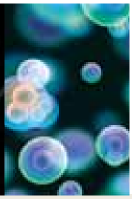
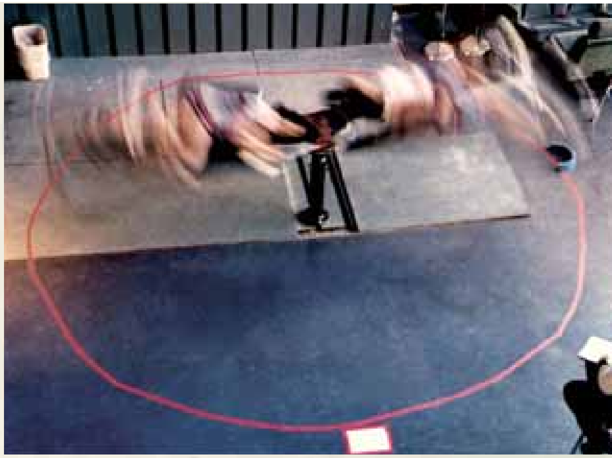
Learning to Communicate in Science and Engineering



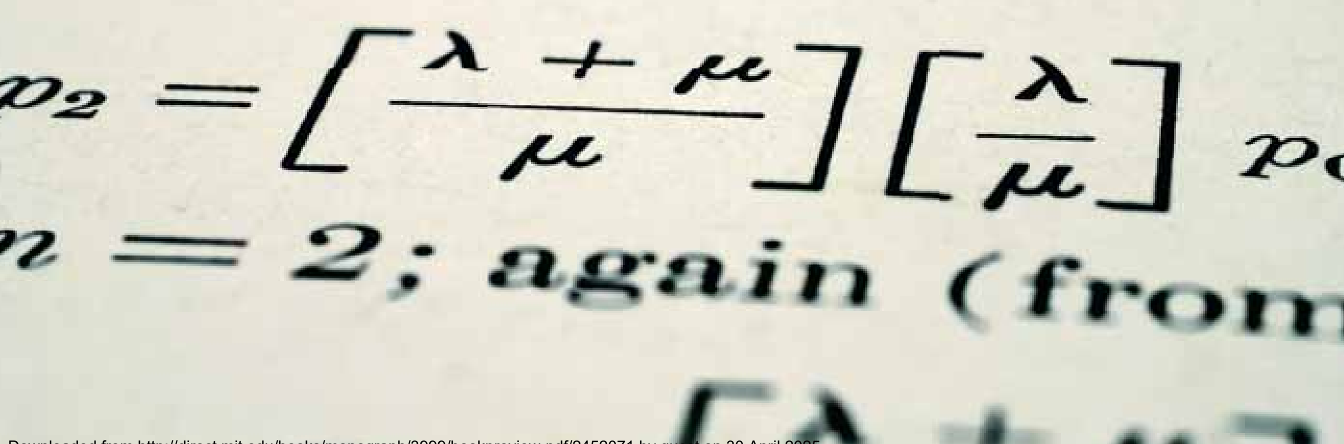


CASE STUDIES FROM MIT



MYA POE,
NEAL LERNER, AND
JENNIFER CRAIG

FOREWORD BY JAMES PARADIS



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Case Studies from MIT

Mya Poe, Neal Lerner, and Jennifer Craig

foreword by James Paradis

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Foreword

Although writing and speaking skills are stock-in-trade for the practicing scientist or engineer, communication is by no means an easy subject to teach in the university. It helps, no doubt, to have students write and speak as much as possible across the university curriculum. Yet communicating science and engineering, the authors of this detailed and fascinating study show, is also a cognitive and social process that is discipline specific. It flows from a professional identity and, when effective, gives persuasive force to scientific and technological findings while placing them into the framework of a recognizable field.

One challenging but creative approach to teaching students to communicate in their disciplines is to see if we can make learning to communicate an integral part of learning the disciplinary subject. The case studies in this book take the teaching of communication into a series of undergraduate subjects in these majors at MIT: biology, biological engineering, aeronautical and astronautical engineering, and biomedical engineering. Analyzing the writing and speaking development of seventeen students in seven MIT science and engineering classes (in five departments), Poe, Lerner, and Craig explore ways in which learning to communicate helps students identify with and think in a discipline. Effective communication, they show, is closely linked with an emerging disciplinary identity, and certain communication tasks with feedback will strengthen this important connection: practice with forms (genres), working with peers in team projects, and receiving feedback from subject instructors and peers. These case studies, then, can be seen as both detailed explorations of how students learn to meet the expectations of communicating in specific science and engineering disciplines and as a series of best practices that provide educators with clear strategies for improving teaching communication in the disciplines.

The collaborative model of teaching communication showcased in this study has a long history at MIT. Although evaluation of technical reports was a practice of science and engineering education at MIT as early as the 1890s (Russell 2002), Robert R.

Rathbone's efforts in the early 1950s began MIT's modern era of integrating communication instruction into various core science and engineering laboratory subjects. Rathbone, who had been hired as a report writer for Project Whirlwind by Jay Forrester, the MIT inventor of the computer magnetic core memory, developed a popular report writing course in the early 1960s for undergraduate science and engineering majors. He also had a thriving consulting practice as a short-course instructor in industry teaching report writing to scientists and engineers. Extending his collaborations with Forrester to other MIT engineering faculty, Rathbone began experimenting with bringing this real-world short-course experience back into the engineering classroom in a variety of presentations on communication, help with syllabus design in the core engineering subject, and feedback on student written and oral presentations.

The establishment in the mid-1970s of the independent MIT Writing Program in the School of Humanities and Social Sciences gave new force to these collaborations, which Rathbone and his colleagues expanded to a variety of core laboratory subjects throughout the departments of the School of Engineering. This effort, which was increasingly funded by the School of Engineering, demonstrated not only that engineering faculty valued good communication and were interested in experimenting with new models of communication education, but also that a consulting or distributed model of communication instruction could be sustained through a network of collaborative interdepartmental structures.

Over the following twenty-five years, after extensive experimentation and development by various members of the MIT Writing Program, much of it spearheaded by Les Perelman and the coauthors of this well-researched, probing study, the Institute Communication Requirement was developed and passed by an MIT faculty vote in 2000. Perhaps the most compelling of the many features of this requirement was the mandate that communication instruction in the respective major be taken by every MIT undergraduate in both the junior and senior years. The Writing Across the Curriculum Program, a division of the Program in Writing and Humanistic Studies, became the primary source of this collaborative instruction. Poe, Lerner, and Craig take us deep into the territory of the collaborative teaching enterprise, where communication instructors negotiate with subject instructors to design curricular interventions in communication that seek to improve student learning of the subject matter. What I find absorbing about these accounts is their essential honesty about the messiness of the undertaking, with all its conflicts, misunderstandings, lack of closure, and variability. There are questions of authority between subject and communication instructors that do not always get resolved. The reassuring control of one's own classroom is relinquished, in exchange for a kind of opportunistic pedagogy seeking to insert itself at crucial junctures in the harried process of a demanding learning curve. Follow-through is a constant problem. Timing can be a nightmare. Students sometimes resist working with the communication instructor, the subject instructor, or each other. The measured world of the communication textbook or even the luxury of one's own classroom space seem distant. And yet these situated learning spaces provide what is undoubtedly a dynamic locus for teaching students to communicate in the disciplines. They come close to the near chaos of real world multitasking, where learning, thinking, and communication tasks are often completed with colleagues just in time.

This book takes a major step forward in both the scholarly study and the pedagogy of writing in the science and engineering disciplines. Its chapters are framed in the most up-to-date research in writing studies, but the research is thoughtfully subordinated to the object of improving our understanding of the classroom situation. It offers a new window on the complex relationship between communication and the practice of science or engineering, and it provides many concrete strategies for improving the teaching of communication in science and engineering fields where multiple authorship is the norm. As a writing program administrator who has had the privilege of seeing Rathbone's wise and entertaining one-man communication show mature into the substantial, far-ranging collaborative pedagogy of Poe, Lerner, and Craig and their many MIT colleagues in science, engineering, and communication, I highly recommend this book to science, engineering, and communication educators everywhere.

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To the faculty and instructor colleagues in the disciplines who graciously allowed us to study their practices and describe them in this book, we owe a tremendous debt. In the Department of Biology, we thank Marilee Ogren, Dennis Kim, Thomas Schwartz, and Stephanie Capaldi. In Biological Engineering, we thank Natalie Kuldell and Drew Endy. In Health Sciences Technology, we thank Sangeeta Bhatia and Martha Gray. In the Department of Electrical Engineering and Computer Science, we thank Dennis Freeman, Jongyoon Han, Tom Weiss, and Joel Voldman. In the Department of Aeronautics and Astronautics, we thank Edward Greitzer, Sheila Widnall, Ian Waitz, David Darmofal, Earll Murman, David Miller, John Keesee, Jane Connor, John Hansman, Brad Holschuh, Dick Perdichizzi, David Robertson, and Todd Billings in addition to the exceptional support and administrative staff members that keep us all going. In addition to instructional staff, we are indebted to the student participants in this study, and envision long, fulfilling careers for all, whatever the types of communication practices they are engaged in.

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Introduction

Engineers who don't write well end up working for engineers who do write well.
—The MIT Writing Across the Curriculum Program

MIT students, by and large, do not love to write. Although that charge might be made against many students at many institutions (and against faculty, for that matter), the science and engineering orientation of MIT undergraduates can often lead them to believe that in their professional careers, the search for engineering solutions or scientific phenomena, not the seemingly tedious process of communicating those findings, will dominate. And while many of our students do have secret writing lives, those activities are centered around what they often describe as ''humanities writing,'' such as fiction, poetry, essays, or informal writing over the Internet. Overall, the idea of writing as a scientist or engineer is somewhat foreign and fairly intimidating to them.

Nevertheless, when students arrive at MIT, they find that they will need to write and speak a great deal and that these activities carry evaluative weight. Most of that activity centers on classes that are designated as communications intensive (CI). Undergraduates are required to take four CI classes: two in a distribution of humanities, arts, and social science classes (CI-H) and two in their majors (CI-M). A 2008 assessment report on students' satisfaction with these classes found that student buy-in was generally good, though seniors placed higher value on the CI-M classes—the writing and speaking they did in their majors—as compared to CI-H classes—the writing and speaking they did outside their majors (MIT 2008). This finding is not particularly surprising, given the exigency of major classes and students' impending start of their post-undergraduate careers. This finding is also in accord with previous longitudinal studies of students' reflections on the importance of writing instruction (Beaufort 2007, Sternglass 1997, Carroll 2002). MIT devotes considerable resources to support CI activities, including a staff of forty-five full- and part-time lecturers who offer supplemental instruction in CI classes. CI teaching and learning activities make a great deal of sense in a climate of increasing demands for science and engineering professionals to be skilled communicators and given what we know about how important writing and speaking are in helping students learn content.

Still, these larger goals potentially mask a whole host of issues that need to be addressed to ensure the success of a communications-intensive requirement—and the administration and instructional components created to support it. This book looks deeply at those issues and at the processes of student learning in a range of CI science and engineering classes. In biology, biological engineering, aeronautics/astronautics, biomedical engineering, and health sciences technology, students are faced with the tasks of writing, speaking, persuading, and collaborating that are modeled closely on professional standards. This work is embedded in the particular cultures of those classes, majors, and professions, adding a host of implicit expectations that shape the evaluation of student work. Finally, student learning occurs in the context of schooling, rather than in the workplace or research lab, and the time constraints, cultures, and demands of MIT strongly shape that experience. Overall, the faculty and instructional staff described in this book are involved in the complex activity of teaching students to write and speak as scientists and engineers and are doing so within specific discourse communities. An improved understanding of the key factors in these contexts can tell us a great deal about what works and what does not, as well as expand our theoretical knowledge of teaching and learning in Writing Across the Curriculum and Writing in the Disciplines programs.

The Call for Communication in Professional Contexts

The classes we describe in this book are not unique to MIT but instead are part of a national trend in engineering and science education toward achieving communication outcomes. In many ways, this trend has been driven by professional organizations that have recognized the importance of good communication skills for engineers. For example, the National Science Foundation (NSF) has long recognized the importance of communication education in the sciences and has encouraged changes in the way that student scientists are educated. NSF supports efforts in science and science writing in various venues, including the Beyond the Classroom professional development program at the University of California Santa Barbara, a "partnership between scientists and science teachers to support the use of technology in science courses for the purpose of enhancing students' scientific investigation and English language skills" (Materials Research Laboratory, n.d.). The American Association for the Advancement of Science (2008) Benchmarks for Science Literacy include as one learning goal to ''choose appropriate communication methods for critically analyzing data.''

A major force for recognition of the importance of communication skills has also been the influence of accrediting agencies. Since 2000, the Accreditation Board for Engineering and Technology has required that engineering programs demonstrate that their graduates show proficiency in a number of ''soft skills,'' including:

- An ability to design and conduct experiments, as well as to analyze and interpret data,
- An ability to function on multi-disciplinary teams,
- An ability to communicate effectively.

The adoption of these goals has driven a great deal of curricular reform in science and engineering, but their relative abstractness has presented a problem (Paretti and McNair 2008). As Driskill (2000) asks, what does it mean to ''communicate effectively''? And what are ''communication skills,'' particularly in light of research on the development of writing abilities and sociological work on the role of communication in the lives of practitioners? On one level, it is tempting to define *communication skills* as grammar or correctness—concrete, easily identifiable elements of good writing, yet writing instructors and their engineering and science colleagues know there is more to good writing than grammar and syntax.

A traditionalist point of view would argue that writing occurs after the science or engineering has been done and that the role of communication is to transmit that information to readers. In this view, scientific or engineering education should focus on the accumulation of factual and procedural knowledge with communication education occurring outside the technical classroom after students acquire technical expertise. Although this appearance of the functionality of communication as a funnel from writer to reader is tempting, it ignores the day-to-day microcommunications that occur in labs and other workplaces. A traditionalist view of communication also does not help students learn the ways that disciplinary values are embedded in the ways of speaking and writing used in science and engineering. For professional scientists and engineers, writing does not occur at the end of research or design; it permeates the research process. As Robert Locke explains, ''To be sure, at some stage in scientists' work a writing down (a writing up) occurs; they prepare, finally, written documents, scientific papers or reports, which . . . 'represent' their findings. Yet the specific language in such a paper does not arise *de novo* when scientists come to write; much of it is already present *in posse* in everything they think about their work'' (1992, p. 34).

In our experience, working scientists and engineers have little difficulty acknowledging the persuasive aspects involved in their written publications and presentation choices, and they have little problem balancing these rhetorical decisions against the objective persona involved in a science or engineering professional identity. In making decisions, they do not deny the ''brute facts'' of nature, but they acknowledge that these facts are not science itself (Gross 1990).

For professional scientists and engineers, communication skills include a wide range of abilities, including knowing when and what types of communications to use, how to use evidence that is recognizable and understandable to the audience, how to deploy communication in ways that appeal to a group's sense of itself, and how to work collaboratively to achieve those ends. Such aspects of communication skills are not esoteric qualities. Rather, these skills are teachable through instruction, practice, and feedback. Nevertheless, despite a good deal of professional activity directed toward refining these practices, challenges remain. These include, according to Paretti and McNair (2000), disciplinary faculty not having a foundation in composition and communication practice and theory, institutions unable to create interdisciplinary partnerships between disciplinary faculty and communications specialists, and students not having flexibility in their schedules for communication instruction. To overcome these challenges, our approach at MIT has been to embed CI writing and speaking instruction in the structures of students' classes and, ideally, the cultures of the disciplines. The case studies we describe attest to the challenges and opportunities of this approach.

Communication Instruction and Student Learning at MIT

In our teaching practices and in the research we describe here, we take the approach that communication helps shape scientific and engineering practice by constructing how knowledge is articulated; that is, ''scientific knowledge emerges from a nexus of interacting people, agencies, materials, instruments, individual and collective goals and interests, and the histories of all these factors'' (McGinn and Roth 1999, p. 15). This approach is deeply indebted to the Writing in the Disciplines (WID) movement, which began in the 1980s along with the Writing Across the Curriculum (WAC) movement as a method to teach students disciplinary ways of communicating in their respective professional fields (Russell 2002; McLeod, Miraglia, Soven, and Thaiss 2001; Pritchard and Honeycutt 2006). First principles of the WID movement are to model the authentic communication genres and processes of professionals as closely as possible within school contexts. More recent innovations in WAC and WID have been toward Communication Across the Curriculum (CxC), which attends not only to written work but also to oral and visual ways of doing communication in the disciplines (Bazerman et al. 2005).

As instructional movements, WAC, WID, and CxC have offered examples of and justification for curricular structures that are now in place in a wide variety of institutions. Less well known is how students learn in these programs, particularly in the context of science and engineering education. Studies point to the need to help students understand the discourses of science and engineering and how to use those discourses to specific ends (McGinn and Roth 1999). Many institutions have created stand-alone writing courses for students in hopes of efficiently improving their academic writing (Leydens and Olds 2007). Although these courses can offer valuable insights into the discursive conventions within a discipline or procedural knowledge about grant submissions or human subjects training, they run the risk of drifting from the actual practices in which science and engineering professionals engage during lab and field research. Moreover, stand-alone courses often neglect oral communication, a key skill for engineers and scientists. The case studies in this book offer a number of innovative oral and written tasks, all based on the exigency of problems to be solved in specific fields, and thus representing authentic opportunities for students to learn to communicate in those fields.

In terms of the context for the classes and students we describe, the integration of writing instruction into science and engineering classes at MIT began in the late nineteenth century (Russell 2002); however, curricular reform to bring about the current communication requirement was the result of alumni feedback gathered in the mid-1990s. While alumni felt that they had received top-notch technical educations, their lack of proficiency with writing and speaking was a significant hurdle to professional success. In response to this feedback, in 1997 MIT initiated multiyear curricular pilot programs involving communication education, and these pilot programs became the basis for the current CI curriculum. In 2000 MIT faculty passed the communication requirement, an institute-wide faculty initiative with the intention to integrate "substantial instruction and practice in writing and speaking into all four years and across all parts of MIT's undergraduate program" (Office of the Communications Requirement 2008).

As we noted previously, the communications requirement requires MIT students to take at least four CI courses in their four years at MIT. Two of these courses must be completed in the major. Such courses emphasize communication in the learning of technical content. Unlike some other universities where such courses might be taught as stand-alone entities or with minimal input from the writing program, MIT's CI courses are taught collaboratively with technical faculty and communications instructors. Each department at MIT develops its own CI courses to reflect the disciplinary needs of its students, some of whom enter industry and some of whom continue to graduate or professional school. This integrated approach develops students' writing and speaking skills in the practice of doing science and engineering.

Our initial goal in designing CI instruction was to work with engineering and science faculty to design meaningful, well-defined assignments, use revision and peer review to improve student writing, develop learning goals, and effectively assess student writing. Fundamental writing and speaking instruction still forms the basis of our collaboration with engineering and science faculty. What has also emerged, however, is a move away from these initial steps to writing and speaking activities that resemble the more advanced challenges of engineering communication that occur in the practice of doing engineering (Carter, Ferzli, and Wiebe 2007). In this way, we have been able to ask not only, ''What forms of writing should students be doing?'' but also ''What activities encourage students to work and to think like professional engineers?'' Our particular interest is helping students move from general academic writing or novice approximations of disciplinary writing to internalizing the communication-thinking practices of professional engineers (Leydens and Olds 2007; Bransford, Brown, and Cocking 2000). Thus, our CI classes are tailored to fit the communication practices of the young professionals in the particular discipline in which we are working. Our collaborative work with engineering and science faculty blends our understanding of writing pedagogy with the expectations of the specific discipline.

One might argue that this considerable commitment of resources makes MIT unique in its approach to integrating communication instruction in engineering classes. However, institutions ranging from large state universities such as North Carolina State University to smaller institutions such as Presbyterian College have active communication-intensive programs, albeit using quite different approaches. At some institutions, communication and writing-intensive instruction is offered on a workshop basis to interested faculty. At others, CI instruction has been added to general education requirements and is supported through writing fellows or a writing center. The integrated model we use at MIT is also found at other institutions, although on a smaller but nonetheless quite effective scale. As we describe in the MIT case studies that follow, the realities of working with faculty, staff, and students to help them achieve communication and course goals can be easily applied to a wide variety of settings. The importance of helping students meet the target competencies of professional practice, of teaching effective teamwork and collaboration, and of teaching students to understand and argue with visual data are recognized as widespread needs, particularly in the framework of the Accreditation Board for Engineering and Technology's engineering communication criteria (Shuman, Besterfield-Sacre, and McGourty 2005). We believe that our examples attest to the possibilities and challenges in meeting those needs both inside and outside MIT.

Sociocognitive Theories of Writing, Speaking, and Learning

The teaching and learning reported in this book are informed by the particular curricular needs of our institution and the developing relationship between disciplinary faculty and communication instructors. However, contemporary models for understanding how science and engineering students learn to communicate strongly shape this teaching and the research studies that follow. These models are based on the idea that writing and speaking are essentially sociocognitive acts and that specific communication tasks are intertwined with the social context in which they are situated (Lave 1996, Gee 2000, Prior 2006).

The sociocognitive view is useful for studying student learning because it takes into account human interactions within the contexts in which those interactions occur. In other words, a social model of learning takes into account the many relationships essential to successful study, whether with other students, classroom faculty, or laboratory personnel (McGinn and Roth 1999). A purely cognitive view of learning, while useful, does not consider the social or rhetorical purposes that writing serves in communities. Science and engineering, like other communities, have their own ways of getting things done, their own internal disputes, and their own ways of inculcating new members into the community. Teaching writing without paying attention to these dimensions of learning to become a scientist or engineer risks disconnecting writing from the practice of doing science and engineering and further relegating writing as a remedial task that is to be acquired outside science and engineering. Research has long shown that decontextualized approaches to teaching writing, particularly disciplinary forms of writing, do not yield the kind of learning that comes with learning to write within specific contexts and performing the communication activities typically done within those contexts (Smith, Cheville, and Hilloks 2006).

This socially situated view of learning encompasses four factors present in school-based contexts:

Faculty The experiences, expectations, beliefs, and skills that faculty and mentors bring to the learning context mediate students' learning.

Students The experiences, expectations, beliefs, and skills that students bring to the learning context shape students' readiness for learning, as well as the outcomes of their learning.

Learning contexts The contexts for learning to communicate—whether classroom, laboratory, research group, or peer group—all present different or distributed opportunities for learning that cannot be isolated solely in classroom settings.

Communication tasks and processes The particular communication tasks (processes, practices, and genres) that are undertaken are shaped by the institutional setting as well as the values and functions of the larger professional community.

Each of these areas is represented by considerable bodies of research, which we next review to indicate the theoretical grounding for the research that follows and the foundation for the CI program at MIT.

The Role of Faculty, Instructors, and Mentors

One way to theorize sociocognitive factors in learning is to view the learning context for science and engineering students as one in which they are novice learners in a novice/expert system. The two dimensions to this theory largely draw from the work of Soviet theorist Lev Vygotsky (1962). One is the idea of the *zone of proximal development*, or the achievement that a novice might accomplish with the guidance of a more knowledgeable peer or mentor. Key to this instruction is the need to provide scaffolding or the support structures that introduce novice learners to professional practices and enable them to perceive and undertake communication tasks more effectively than they would be able to were they working alone (Wood, Bruner, and Ross 1976). Also essential is that the expert or mentor in the system makes visible the thinking and problem-solving processes underlying her performance. The second contribution based on Vygotsky's theories is the concept of learning as a *cognitive apprenticeship* (Collins, Brown, and Newman 1989). This model asserts that learning comes from gradual and guided participation in the communication activities essential to the system (Lave and Wenger 1991). For science and engineering students, this means learning the structures of professional practice in which communication occurs, that is, attending to the wider network of situations in which they need to write and speak.

Ideas of apprenticeship offer attractive ways of envisioning a teaching-learning environment that is in contrast to traditional schooling (Collins, Brown, and Newman 1989; Rogoff 1995). Apprenticeships "characterized learning before there were schools, from learning one's language to learning how to run an empire" (Collins, Brown, and Newman 1989, p. 491). For Rogoff (1995), apprenticeship is not merely one master teaching his or her craft to an eager novice. Instead, "apprenticeship as a concept goes beyond expert-novice dyads; it focuses on a system of interpersonal involvements and arrangements in which people engage in culturally organized activity in which apprentices become more responsible participants'' (p. 4). Collins, Brown, and Newman use the term *cognitive apprenticeship* in contrast to traditional apprenticeship in order to highlight two key differences: (1) apprenticeship in school settings emphasizes an expert's processes of problem solving in which ''conceptual and factual knowledge are exemplified and situated in the contexts of their use'' (p. 457), and (2) cognitive apprenticeship ''refers to the focus of the learning-through-guided-experience on cognitive and metacognitive, rather than physical skills and processes'' (p. 457). In other words, the intellectual work of schooling is the subject matter of cognitive apprenticeship, and it is through the activities of observation, coaching, and independent practice that students develop as successful learners.

In science and engineering education, mentoring and cognitive apprenticeship models are particularly prominent. In the case studies in this book, we show mentoring in a variety of dimensions, which include the kind of professional standards or competencies asserted by a professional's comments on a student draft or oral presentation, as well as more direct modeling of scientific thinking and problem solving.

What Students Bring to Learning

The connection between identity formation and learning is a central concept to social theories of learning, in which identity is socially constructed through a person's interactions with others, with knowledge, and with the physical and symbolic elements that he or she uses to communicate (Gee 2004). Central to identity formation are the motivations, beliefs, and attitudes that students bring to the learning context, and uncovering these affective dimensions is essential to both research that attempts to understand the factor that may limit or enhance newcomers acquisition of new skills (Blakeslee 1997) and to design interventions that capitalize on students' growing sense of identities as professionals. The research we report on in this book relies largely on interviews with students to understand these developing identities.

For students writing about their scientific research, identity also comes into play in terms of knowledge-making processes. Leydens (2008), in a study of engineers at various professional stages (including data from when some were still students), found that participants' conception of their role in the knowledge-making process—whether as a relatively static conveyor of relatively static knowledge or active shaper of meaning through rhetorical prowess—marked the path from novice to expert communicator. In Leyden's words, the most experienced engineering writers ''enact identities as confident change agents'' (p. 254). Identity formation—particularly a ''discursive identity'' or that formed by engaging in particular communication tasks (Brown, Reveles, and Kelly 2005)—is particular important for the students we describe in this book.

Contexts and Processes for Learning

Another element essential to sociocognitive theories of learning is the role of the context in which that learning is taking place. Whether students are learning in the classroom, the lab, or the field, each site socially situates learning activities, and a challenge for instruction becomes how to transfer student learning from those contexts to new and unfamiliar ones. Research on science and engineering students making the transition from school to workplace contexts demonstrates the ways that individual contexts strongly determine the means, forms, and success of communicative acts (Freedman and Adam 1996; Freedman, Adam, and Smart 1994; Beaufort 2007; Leydens 2008).

One way to think of science and engineering contexts in regard to communication are as discourse communities. In a simple sense, discourse communities comprise individuals who share certain language-using practices (Bizzell 1992). (For elaboration, see Swales 1990 and Porter 1992.) Typically when we talk about professional contexts for language use, we talk about discourse communities. Tissue engineers, for example, share a common way of talking about the human body, even if they do not always agree. Discourse communities need not be rooted at a physical location, but they do need a context for their practices to occur. Context, in this sense, is a place for the accumulation of wisdom, a place for members to air their grievances, and a place for new members to be initiated into the style, norms, and ideologies of the community.

When talking about school, discourse communities might be better labeled as ‘‘learning communities.’’ Learning communities are, Riel writes, a ‘‘way of knowing, a set of practices and shared value of the knowledge that comes from these practices’’ (1998, p. 1). A learning community might be more specifically described as a setting in which the community is organized rather than disciplined; characterized by collaboration rather than competition; focused on knowledge construction rather than knowledge delivery from one central source; student centered rather than teacher centered; interdependent rather than strictly independent. Instead of expertise flowing from the teacher to many students, expertise flows in many directions. Community members are recognized for what they know and can do, while leaders are people who inspire others to work toward common goals (Riel 1998). Smith et al. (2005) describe this kind of learning community as ‘‘engaged.’’

Anchoring instruction in authentic activities from the science and engineering professional world also calls for students to engage in steady collaboration and requires them to develop team skills. Collaborative communication within science and engineering education is based in the activities that naturally occur in design and research. Although the academic environment can never completely mimic the professional workplace, there is (or can be) enough verisimilitude within most design and research projects to introduce students to the authentic requirements of collaborative communication and teamwork.

Cooperative learning is often bundled with collaborative learning, and although these two approaches are similar, they have different historical roots. Collaborative approaches emphasize student interaction rather than solitary activities. Cooperative learning has a similar emphasis and in addition emphasizes cooperation and mutuality over competition (Prince 2004). The efficacy attributed to cooperative learning comes from several assertions. Cooperative learning can reduce the unproductive competitiveness that individually focused instruction can sometimes produce. By valuing the success of the group, students help one another to meet the group goal. Cooperative learning groups can create a supportive and collegial atmosphere in which to learn, thereby enhancing learning. Cooperative learning also allows groups of students to approach larger and more complex problems because the groups can offer a range of skill sets and increased critical thinking capacity and energy for problem solving (Springer, Stanne, and Donovan 1999).

In terms of team skills, when cooperative learning is structured around a realistic task (design, research, writing, presenting), it also offers a "natural environment" in which team skills can be practiced and developed (Prince 2004). In fact, Burrell and Colton (1999) argue that team activities should be "highly contextualized to that point that [they] are an inseparable part of what is normally done in the course" (p. 1). As student and faculty surveys and interviews have articulated, the experience of teamwork is the most effective way to learn how to work in a team. Certainly a modicum of explicit instruction and a good deal of reflection and assessment help refine and expand team skills, but the cooperative experience is fundamental to learning.

While there may be challenges in measuring the efficacy of certain models, researchers agree that the data are conclusive: active learning and, more specifically, collaborative and cooperative learning are effective in undergraduate science, mathematics, and engineering and technology courses and programs (Prince 2004; Springer et al. 1999; Smith 1995).

Communication Tasks and Forms

A feature of discourse communities is their use of shared genres to advance communication goals. One of the hallmarks of membership in a discourse community is fluency with the forms, or genres, of writing and speaking used in that community. However, as North American genre theorists have suggested, genres are not merely a collection of conventions of written or spoken discourse. Genres, or typified rhetorical reactions to recurrent situations (Miller 1979), allow members of a community to interact in a way that signals their membership in that community. Embedded in these forms are linguistic markers to a community's ways of knowing and arguing, and to its values (Driver, Newton, and Osborne 1997). Readers pick up on these markers and make assumptions based on them "about the text's purposes, its subject matter, its writer, and its expected reader" (Devitt 2004, p. 12).

North American genre theory has played a particularly strong role in research on students' learning in science and engineering (see, e.g., Luzon 2005; Walker 1999; Russell 1997; Freedman, Adam, and Smart 1994; Artemeva 2005; Artemeva, Logie, and St-Martin 1999). Key features of this theoretical perspective are that communication forms, such as a laboratory report, are not static but instead are shaped by the contexts in which they are produced and the social exigency of that production. Unfortunately, many science and engineering classrooms and how-to guides present scientific texts as relatively static products, seemingly codified through years of repetition. In other words, students learn "what" but rarely are offered the "why" or the knowledge production possibilities essential to a genre approach. For example, the long history of the school-based laboratory report as a "plug-and-chug" format or regurgitation of content in static forms ignores the critical role of the scientific report within the discourse communities of scientists. From a genre studies perspective, the scientific report shapes and is shaped by the needs of writers and readers; its production is a meaning-making activity occurring for particular social needs, and its more stable formats are a result of patterns of those needs (Bazerman 1988).

Another key feature of research on genre has been the observation that genres do not work in isolation. They travel together in sets and even operate in entire systems, all supporting a human activity (Bazerman 2004). What this means is that students must become knowledgeable not just about a single genre, such as a research article, but about the interrelationships among official genres in systems (e.g., letter of intent, grant proposal, supplemental reviewer material, reviews) as well as the unofficial or supporting genres (e.g., calls to program officer, e-mails to collaborators) (Berkenkotter and Huckin 1995; Spinuzzi 2003).

In the class and lab contexts we offer in this book, students were writing and presenting a variety of forms: design reports, PowerPoint presentations, research articles, laboratory reports, and business plans, among others. Certainly some of these forms are more codified than others (and thus in some, students had more leeway to veer from standard formats), but all forms are products of social action, and from a genre studies perspective, it is essential to recognize that students ideally become players in that production process.

Studies of Writing and Speaking in Sociocognitive Environments

In addition to the theoretical context for our research, the case studies that we present in this book are informed by research on students' learning to write and speak in disciplinary contexts, particularly in science and engineering. The methods, findings, and analysis from these studies provide a disciplinary context for our work, as well as the research gap (Swales 1990) that we felt needed to be addressed.

Studies of the link between communication instruction and learning have produced mixed results, in some showing a positive impact on student learning while others showing inconclusive results (Bangert-Downs, Hurley, and Wilkinson 2004; Oschsner and Fowler 2004; Klein 1999). Students who engage only in traditional schooling writing activities such as note taking evidence little change in learning (Tynjala, Mason, and Loonka, 2001; Langer and Applebee 1987). Students who participate in writing assignments that model those genres and inquiry activities that professionals in their field use learn communication within the social practices of their disciplinary communities and develop new verbal abilities as the result of that socialization (Keys 1999, Luzon 2005, Freedman et al. 2004, Carter et al. 2007).

In research specific to students' writing in science and engineering, early qualitative studies include Herrington's (1985) study of chemical engineering students in two classes; Walvoord and McCarthy's (1990) study of students in four disciplines, one being biology (see also McCarthy 1987, which included a student taking a cell biology course); and Haas's (1994) study of one undergraduate learning biology. Herrington's study, which relied on survey data as well as interviews and analysis of written texts, showed that students could be introduced to the social roles of a discipline through writing but that they may have difficulty in shifting from a school to a professional context. Her study also showed that each chemical engineering class represented its own discourse community: ''Even within one discipline, chemical engineering, different courses may represent distinct forums where different issues are addressed, different lines of reasoning used, different writer and audience roles assumed, and different social purposes served by writing'' (1985, p. 354). The main insight from Herrington's study was that a monolithic sense of academic disciplines as homogeneous communities was overstated, even in school contexts (a claim supported by sociologists).

Walvoord and McCarthy's study, which included think-aloud protocols, interviews, and analysis of student writing, also showed a link between student writing and the social role students were expected to enact: "Students experienced difficulties not only in adopting the role of scientist, but also in performing it appropriately—that is, using the scientific method and writing their reports in the appropriate format" (p. 226). Winsor's (1996, 2003) studies of two groups of engineering students over five years have provided specific insights related to the socialization of engineering students into the profession through the written genres and textual negotiations they encountered in a cooperative learning program and in the workplace. Finally, Beaufort (2007) tracked one student, Tim, from the writing he did as an undergraduate with a double major in history and engineering to the writing he was doing on the job as an engineer after graduation. Beaufort found that Tim's education gave some measure of preparation for the challenges he faced writing on the job, but that the learning curve was still steep.

These studies show us that writing development is not linear. They also tell us that the development of writing ability is related to the other developmental changes going on in students' lives. And finally, these studies tell us that students learn to write through instruction and practice. The ethnographic studies on writing development in the disciplines have been insightful because they use the disciplinary community's own definitions of effective communication rather than externally imposed measures. Additionally, such methods are best suited to capturing the full range of contextual factors that affect students' learning of communication skills (see also Patton and Nagelhout 2004, Geller 2005).

The Structure of Learning to Communicate in Science and Engineering

The chapters that follow describe students as they learn to write and speak in five different classes and disciplines. Each chapter has a particular frame: the role of identity for students in biology, the importance of authentic communication tasks for students in biological engineering, finding a research niche in health sciences technology, learning how to persuade with visual data in biomedical engineering, and the relationship of collaborative communication and teamwork in aeronautic/astronautic engineering. As our teaching of writing and speaking has been integrated into disciplinary subjects, these topics have emerged not simply as concepts but more specifically as practices integral to the instructional goals of CI work in the disciplines. In the classes described, we illustrate the implementation and refinement of these practices. From our teaching in these class contexts, we designed research to explore the practices that we believe have been largely underexplored in terms of previous research. Our research conducted over one or two semesters employed interviews with and surveys of students and instructional staff, observations of class and laboratory sessions, and analysis of students' written, visual, and oral work, as well as assignment sheets and departmental descriptions. (Appendixes A and B contain detailed descriptions of the methodology, survey instruments, and interview questions.) Student communication tasks included scientific articles, grant proposals, design proposals and reports, experimental reports, oral design reviews, PowerPoint presentations, business plans, and editorials. Based on these data sources, each chapter explores how identity, authenticity, persuasion, and teamwork are embodied, practiced, acknowledged, and resisted in actual classrooms.

The courses that we profile are not representative of every discipline at MIT. Instead, they represent courses that we have identified as having developed highly effective and efficient CI instruction methods—current "best practices." Each chapter also presents courses that might follow from one another so readers can see the learning trajectory of students as they move from one CI experience to the next. In the chapters that follow, student names have been changed, and particular demographic criteria have been modified or edited to protect student confidentiality. We can report that our limited sample of students and teachers represents a wide spectrum of gender, lifestyle, age, and ethnicity. The seventeen students in the seven classes studied in this book were consistent with the diversity found at MIT, where nearly half of the undergraduates are women and nearly half are from U.S. minority groups (*MIT Facts* 2007). Our student group had both native-born and international students. Also, a number of the faculty and teaching assistants in this study were women, representing not only the contemporary face of engineering and science but also MIT's effort to enhance ethnic and gender diversity across the campus. Although we did not specifically address these identities in our chapters, such identities are certainly important to students' educational experiences. It would be fruitful in subsequent research to understand more how these identities shape student learning. While the WAC and WID research has considered gendered identity (Wolfe 2005), it has been virtually silent on issues of racial/ethnic identity and sexual orientation (Anson forthcoming).

In chapter 1, we examine the ways in which undergraduates in biology take on the discursive identities of professional scientists as they work to turn scientific findings into a research article. The development of this professional identity guides the case studies in this chapter as we explore the following topics:

- What are students' challenges and opportunities as they face the dominant writing task of scientists: the scientific research article?
- How do students' identities as science students and neophyte scientists shape teaching and learning in a molecular biology laboratory class?

Key to this chapter are the developmental steps students take as they learn that scientific communication is more than efficient transfer of knowledge and includes a wide range of rhetorical concerns.

In chapter 2, biological engineering majors take more fully developed scientific identities and apply them to the range of authentic tasks that biological engineers encounter. In this chapter, we ask,

- What is the relationship between authentic writing tasks and students' development of scientific discursive identities?
- What are students' challenges and opportunities as they face multiple writing tasks of biological engineers?

The students featured in chapter 2 are more advanced in their academic careers and have a clearer sense of their futures than students in chapter 1. However, this clarity was not always an ally in their completion of the writing they faced, as the need to develop facility in and understand the importance of a variety of genres was a consistent challenge.

In the chapter 3, we examine how grant writing brings forth certain tensions as graduate students in health sciences technology learn to define and motivate a research agenda. In this chapter, we focus on three questions:

- How do students learn to motivate their scientific ideas in an organized fashion that appears significant to other scientists?
- What is the role of a student's mentor in learning to stake out a research territory?
- How do authentic writing activities like grant writing contribute to student learning?

Key to this chapter is the pivotal role of a graduate student's mentor in the learning process and the importance of authentic peer review.

In chapter 4, we examine the ways in which undergraduates in biomedical engineering learn to use data as evidence. Specifically, we look at the ways that students are taught to argue like scientists and explore the following questions:

- How do students learn the persuasive devices that professional scientists use when communicating data to other scientists?
- What challenges do students encounter in learning how to use visual evidence in scientific communication?
- What role does faculty feedback play in the development of this professional skill?

In chapter 5, we turn to the challenges of collaborative communication in aeronautical/astronautical engineering and the ways in which students learn to communicate collaboratively and develop the team skills so central to collaboration. We explore three questions:

- How do students efficiently and effectively learn to write and present collaboratively?
- What specific team skills are central to this task?
- How are those team skills best learned? By instruction? By mentoring? By experience?

Each chapter begins with an introduction that contextualizes the studies in that chapter and is followed by a description of the goals for student learning and communication activities. We then present case studies of individual students and overall findings from this research of undergraduate and graduate students as they learn to write and speak in a variety of science and engineering classes at MIT. In each chapter, we refer to students and teaching assistants by a first-name pseudonym to ensure confidentiality. We refer to faculty by their full name at first use and then last name subsequently. They have given us permission to use their names in this book.

We conclude the book with implications for pedagogy. In terms of those implications for any department wishing to design its own program, it is important to note that the structures of the CI courses presented in this book are quite different from one another. In this book, we present three types of CI courses. First are whole, or integrated, models in which the CI component is integrated entirely with the technical content of the class and works independently of other CI classes (e.g., chapters 2, 3, 4, and 5). Second are "stretch" models in which the CI curriculum dovetails with the CI curriculum in a subsequent class (e.g., chapter 5). Third are what we call "sidecar" classes in which the CI curriculum is independent of the technical course curriculum. These include tutorial models in which students meet once a week to discuss drafts of their research findings (e.g., chapter 1). The design of each course reflects a combination of faculty input, departmental resources and commitment, and goals for student learning.

It is important to note that it is not our intent to create a divide between what is possible at a resource-rich institution such as MIT and other institutions not similarly fortunate. If anything, the questions we raise in these case studies and the limits of our instruction are applicable to many institutions struggling to create meaningful educational opportunities in engineering communication.

Our research and the case studies we present raise other widely applicable questions: What does it mean for educational practice if professional communication competencies and tasks are the goals? How can engineering students move from mere display of data to making skilled visual arguments based on those data? How can students and technical faculty best create the conditions for students to learn to be skilled team members? By no means have we figured out the complete answers to those questions, but we hope that the case studies we present show some potential paths to finding those answers

Our inquiry into the teaching of communication at MIT also represents ‘‘teacher-research’’ or ‘‘action-research’’ (Cochran-Smith and Lytle 1993) meant both to improve practice and to broaden our knowledge of what it means to learn to communicate as a scientist and engineer. Thus, the sustained research in which we continue to engage through surveys, focus groups, individual interviews, and analyses of students’ work, all in the context of contemporary theories of teaching and learning, are essential activities for communication professionals in any setting.

The case studies we present here are not the final word on the redesign of communication instruction in engineering education. Our intent instead has been to highlight the ways that a commitment to teaching communication within disciplinary frameworks at MIT has brought to the four key aspects that require attention: identity, authenticity, argumentation, and teamwork and collaboration. Each of these aspects is present in some degree to all of our CI classes, and each reveals the opportunities and complications for designing communication instruction.

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