferred specialist tutors. Asked if students considered it “essential to have a content expert (someone who understands the field) give you communication advice and support,” graduate students in BE and NSE responded “yes” at 85.7 % and 84.8 % rates respectively.

Students in the course were not surveyed directly about their preference for specialist vs generalist tutors, though there is little reason to suspect responses would greatly differ from the Communication Lab results. Post-class interviews did indicate that students found it both difficult and beneficial to target a broader audience of peers (within the same department). It was also observed that those students whose research was least connected with typical EECS topics (e.g., the biological aspects of medical devices) often had difficulty conveying their work and receiving useful feedback.

Overall, students found it beneficial to receive feedback from those with roughly similar background knowledge, though not necessarily in their specific research area. Indeed, we observe an optimal “intellectual distance” that allows tutors/peer groups to give effective feedback while also forcing students to question their assumptions about their audiences’ prior knowledge. Individuals from the same discipline but not the same field seem to approach that optimum.

4.1.2 Communication Lab tutors become an embedded informal resource in departments

As the Communication Labs have gained footing, tutors have sometimes observed that their assistance is requested outside of the Communication Lab setting. They become “local” communication experts within their research groups and their inter-group labs. In this way, the Communication Lab informally supports both students’ education and final output (presentations, papers, etc.), in addition to the formal support provided by actual tutoring sessions. Because tutors are typically hired from a variety of research groups, their presence becomes a distributed resource naturally embedded across the department.

We hypothesize that this benefit would not be as pronounced from a communication class, even if it were offered every year. Faculty and other instructors have far fewer opportunities to informally pass on communication advice, and their formal time is often very constrained. In addition, faculty do not typically occupy the kinds of spaces that foster organic interactions (e.g., communal graduate student offices). While teaching assistants (used to run the workshops and grade) could become a more distributed resource, they are likely to only be a teaching assistant a few times (at most) and for only part of the year. By contrast, Communication Lab tutors’ experience is greater and more consistent.

While it is difficult to measure or even estimate the value of distributed communication experts across a department, the effect is worthy of consideration.

4.1.3 The Communication Lab is adaptable and agile in meeting department needs

Both the Communication Labs and the communication course provide opportunities for customization to department needs. Indeed, both programs originated in response to the focus group report

asking for improved communication resources *specifically for graduate students* [17]. As such, the course was designed specifically for (and attended exclusively by) EECS graduate students, and the Communication Lab was primarily advertised to the graduate student population.

The EECS Communication Lab’s graduate student focus is reflected in the client visits data of Table 2. Fig. 4 shows that 66 % of Communication Lab appointments were made by graduate students in EECS. Graduate students are the largest population in NSE, which likewise has a higher percentage of graduate student appointments. Meanwhile, the BE Communication Lab strategically focused more on the undergraduate population; as such, over half of BE appointments were made by undergraduates. The Broad Institute has no undergraduate students, and in fact provided 50 % of their appointments to staff, visiting scholars, and faculty.

It is also noteworthy that even though the various Communication Labs have the ability to target specific population subsets, they can still provide services to the entire population. By contrast, the EECS communication course was attended by *only* graduate students and would be difficult to design for a more expansive audience.

The Communication Lab can also adapt very quickly. For example, before the Fall 2016 MIT Career Fair, the EECS Communication Lab advertised and held resume-building appointments for undergraduates seeking summer internships and research positions. The class, on the other hand, is customized prior to holding the course. This customization can only be changed prior to each semester, hampering its agility.

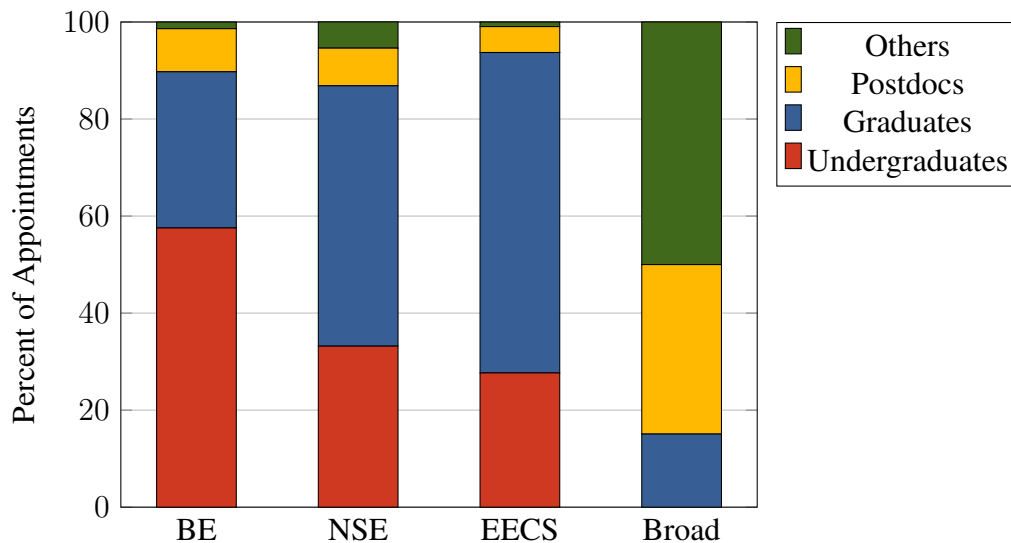


Figure 4: Distribution of Communication Lab appointments in each department, showing the adaptability of the Communication Lab model to different populations and department needs. BE focuses on undergraduate education, NSE and EECS focus on graduate students, while the Broad Institute has few students but does have a significant population of staff scientists, visiting scholars, and other technical employees.

4.1.4 The Communication Lab and the course comparably affect student confidence and self-assessment

Fourteen of the 20 students who completed the EECS communication course participated in both pre- and post-course self-assessment surveys. These surveys asked students to rate their ability to technically communicate on a scale of 1 (still learning) to 7 (very confident). Specifically, they were asked how well they communicate their science orally (e.g., presentations), through writing (e.g., papers), and through visual design (e.g., figures and posters). They were also asked about their abilities to communicate with broader audiences (e.g., children or lay audiences) and for the purposes of securing funding (e.g., scholarships, grants, or venture capital). Finally, students were asked to rate their confidence in their abilities to communicate science overall. These “categories” corresponded to the majority of the lecture and workshop topics covered in the class (Table 3).

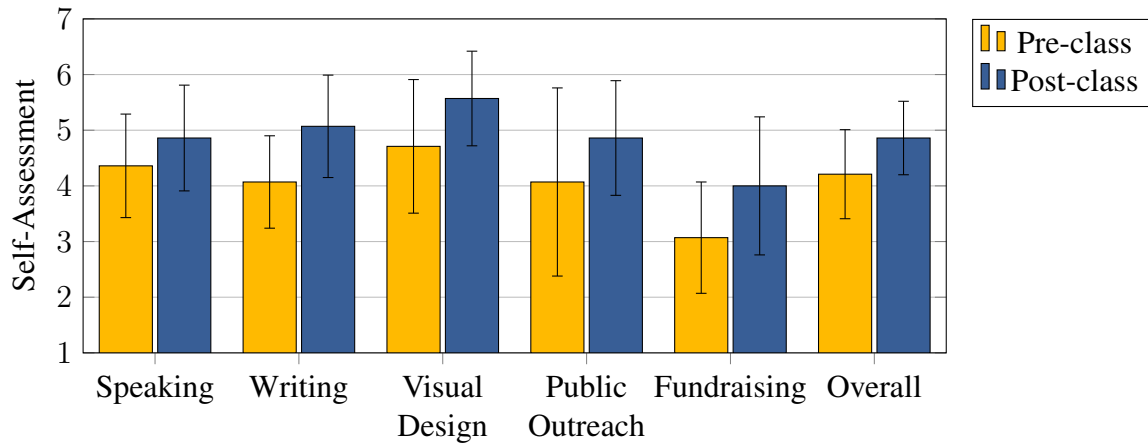
The distribution of the students’ answers to these questions are shown in Fig. 5a. For all categories, the average self-assessed scores increased indicating a general improvement in the students’ self-confidence to technically communicate. The largest and most statistically significant increase was seen in writing while the smallest and least significant occurred in speaking. While the course did emphasize public speaking through several lectures and workshops, e.g., conference talks, flash talks, and venture capital pitches, perhaps the course could have focused more on public speaking *techniques* in addition to the public speaking *content*.

Fig. 5b illustrates the same survey results in terms of the students’ self-assessed *change in ability*. For all categories, over half the students reported an increase, again with the largest increase occurring in the writing category. The public outreach question showed the highest number of students reporting a negative change. While ostensibly this could indicate that students felt the class reduced their communication skills, it is more likely these students became more aware of the difficulties in communicating science to the general public. In terms of their overall communication abilities, half the students reported an increase, while none reported a decrease.

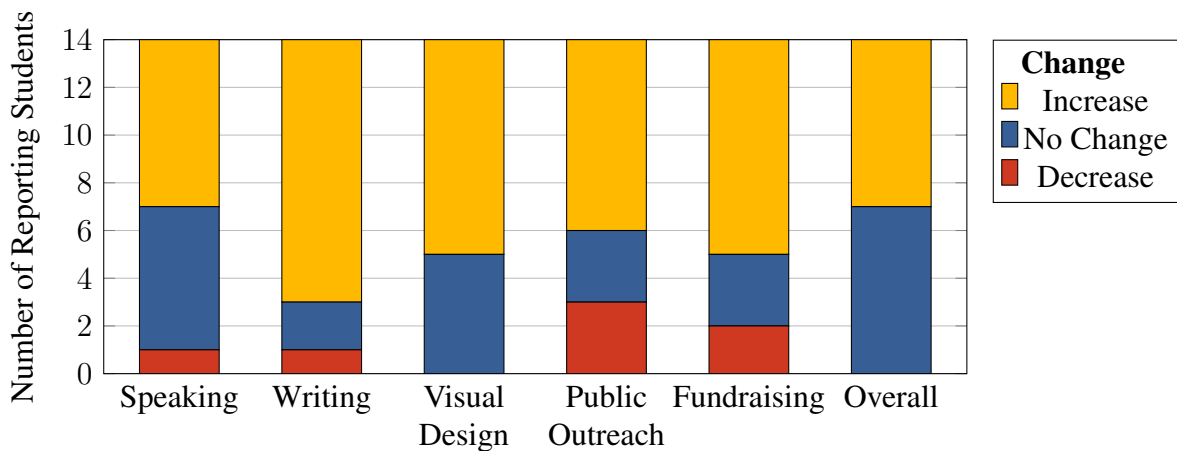
The most comparable information obtained from the NSE and BE Communication Lab client surveys is shown in Fig. 6. Answered by 45 and 34 graduate student clients respectively, these surveys asked the respondents to answer true or false to the statement, “My communication skills have improved since working with the Communication Lab.” They were also asked how likely they were to recommend the Communication Lab to a friend on a five point scale from “not likely” to “highly likely.”

The self-assessed improvement in communication skills, though not broken-out into categories, is very comparable with that of the EECS course. Clearly the course provided students a wider and deeper investigation into technical communication due to the higher number of student participation hours. However, Communication Lab appointments appear to improve student self-assessment by the same amount for a far smaller time commitment, at least with respect to the students’ immediate appointment topic. The correlation between repeat Communication Lab users and those who responded to the survey was not recorded, and those who responded to the survey may have been the same who made multiple appointments with the Communication Lab.

Fig. 6 also reveals an interesting finding when comparing the percentage of students reporting an



(a) Pre- and Post-Class Survey Distributions



(b) Self-assessed Change in Communication Skills

Figure 5: Pre- and post-class self-assessment surveys revealed that students broadly felt their technical communication abilities increased while taking the EECS communication course. (a) Depicts the pre- and post-class distributions by communication genre, with the box height indicating the mean response and the whiskers representing the standard deviation. For each genre, the average self-assessed score increased after taking the course. (b) Shows the distribution of the students' self-assessed *change* in abilities by genre. While in a couple cases, students actually reported a decrease in their perceived abilities, the majority of students reported an increase.

improvement in their communication skills (approximately 55%) with those who would at least moderately recommend the Communication Lab to a friend (approximately 90% reported 3-5/5). While there might be several motivations for the second answer, one possible reason is that the vast majority felt the Communication Lab had helped to improve their particular communication piece, while fewer felt that they had actually improved as communicators. This suggests that Communication Lab appointments may be improved by emphasizing skill-building while still addressing short-term task needs.

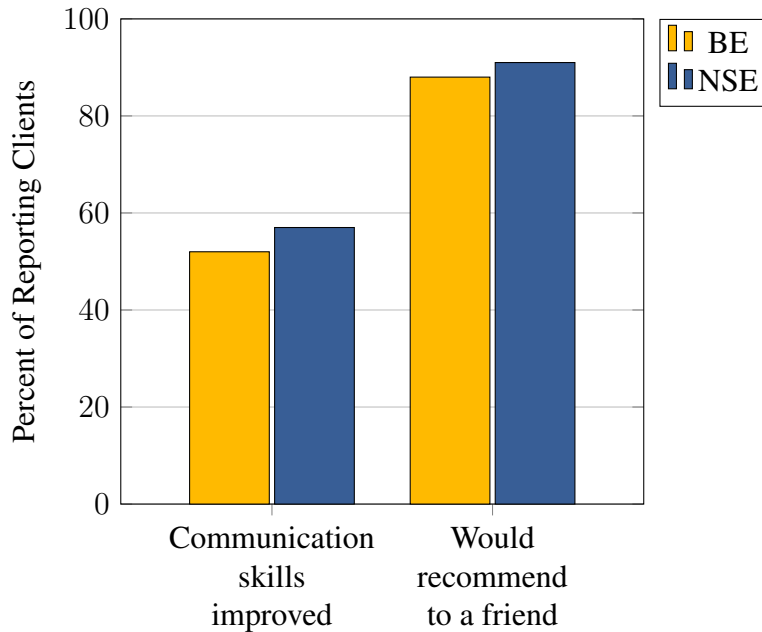


Figure 6: Of the responding BE and NSE clients, approximately 90% said they were at least moderately likely to recommend the service to a friend, but a smaller majority believe their communication skills had improved as a result of their visits. While there may be several motivations for the second answer, it suggests that Communication Lab appointments may need more emphasis on skill-building while still addressing short-term task needs.

4.1.5 Students in the course showed unexpected affinity for peer feedback

Feedback has been shown to be a crucial element for all kinds of education (Appendix B), and both the Communication Lab and EECS course incorporate one-on-one tutor, group tutor (one tutor with a small group), and peer-to-peer feedback mechanisms into their operations. Communication Lab coaching sessions provide one-on-one tutor feedback; workshops contain the opportunity for attendees to receive both peer-to-peer feedback in addition to group tutor feedback. As the EECS course contains a weekly workshop, this too combines the group tutor and peer-to-peer feedback mechanisms.

Students in the EECS course were surveyed on their preference for group tutor versus peer-to-peer feedback. Overall, peer-to-peer feedback was preferred. Students enjoyed the breadth of perspectives they received from students from a variety of different sub-disciplines. However, these two forms of feedback are not truly independent, since the very first workshop had tutors providing guidance in how to provide effective feedback. We also hypothesize that student feedback was preferred partly because tutor feedback was divided amongst several students, limiting the amount of time they could provide one individual.

While this same survey was not conducted within the context of the Communication Lab, this feedback from the course indicates that peer-to-peer feedback should be highlighted in workshops. Furthermore, it is important to train students on providing constructive, effective feedback. It should be noted that, in addition to the in-class motivation, giving effective feedback is itself useful

for students as a long-term communication skill.

4.2 Costs and effort

In evaluating the pedagogical impacts of the Communication Lab and course, it's also worthwhile to consider their resource intensity. Here, we assess this intensity in terms of the personnel hours (comparable to costs), administrative scalability, and student effort and commitment requirements.

4.2.1 Personnel hours

Quantitatively comparing the total financial costs of the two initiatives is difficult as both make use of salaried employees, e.g., the faculty advisor for the course and the lab's communication director, whose time efforts are not easily itemized. Therefore, the costs are broken down in terms of personnel commitments on a per-year basis (Table 4). While the Communication Lab is available to students year-round and the course was only offered for one semester, it is reasonable to consider the case where the course is offered once per year (i.e. its per-semester costs/benefits are equal to its per-year costs/benefits). The Communication Lab has a fixed cost to remain open, with a $1/2$ full time equivalent (FTE) manager position and a flat fee that contributes to the director's salary (which does not change with the number of Communication Labs). The main upfront expense for the class comes from the assigned faculty member. Because the Communication Lab operates throughout the year while the course only operates for 12 weeks (with in-place course development structures), we reason that the non-tutor labor costs for the Communication Lab are higher than that of the course. This means that the Communication Lab has a higher financial "barrier to entry" as it costs more to make it available to students than the class. Beyond upfront costs, both initiatives have tutor commitments that scale nearly proportionally with the number of students/clients.

Table 4 also includes the educational output for each initiative in terms of measurable quantities. The Communication Lab reaches an order of magnitude more students (not accounting for workshops), though at fewer hours per student. This is the main distinction between the class and the Communication Lab – intensive work for a few students is traded for smaller commitments across a larger population. Nevertheless, this trade-off is not necessarily balanced and may favor one intervention or the other, depending on the metric of interest. For example, it can reasonably be argued that the reach of the Communication Lab makes the cost per student lower, but the group-instruction nature of the class makes its cost per student-hour lower. The balance may also be tipped by considering pedagogical added-value for every unit of investment (both the institution's and the students') which, for the purposes of this analysis, are ignored here and left to other sections.

³Tutor hours for the class are calculated as $5 \text{ tutors} \times 5 \text{ hrs/week} \times 12 \text{ weeks} = 300 \text{ tutor-hours}$. Tutor hours for the Communication Lab are calculated as $227 \text{ recorded one-on-one hours} + 24 \text{ hrs/workshop} \times 6 \text{ workshops} = 371 \text{ tutor-hours}$. In-person student-hours for lectures are calculated as $9 \text{ lectures} \times 30 \text{ min/lecture} \times 20 \text{ students} = 90 \text{ hrs}$.

	Class	Communication Lab
Resources Required		
Faculty	1 (teaching slot)	1 (faculty advisor)
Teaching Assistants	1	0
Guest Lecturers	8 (1 lecture each)	0
Director	0	1
Manager	1	1 (1/2 FTE)
Tutors	300 hours	371 hours
Educational Output		
Unique Students	20	218 (one-on-one only)
In-Person Student-Hours	90 lecture hours	227 one-on-one hours
Workshops	11 Workshops	6 Workshops @ 47.5 students (avg)

Table 4: Yearly resource allocation and educational return for both the Communication Lab and the class.³ Communication Lab figures are yearly projections based on about six months' worth of data in the EECS department. The Communication Lab director is listed explicitly, though should only be considered at a fraction as the full cost of the director is covered across multiple Communication Labs. For the class, while guest lecturers covered the majority of the lecture periods for the class, both the faculty advisor and the manager were involved and present for each lecture. The manager's role was primarily advisory in the course, while for the Communication Lab the role was 1/2 FTE, which represents a significant cost.

4.2.2 Administrative scalability

Financial costs alone can obscure hidden costs to implement a program or a class (e.g., added labor hours from salaried employees, navigating bureaucracy, etc.). These effort "costs" can enable or prohibit the scalability of the program just as much as funding concerns.

Initial setup for both the Communication Lab and the course required significant effort. The differences between the two approaches become more apparent when examining scalability. To first order, the main administrative effort for the Communication Lab is complete after its initial setup – expanding in size merely requires hiring additional tutors (training is done in bulk, and as such the difficulty does not scale much). Expansion to additional departments is relatively straightforward, with the addition of hiring a part-time manager for the new department. Expansion at MIT has been further eased by initially managing new Communication Labs through existing managers and the director prior to finding a manager to hire.

By contrast, the communication course has features that are more difficult to scale. The course as implemented was designed to appeal to EECS graduate students, with lecturers, examples, and assignments chosen from that discipline. Scaling in size is relatively straightforward, but appealing to different audiences (e.g., undergraduates) or expanding across departments is nearly as challenging as creating the first course. Workshop leaders were also chosen from the EECS Communication Lab tutors; attempts to create or scale the course where there is no Communication Lab would require a great deal of training. The course also incorporated guest lecturers rather than a single instructor; scaling, or even simply repeating, the same course requires coordination for every im-

plementation. Various features mentioned above could be removed to improve scalability; in the authors' opinions, such removals risk negatively impacting the quality of the course.

4.2.3 Student effort

The impact of both the Communication Lab and the course is directly affected by student buy-in. For such elective programs, students must consider their investment of time and effort to be worthwhile.

The personnel commitment analysis in Section 4.2.1 showed an order-of-magnitude difference in number of students helped by each approach, from tens of students in the course to hundreds of clients using the Communication Lab. This was not for lack of availability of seats in the course – a greater number of students enrolled at the beginning and then dropped (see Section 3.2.2)

Overall, how students are willing to spend their time depends a great deal on the population to be reached and its culture. Graduate student requirements in EECS at MIT involve a great deal of research and relatively few classes; students often choose to focus time on activities that will yield proximate or tangible benefits, and will frequently evaluate classes (including technical classes) on the metric of immediate value to their research. Even a six-credit (6 hours per week, half-subject) course represents a significant investment as perceived by students. To contrast, Communication Lab appointments are low commitment, give immediate value, and are directly authentic not only to students' research but to their exact communication task.

5 Moving forward at MIT

After experimenting with both the Communication Lab and the course, the Communication Lab was chosen to persist. For the specific circumstances at MIT, the Communication Lab reaches more students and is sustainable at reasonable expense. The model is expected to be more effective per hour of student time based on the research literature for one-on-one tutoring (Appendix B). It is additionally an enabling organization, providing a pool of trained communication experts capable of partnering with technical courses, helping run communication courses (should they exist), providing distributed informal support, etc.

Nevertheless, aspects of the communication course are important enough to try to retain. The course participants' affinity for peer feedback in student groups, exposure to non-expert groups for practice, and exposure to students of other sub-fields was largely unexpected and is not naturally provided by Communication Lab tutoring. One attempt to retain this feature will be through a strengthened effort to run workshops – short, targeted sessions or series of sessions, organized and run by Communication Lab tutors and strategically timed within the departmental calendar (e.g., thesis proposal workshops before submission deadlines). These workshops preserve aspects of a course while stripping away a great deal of overhead, expense, and required student commitment.

The course was also able to address communication skills in more general terms than a typical Communication Lab appointment, arguably allowing students to create a broader and better con-

nected “knowledge organization” for future applicability (see Appendix B). In the course, this was easily visible in the form of a rubric of communication principles like that of Fig. 2; the particulars varied from task to task, but the essential continuity was made to be obvious. Similar efforts are currently underway in the Communication Lab. Tutors are being trained to help students recognize the transferability of principles under discussion, relatively general formative assessment rubrics are being designed for use in tutoring sessions, and an online resource [55] is under continuing development to provide guidance on a range of tasks while emphasizing the consistent features of good technical communication.

The Communication Lab is having a large and expanding impact at MIT. In a few short years, it has expanded from one department to four. Each department’s participation is an independent vote of confidence based on prior success, and Communication Labs in additional departments will already have been formed prior to this paper’s publication. The authors believe that this is not peculiar to MIT, but that the Communication Lab model could be adapted to other institutions and scenarios.

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Appendix A Rationale for specialist tutors

Writing center literature contains a long and ongoing debate over the best level of specialization for writing tutors. The typical binary consists of “generalist” versus “specialist” tutors. Both are meant to be experienced writers and tutors, though generalists may have broader professional writing experiences while specialists have discipline-specific content expertise (i.e. they are or were engineers/scientists themselves). Each option offers certain advantages.

Specialist tutors are able to engage with technical content as well as form. In focused studies (e.g. [56]), patterns emerge that specialist tutors in technical settings are frequently better able to:

1. Accurately assess paper content and issues;
2. Set appropriate agendas focusing on global issues (e.g., organization, presentation of evidence) rather than superficial points (e.g., grammar and spelling);
3. Analyze and evaluate student input;
4. Push back when students’ ideas are limited/limiting;

5. Circle back to larger learning goals and draw general lessons from sessions rather than following a linear agenda;
6. Provide guidance about communication in the discipline.

These advantages are also identified in [43, 57, 58].

Additionally, in [58] it is observed that non-specialist tutors sometimes make important mistakes under the pressure of technical writing outside their expertise. These mistakes include misapplication of rules regarding surface features, attempts to make informative writing persuasive, and insistence on an overly formal tone. In other words, generalists may not only focus on less important things, but may make incorrect recommendations as well. Still, it is possible that the disadvantages of generalist tutors can be mitigated through familiarization with the writing traditions and culture of the target discipline, even without technical training.

There are also advantages to generalist tutors over specialists. One of the primary arguments against specialist tutors is the risk of over-directiveness, i.e. that tutors will dominate the conversation, substitute their own ideas for those of the student, “tell not show,” etc. Generalist tutors, it is argued, are more likely to engage in dialogue and affirm the knowledge (however great or small) of the student. The importance of this advantage should not be understated – overly directive tutoring sessions can seriously impede educational growth.

Nevertheless, it has been observed that this risk is mitigated when tutors are not *specific content experts* in the topic of the session, although they may still have *disciplinary expertise* [56, 58] to access the benefits discussed above. For example, a tutor with background in integrated circuits is unlikely to be tempted to domineer a student who works in power systems, but still has enough relevant disciplinary expertise to evaluate both content and form in the communication task.

It remains unclear how much and what kind of expertise is ideal and whether negative tutoring behaviors can be mitigated through training. What is clear is that a solid understanding of engineering writing mores and (at least) a loosely related technical background offer significant benefits. Additionally, we hypothesize that these benefits are especially pronounced at higher levels of technical work (e.g., graduate school) and when using peer tutors (as opposed to professionals) whose training must be relatively quick and repeatable.

Appendix B Pedagogical principles distinguishing one-on-one tutoring and classes

Although studies comparing various writing interventions (writing centers, courses, WAC approaches, etc.) are relatively sparse, a great deal of research has identified broader pedagogical principles that contribute to student learning. Several such principles are listed in Table 5, along with our observations from Communication Lab tutoring and the communication course that relate to each principle. References to research literature are provided; additional primary references can be found in the relevant sections of [59, 60].

A survey of Table 5 appears to favor one-on-one tutoring to courses. This is consistent with empirical findings which show tutored students far outstripping their conventionally-taught counterparts,

an observation known as the “2-sigma problem” [61]. Nevertheless, this is typically an expensive intervention, and the use of peer instruction is necessary to keep monetary costs low.

Neither approach is absolutely superior. Identifying the best intervention requires analyzing the needs, characteristics, and objectives of the students/department, including the human and physical resources that can be dedicated to achieving said objectives.

Pedagogical Principle	Tutoring	Course
Strongly interconnected knowledge organizations distinguish experts from novices; are necessary for both effective recall and transfer; are built through contact with similar principles in diverse contexts [59, 60]	Single-context but advisors should refer back to general principles	Multi-genre; repeated exposure to general principles; repeated grading rubric
Peer coaching can be effective to scale the impact of teaching; peer coaches represent more “proximate and credible models” and can individualize instruction and feedback [59, 62]; peer coaching can be cost effective; coaches must be well trained; see [40, 63–65]	Very resource-slim, fully utilizes peer interaction; coaches can be selected by client, interchanged from session to session	More resource intensive; uses more faculty/professional input; harder to match students and coaches
Both content knowledge and pedagogical content knowledge can be important for effective teaching [59]	Advisors have variety of specialties and extent of content knowledge; are trained and well practiced at coaching in communication skills, though less than full-time tutors	Somewhat more arbitrary matching of advisors to students (may be good to force students outside of niche); advisors also trained to coach.
Authentic learning can effectively tap into student motivation. May risk over-contextualizing knowledge, disconnected from transferable principles (i.e. disconnected knowledge organizations) [59, 66, 67]	Always authentic needs (upcoming paper, presentation, etc.); may lose this quality when task is a class assignment	Authentic tasks in theory, often less so in practice; questions about “when would I ever” e.g., write a paper for the press, lack of urgency
Practice and feedback are crucial to learning and retention; feedback should be qualitative and useful with opportunities to revise; summative assessment is useful, but usually more formative assessment is necessary [60]	Students encouraged to revise, revisit the Communication Lab; feedback very directed, specific	Less time for feedback from coaches, but adds feedback from faculty and peers; every assignment is submitted, revised with feedback, and re-submitted
Inaccurate or ineffective prior knowledge can skew a student to incorrect interpretations of teaching; can also entrench students in ineffective approaches [60]	Good opportunity to invoke or correct prior knowledge directly	Less opportunity to confront misconceptions; broader buy-in from students may help convince the reluctant few that principles work
In general, student motivation is strongly connected to learning [60]. This includes understanding and believing that what they are learning is important, seeing an applicable use-case, and believing that they can accomplish the task at hand	Student comes with authentic use-case, usually understanding and believing in its importance	Not all topics appeal to all students; some believe they will never use certain genres (e.g., writing for the press); short exposure to topic may not be sufficient to overcome student self-doubt about skill

Table 5: A survey of pedagogical principles which elucidates some advantages and disadvantages of peer tutoring versus formal courses.

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