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CHAPTER 6

# Graphics and invention in academic engineers' writing for publication

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This chapter explores how academic engineers write for publication, focusing on "invention" – that is, moments when writers identify the research results they want to present and decide on the arguments they want to make in an article. A key finding presented is that beyond the well-documented role of graphics in displaying research results, graphics also play a crucial heuristic role in invention. This finding emerged from an ethnographic study of three engineering research groups, which entailed the analysis of a range of qualitative data to offer perspectives on the experiences of academic engineers writing for publication. Drawing on this research, the chapter documents that in developing texts for publication, engineers often begin with the graphic results of data analysis to identify findings and begin to craft arguments. Further, in research group and informal meetings, engineers invoke the notion of storytelling through graphics as they socialize their group members into the practices of research dissemination via posters and articles.

## Introduction

A chief feature of communications practices in the field of engineering is multimodality, as Mathison (2000) notes: "an engineer's way of knowing involves multiple symbol systems, some of which are verbal and some of which are numerical and visual" (p. 75; see also Amare & Manning 2007; Archer 2006; Selzer 1983). Research has identified the recursive interplay between text and graphics in the communication of engineering knowledge by undergraduate students (Archer 2006) and engineers in the workplace (Hutto 2007; Lloyd 2000). In presenting new knowledge, "visual representations of data are the work horses of argument," as Poe, Lerner, and Craig (2010, p. 115) claim in their overview of graphics and the scientific research article. Graphics therefore appear to be integral to the construction of knowledge and its communication across a range of contexts in which

engineering texts are produced. This chapter focuses on the heuristic role that graphics play in invention in the professional writing practices of academic engineers. Addressing the need for more empirical understandings of how scientists and engineers write, it presents findings from a three-year ethnographic study of the research dissemination practices of academic engineers (faculty members and their research group members), as they write professional genres such as conference papers/posters and journal articles. Ethnographic research can provide a window onto engineers' actual writing practices, enabling us to document practices and the perspectives of writers. Because it adopts an insiders' or "emic" perspective on particular social practices, ethnographic research enables an analysis of engineers' writing practices in terms of their meaning for both writers and the construction of disciplinary knowledge.

In this chapter I argue that (a) engineers often envision and construct the argument of a paper through the graphics (visuals such as tables, figures, and plots) that they generate in data analysis – thus in their writing visuals play a more central role than simply as illustrations for previously determined research findings and arguments; (b) the work of constructing findings and articulating arguments in text is a social, rather than an individual, practice; and (c) engineering faculty members use the metaphor of storytelling to conceptualize the development of a paper's argument and to persuade their readers. Faculty members draw on this storytelling metaphor to advise post-doctoral fellows, graduate students, undergraduates, and technicians working on specific projects as well as writing more generally.

The chapter first reviews the literature on multimodality and academic writing, then discusses the theoretical framework of academic writing as a predominantly social rather than individual practice (Curry 2003; Lea & Street 2006; Lillis & Scott 2007). I link this theoretical stance to the social turn in understandings of the rhetorical notion of invention (Lauer 2004; LaFevre 1987). After describing the three-year ethnographic study of engineering research groups, I present my findings about graphics and invention. I conclude with a discussion of the value of ethnographic research for understanding what goes on in the professional communication practices of engineering faculty members and students. These findings have implications for teaching and advising students and early career scholars about crucial communication practices in engineering, and by extension, other STEM fields.

## Theoretical framework: Engineering writing as multimodal social practice

Social practices are repeated patterns of activity aimed at particular purposes, such as, here, publishing and presenting academic research (Wenger 1998). A social practice perspective takes account of the range of activities comprising a practice

and considers how people learn the practice. It posits that learning occurs through increasing participation in valued practices, often under the guidance of more expert members (Barton & Tusting 2005). A social practice perspective helps with understanding how students, for example, gain access to academic knowledge-making practices (Lillis 2001). In the present study, learning academic publishing practices involves interactions among students, post-doctoral fellows, and faculty research group leaders. It illustrates what Lea and Street (2006) describe as an academic socialization model, in which learners are seen to participate in "the ways of talking, writing, thinking, and using literacy that typify members of a disciplinary or subject area community" (p. 368).

Scholars concerned with learning about the communication practices of academic disciplines have focused on novices producing writing that meets specific genre expectations in educational and workplace settings (e.g. Li 2002, 2005; Poe et al. 2010; Winsor 1992). In the field of composition studies, a predominant focus on the individual student has reinforced the notion that invention is a stage of writing that takes place before writing (as in 'pre-writing' in the process approach to writing) as well as being an individual practice (Bawarshi 2003). Invention, according to a summary by Odell and Swersey (2003, p. 40), was "for Aristotle, the discovery of persuasive arguments; for modern rhetoric, the formulation and articulation of ideas" – or the "discovery and creation models" of invention (Hawhee 2002, p. 17). Instead, Hawhee proposes the notion of "invention-in-the-middle," which connects to social practice theories by acknowledging that generating ideas and developing arguments occur in social encounters. These encounters include the collaborative writing that characterizes engineering (Gimenez & Thondhlana 2012; Winsor 1994) and indeed encounters taking place in an "individual" writer's head, as writers are always knowingly or unknowingly responding to the voices of others (Bakhtin 1986; LaFevre 1987; Lillis 2003).

Problematizing notions of the nature of engineering writing itself, Winsor (1992) argues that research data per se – represented as tables, figures, charts, and other graphics – in fact constitute a form of writing. In Winsor's study, "the engineer actually worked very hard to make these written traces [of research activity] appear" in his text (p. 342). She advocates that researchers move beyond "the insistence on the presence of words [that] comes from the deeply ingrained idea that writing is recorded speech" (p. 342; see also Winsor 1994). This perspective aligns with research pinpointing academic knowledge as increasingly being constructed and presented through a range of modalities (Bezemer & Kress 2008; Hanauer 2006). For example, in ethnographically studying the "linguistic landscape" of a microbiology laboratory, Hanauer (2009) documents how scientists and students graphically represented the knowledge they were constructing in the laboratory and used such representations (e.g. conference posters) as learning tools. Likewise,

Dicks, Flewitt, Lancaster and Pahl (2011) argue for the value of ethnography in studying multimodality, claiming that "any instance of literacy is in fact a multimodal 'event'" (p. 230). Nevertheless, considerations of multimodality have often been downplayed in relation to the written word, as I discuss next.

## Research on writing for publication in science and engineering

While some of the literature on scientists writing for publication (e.g. Bazerman 1988; Knorr-Cetina 1981; Latour & Woolgar 1979) makes passing note of the graphic display of research findings, most researchers do not closely examine its role.[1] However, in a rare study of the interactions among scientists as they write for publication, Rymer (1988) documents how nine "esteemed" biochemists write articles. Among her findings, she points to the generative role of graphics:

> Some invention procedures – using graphs, tables of data, and the author's own previous papers as planning devices – characterize all the [scientists'] practices. Typically, figures and tables of the data … function as visual aids to invention and as organizing points during planning and drafting. (p. 220)

In contrast to Rymer's apparent assumption that graphical representations of data have a function in invention, the literature on scientists learning to write for publication concentrates on the social practices of writing. For instance, Blakeslee's (1997) study of collaboration among a physics graduate student, post-doctoral fellow, and faculty member in a research group describes the student drafting his first article. Although she discusses the visual display of information, it is only mentioned as embedded in a data extract about how the student approaches the presentation of "information appropriate for their auditors." The student recounts:

> When I say what kind of results, I mean what kind of figures – like all these tables I have to get rid of [in the revision]. Now I have to decide what to put instead. I'll base my decision on results on which ones actually show that one method is better than another. (p. 146)

Here again, however, graphics receive only fleeting attention. In engineering specifically, the literature on writing for publication has mainly analyzed published texts and genres (e.g. Koutsantoni 2006; Luzon 2005; Shehzad 2006) or described and evaluated workshops and other instructional activities (Alford & Stubblefield

1. In fact, none of the 40 studies that Swales (1990) includes in Table 3, 'Overview of the Textual Studies of the English RA [Research Article]', focuses on the role of graphics; article structure is the primary concern of many researchers.

2002; Leydens & Olds 2007). Of the few investigations of professional engineers' writing practices, Shaw's (2010) study of the research report as deployed in the distinct but related domains of academia and industry demonstrates the relationship of context, purpose, and expertise in writing for different audiences. In a recent study of engineers writing for publication, Chiu (2011) focuses on two early career Taiwanese scholars. One of them, a mechanical engineer, Eric, "wrote the first draft only after organizing experiment data and discussing the major findings with his advisor and lab mates. … Eric negotiated with his data and tried hard to find a perspective by which to present his claims" (p. 472). Perhaps in foregrounding scholars' use of English as an additional language, this article presents findings about their "extensive reading and textual borrowing strategies" (p. 472) but does not explore the role of graphics. Overall, then, much of the literature on writing science and engineering journal articles mentions graphics only incidentally, with little sustained exploration of its role in writing. However, as Graves (2005) cautions in discussing scholarly publications:

> the process of creating the knowledge presented in academic articles is complex and multifaceted, suggesting that conclusions about a particular academic discipline that use as their evidence only the product – the written and published article – do not represent the whole story especially if claims about process are extrapolated from the written text. (p. 255)

The paucity of research on the practices of academic engineers writing for publication was one prompt for the present study, which I turn to next.

## Methodology of the larger study

This paper comes from a larger study, "Publishing Engineering Writing" (PEW), whose primary research question was: "In what experiences or activities do engineering faculty members, post-doctoral research fellows, and students engage in writing for research publication?" In this chapter I address two sub-questions:

- What are the professional writing practices of academic engineers?
- How do engineering students and post-doctoral research fellows learn the practices of writing for publication?

Ethnographic methodology offers an approach to understanding the lived experiences of writers in terms of their practices over time (Kress 2011; Lillis 2008). Ethnographic methods of data collection include participant observation of specific contexts; video- and audio-taping of specific events; conducting focus groups; and holding individual interviews. To study the practices of writing for publication,

the PEW study adopts the "text-ethnographic" methodology developed to explore writing for publication within specific contexts of production (Lillis & Curry 2006, 2010). Text-ethnographic methods include the collection of texts written for publication as well as other relevant documents including participants' correspondence with journal gatekeepers. Analytic methods used in text-ethnographic methodology follow the principles of modified grounded theory (Charmaz 2006). This approach involves multiple readings of interview/meeting transcripts, field notes, and documentary data in order to create codes, categories and themes that signal specific research findings. Researchers then validate the analytic findings partly by means of member checking, that is, presenting preliminary findings to research participants for feedback.

## Study setting and participants

The PEW study took place over three years at a U.S. engineering school with 81 tenure-track faculty members. The three faculty members and research groups that participated were representative of the school in terms of gender, race, and national/ethnic origin. However, they came from only two sub-disciplines, albeit large departments: electrical and computing engineering and biomedical engineering. Table 6.1 shows the composition of each research group (names are pseudonyms).

**Table 6.1.** Participants in the PEW study research groups

| Research group | Head | Members | Gender | Countries of origin |
|---|---|---|---|---|
| A | Professor Arthur, a white, male, distinguished full professor and department chair | 13 students and post-doctoral research fellows | 3 women 10 men | United States, East Asia, South Asia, central Europe |
| B | Professor Brown, a white, male, full professor and former department chair | six students and post-doctoral fellows | 1 woman 5 men | United States, East Asia, central Europe |
| C | Professor Courts, a white, female associate professor (also collaborating with two faculty colleagues, one at this university and one at another institution) | six students, one post-doctoral research fellow, three technical staff members | 5 women 5 men | United States, East Asia, South Asia |

Data collection consisted of audio- and video-recorded focus groups with various sub-groups (female faculty, female undergraduates, users of English as an additional language); 47 audio- and video-recorded individual semi-structured interviews with the participants; more than 100 audio and/or video recorded

participant observations, with attendant field notes made of formal and informal meetings including Professor Courts's weekly meeting; and multiple drafts of more than 50 texts written for presentation and publication.[2] Interviews and selected meeting recordings were transcribed and data were analyzed using modified grounded theory, as described above. Various data sources were transcribed and coded by me and members of my research team over the three years of data collection and two subsequent years of analysis. Using emerging codes and themes, data were coded independently by research assistants. Resulting analyses were compared, then codes and themes adjusted and reapplied to coded and new data. Ethnography enables us to triangulate emerging understandings of participants' practices by drawing on complementary data sources. In this case, triangulation allowed us to compare participants' self-reports with descriptions of these practices from their collaborators and the researcher team's documentation of practices. Drafts of this paper have been shared with participants, who confirmed our analyses of their experiences and practices.

## Findings: Graphics as invention in writing for publication

As mentioned, two key and related findings from the ethnographic study are that (a) graphics function as invention heuristics in the professional writing of academic engineers and (b) academic engineers convey these practices to those working with them either implicitly through shared practices or explicitly in discussion, often invoking the notion of storytelling. In this section, I use extracts from individual and focus group interviews to construct an overview of the faculty members' practices in directing their research groups' writing activities. Then, drawing on observational data and recordings as well as interview data, I describe a meeting that Professor Courts held in order to begin conceptualizing a paper.

As noted, the three engineering faculty members were highly successful, conducting and publishing research in their sub-disciplines that was funded by large grants and supporting a number of Ph.D. students and post-doctoral fellows. An important writing and teaching practice shared by the engineering faculty members was to assign to group members the initial drafting of papers and conference posters, to which the faculty members then responded. However, the majority of

**2.** My gratitude to research assistants Hairong Shang, Hee-Jeong Oh, Nan Zhang, Rachel Chaffee, Farzana Hafsa, and Qiao Li for support in data collection, management, and analysis over the life of the project. Thanks also go to my doctoral student group, which read an earlier draft of this paper, as well as to Julio Gimenez, David Hanauer, and Fredricka Stoller for their suggestions. Earlier versions of this paper were presented at conferences of the Canadian Association of Applied Linguistics (2009) and the Symposium on Second Language Writing (2010).

their other practices for engaging group members in preparing conference posters and writing articles differed, which affected my own research team's access to observing their practices. For example, Professor Arthur rarely held meetings with his entire group, which was the largest of the participating groups; rather, he moved multiple projects forward simultaneously in small and often quickly scheduled meetings, impromptu hallway conversations, and through email. Professor Brown generally followed similar practices. Thus it was difficult to be on site when interactions related to writing took place in these professors' groups. In contrast, in the second year of the study, Professor Courts initiated an ongoing weekly writing meeting with graduate and undergraduate students, a post-doctoral fellow, and technical staff members and invited me to research the group's activities. Although Professor Courts also met outside of scheduled meetings with smaller groups or individuals working on specific papers, these smaller groups would also bring drafts of these papers to the whole group for peer review and discussion. We were able to observe these scheduled meetings because Professor Courts diligently notified us about them and included me on emails to her group and sub-groups.

In terms of this chapter's focus on graphics, the importance of graphics in the faculty members' writing practices emerged as a strong theme in the data analysis, as illustrated in comments made by Professor Arthur:

> *I like pictures and figures. … You put the text after the figures*. This is … actually how we write the paper. *We visualize the set of pictures, the story that we tell, and then we put the text around it*. That's how … [but it] never works the other way around. Because especially if you write a short paper, you have to get to the point immediately and *you have to tell a story*, because people have no patience in my field. (Interview; emphasis added)

Professor Arthur's comments point to the role of graphics as invention heuristics and in structuring the argument of the paper, which he calls "the story." These comments also highlight his well-developed sense of his audience as busy colleagues – "people [who] have no patience" – and whose lack of time adds pressure for publications to get to the point quickly. Students in Professor Arthur's group corroborated his description of these practices. Yuan, an international Ph.D. student, explained their practice:

> What we [students] do is discuss with [Professor Arthur] about the possibility of writing a paper. *I will show him those graphs,* those results I have, some experimental results, some theoretical results. And he will comment on it. And then he will say, 'Okay, this is a good paper. You should write it.' (Interview; emphasis added)

Yuan's comments underscore how the visual presentation of research results ("those graphs") contributes to the research group determines whether such results might be publishable.

Turning to Professor Brown, his summary of his typical way of working with a research group member on a paper follows the stages suggested by many writing teachers – outline, draft, revision:

> Generally in the meetings with the student, when we mutually agree that there is something worth writing up, then I will ask them to write an outline first. We will sit down with the outline and then we edit that, and then figure out the content, the flow of the paper. And then I will make them write a first draft and then work on that. I try to get them to do all the writing. I make small changes, but it varies. We will discuss the paper and the structure, what would be in it. (Interview)

Any mention of the role of graphics in identifying "something worth writing up" seems notably absent from Professor Brown's description of the writing process he follows and promulgates. However, data from his group members reveals that the advice he imparts to them – and what they actually do – is to begin writing a paper by creating and contemplating visuals that display research results. For instance, Natalia, an international post-doctoral fellow, believes that Professor Brown:

> has a better [approach than mine], I tried it a couple of times and you just jot down figures and then you write the captions and describe what's on the figure like in a text…. To write a paper, that's the process where you put those figures and you describe what you did and you put in the references. (Interview)

Likewise, one of Professor Brown's international Ph.D. students, Christopher, reports the advice he received to pursue these writing practices:

> When we find results that are pretty interesting, we look at the results and work in a kind of backwards way to say, we will put the interesting things that we have discovered and then back it up, support with our findings and our data. One interesting thing Professor Brown said when we were first writing together, he said, "Don't think of how to write it, just put the pictures, images that you think are interesting and then write about it." (Focus group interview)

Thus in practice, Professor Brown shares Professor Arthur's perspective on how graphics function as invention heuristics in writing; the fact that he does not explicitly identify how graphics function in his writing and supporting research group members may reflect a conventional sense of what writing practices consist of, as Winsor (1992), discussed above, identifies. The data extracts included in this section point to the nuanced understandings that research group members have gained about the practices and advice given by professors Arthur and Brown.

In discussing her writing practices, rather than summarize them as did her colleagues, Professor Courts articulated that she and her group members follow a

routine of beginning an academic paper by creating an outline and using it to support student writing. Nonetheless, she lamented:

> some of the students don't want to outline anything… Some of them just want to start writing. Or the first [draft] they give you they've really written it all out and so it is harder. But I have [an international] post-doc right now and his language skill is not very strong. So I really force him to do outlines. So we start from scratch.

Although Professor Courts's comments suggest that she follows the process approach to writing in which outlining is a pre-writing technique, the ethnographic data show that the outlines created in her research group in fact involve graphical representations of research results. As her post-doctoral research fellow, Ali, recalled:

> Usually we have to make an outline, what to include and what not … The first paper that I actually wrote in this lab, *you make an outline what kind of figures we should show, or just the results section …* what are the key figures they should show. Once you know these are the results you want to show, then you can come back to the introduction. (Interview, emphasis added)

The term "outline," therefore, suggests a type of multimodality that writing teachers – and academic engineers who are not writing specialists – may not recognize. This possibility is not surprising given that tacit knowledge about a social practice is not always available for expert practitioners to articulate, whether to their students or researchers (Nathan & Petrosino 2003). To explore these practices in more depth, I next describe the use of the analytic method of "text history" (Lillis & Curry 2006) to present a fine-grained rendering of the function of graphics as invention heuristics. Text histories draw on the range of qualitative data listed above to trace the development of a particular text over time, an approach particularly suited to the long time frames involved in the development of academic texts for publication.

## Text history: Launching a research article

This partial[3] text history[4] is based on recorded participant observations, field notes, PowerPoint presentation slides, and one draft of an article for publication. I draw on these data to describe how Professor Courts and her group began to

3. This text history is partial because Professor Courts and her collaborators put this paper on hold to write other papers during the data collection period.

4. To protect the anonymity of participants in the study, details of the data that might disclose their research areas are omitted and replaced with ellipses or [X], [Y], etc.

conceptualize an article in a one-hour meeting with her post-doctoral fellow, Ali, one of her technicians, Kathy, and an undergraduate, Nathan. Before the meeting began, Professor Courts had identified the target journal for the article, which she considers the top journal in her field, and had provisionally decided that the results the group was about to discuss would be publishable in this journal.

Professor Courts begins the meeting by noting, "I've got a lot of figures and things and I looked up the guidelines in [the journal] to see if we're going to shoot for that [journal], which seems worth doing." She then reads aloud an extract from the journal's website, which she had pasted into the draft document:

> **An article** is a substantial novel research study, with a complex story often involving several techniques or approaches. The main text (excluding abstract, Methods, references and figure legends) is 2,000–4,000 words. … Articles have no more than 8 display items (figures and/or tables). An introduction (without heading) is followed by sections headed Results, Discussion and Methods. … (Extract from Paper Draft 1, boldface emphasis original)

Addressing the group, Professor Courts comments,

> I was just starting to remember the results we've got and of course some of them we're still pulling together the figures for. But we could map out what figures we want to include. I think that's a good way to start. One thing I just did was to run the [X] analysis program, but I think it's easier to look at this PowerPoint™ from a talk I gave in Munich last year.

She then begins to project the 25 slides of her conference presentation, of which 13 either included or entirely comprised visuals. This move itself illustrates the multimodal nature of the process of invention in this conversation: She is using a Microsoft Word™ document in for the article draft and slides from a PowerPoint™ presentation which include the data output in the form of graphs. Professor Courts continues:

> This is just to remind us what figures we've got. And *the general story to remember* is that [summary of the research results from a former Ph.D. student in her group that underpin this study]. … Most papers in the literature would argue that [X] and you can argue that [Y] … that's what we've got to shore up, is the [Y] analysis. … So as we go through these figures it is useful to see, one figure might be the apparatus, I don't know how critical it is to have that in this paper. (Recorded observation transcript; emphasis added)

Ali, the post-doc, then points out that because they used a commercially produced apparatus in doing the research, a description should already be publically available. Kathy, the technician, wonders if Professor Courts's laboratory had previously published a paper with a description of the apparatus, to which the present paper could refer.

> Professor Courts: Not exactly. But it's an optional figure, it might make it easier for people to see. A picture is worth a kilo-word, so if we include it, it would make the Methods longer, but the Methods are not included in the word count, right? It makes the Methods longer if you don't have the figure so I guess it's just a trade. (Recorded observation)

Here Professor Courts points to the tension created between the requirements of the target journal – limiting authors to eight "display items (figures/tables)" and word limits for certain sections of the article – and the need for rigor in the Methods section that would be established in part by describing the apparatus – whether in words or visuals. As the discussion moves on to which types of results to include from experiments with two types of subjects, Professor Courts advocates including both sets:

> Professor Courts: It fits better into this mold of multiple techniques.
> Ali: *Complex story?*
> Professor Courts: [*chuckling*] *Complex story.* (Recorded observation, emphasis added)

While neither of these participants elaborates here, Professor Courts's laugh suggests that the story metaphor that Ali introduces is part of an ongoing conversation in her group (which my ethnographic data verify). Next she presents the slide shown in Figure 6.1, saying, "This is one of the results for [X]."

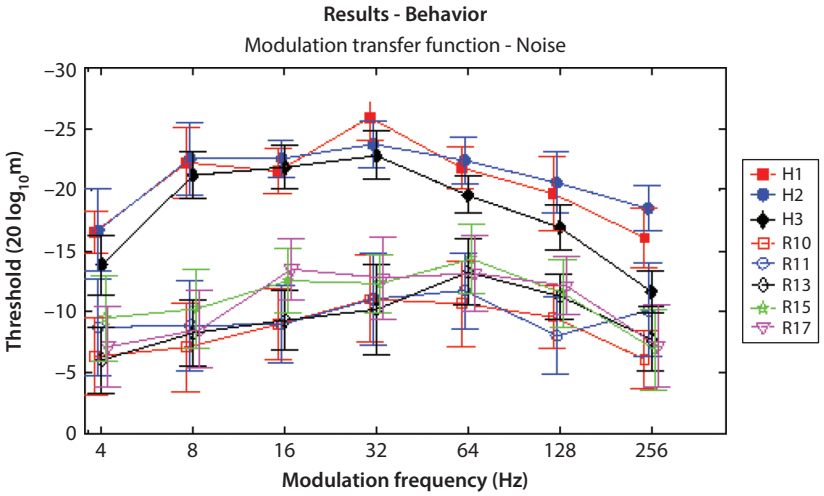


**Figure 6.1.** Experimental results from Professor Courts's research group

The group embarks on a cost-benefit analysis of paying the journal to include the graphic in color. Here the main considerations are the pragmatic in terms

of cost and how color might be reproduced in photocopies or computer printoffs of an article. Of interest here is how important the subject of the graphics in the proposed article remains, in terms of the group's shared understanding of the value that appropriately presented graphics add to the paper even as future reproductions.

When Professor Courts projects the second results slide, a discussion ensues about whether to include the down arrows (visible just above 4, 8, and 16 on the x-axis in Figure 6.2) that represent subjects' performance on an experiment. When Kathy queries whether it is necessary to include the down arrows, Ali suggests that the figure legend could explain their significance. Professor Courts proposes writing a description of the results and their significance and removing the down arrows, then immediately counters this possibility, saying that removing the down arrows might cause readers to miss the point. Here again what might appear to be minutiae in terms of choices about visual presentation take on significance in relation to the argument to be made and how readers might receive it. Professor Courts mentions relevant results from a recently published article, concluding, "Maybe it's worth playing around with the down arrows."

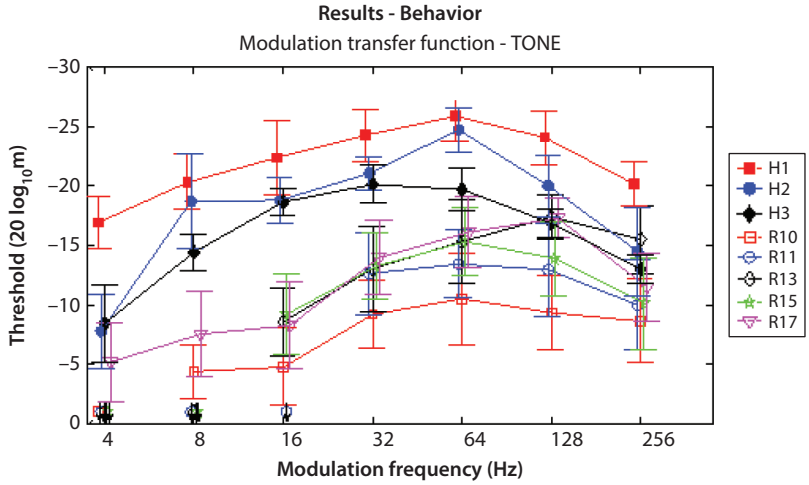


**Figure 6.2.** Experimental results using down arrows

These data extracts and illustrative figures show how a five-minute conversation about what might seem a trivial notation – the down arrow – prompts the group's discussion about presenting a key argument in the paper. In addition, in mentioning a related recent article, Professor Courts steers the group's thinking about research results such that they craft their argument to contribute to the "conversations of the discipline" (Bazerman 1980; see also Shaw 2010).

Invention in relation to writing an engineering article for publication therefore involves considerations of audience (here both the specific target journal and the end-user who will interact with color or black-and-white versions of the published article), how the graphics are constructed (decisions about whether to include the down arrows in Figure 6.2), and the larger research conversations taking place.

As the meeting continues, Professor Courts recaps the functions of Figures 6.1 and 6.2: "These two plots summarize all the behavior [data]. So at least it's concise." When she shows her subsequent PowerPoint slides, Nathan suggests combining the slides shown in Figures 6.3 and 6.4 to introduce the second set of data from which the results come.

Contemplating the results displayed on these two slides, Professor Courts comments,

> *This story* is a little different than the poster, which was earlier. In the poster, the [X] thresholds weren't good and maybe we were goofing somehow when we were calculating because when we went back last summer they were fine. … We'll repeat all these. These are the plots that we need to do, the newly clustered data. *So this story is pretty simple.* It's just a matter of describing. Now … we're only showing [X]; there's a whole lot that fall off the bottom. We have to describe the fact that that's true and actually give numbers. (Recorded observation; emphasis added)

Here the metaphor of story is interwoven in the discussion about articulating the paper's argument about the results. As the meeting continues, Professor Courts records the group's ideas for the paper on the word-processed document on her laptop. Although space does not permit a full explication of the hour-long meeting, these examples show the central role of graphics in the conceptualization of this article: deciding which results to argue for, how many visuals would be needed to convey the argument (the results), and the specific form the graphics should take. This text history also documents how identifying research results can take place over long spans of time, as group members considered the slides that Professor Courts presented a year earlier to be provisional in the process of writing the article and assumed that they would need to revisit and refine their experimental and communication tasks. Indeed, she mentions that the slides showed slightly different results than did an even earlier poster presenting research results. The text history also reinforces understandings of the collaborative nature of writing for publication in STEM, a process beginning with the collaborative invention of research results through the heuristic of the data graphics.

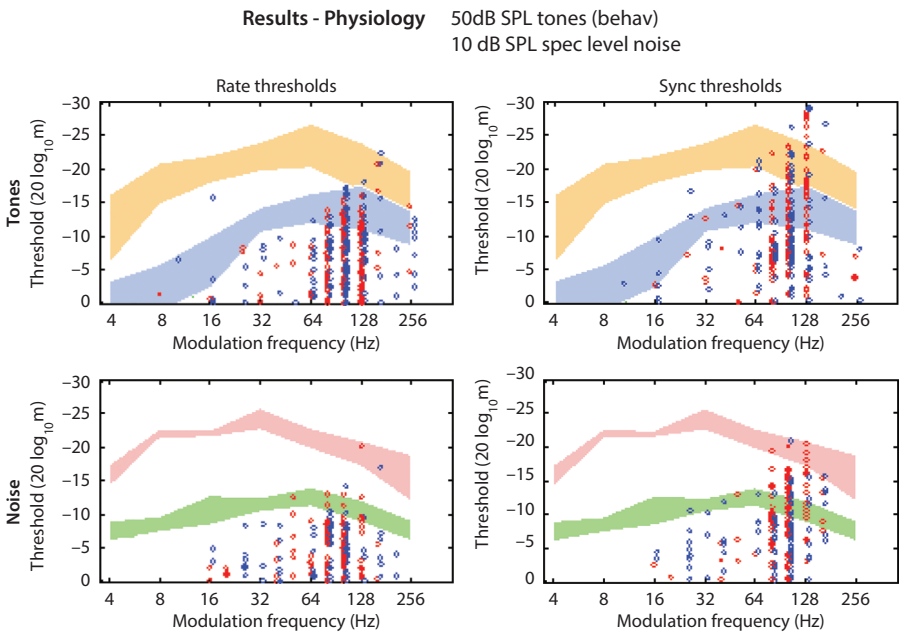


**Figure 6.3.** Experimental results with one set of subjects

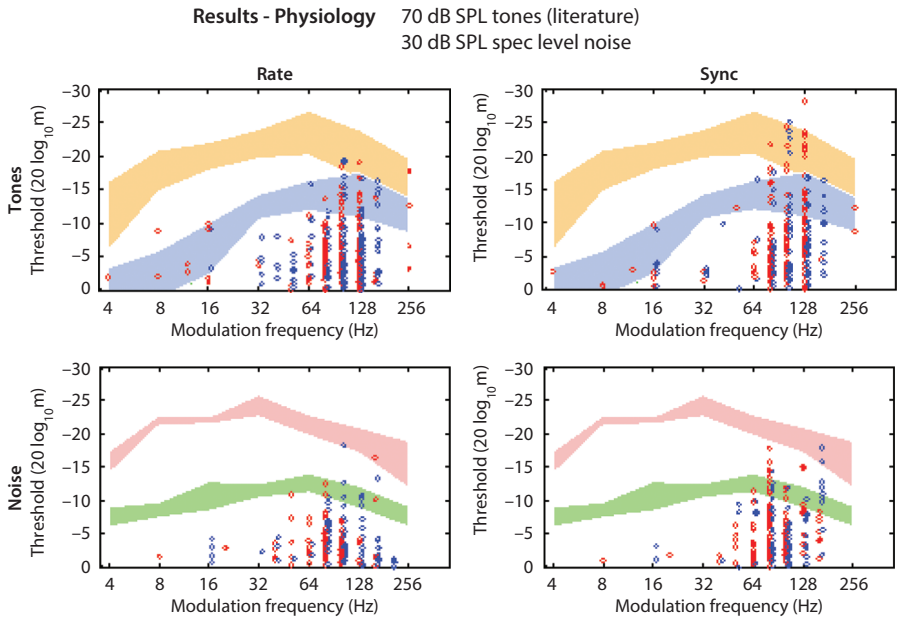


**Figure 6.4.** Experimental results with a second set of subjects

## Discussion and implications

This chapter has documented the heuristic role of graphics in the writing of academic engineering research papers; in contrast to having merely ancillary and illustrative functions, graphics act as invention devices that enable engineers to map out arguments to put forward in research dissemination, often conceptualized as a "story." Participants both articulated and enacted these practices in the three years during which the ethnographic study took place. Ethnographic research allowed the documentation of a range of practices and participants' perspectives in order to arrive at these findings. They suggest that academic engineers do not reserve their consideration of the graphical display of research results for the final stages of writing, but rather begin with the visuals. These findings lend support to Winsor's (1992, 1994) argument for the revision of conceptions of scientific/technical writing that divorce text and visuals. Indeed, both engineers' writing processes and their informal teaching practices manifest a clearly multimodal nature. In various ways, the faculty members in this study articulated or enacted this understanding with the members of their research groups and with smaller teams writing research publications – even if they did not include them in their descriptions of their writing practices.

These findings have implications for understanding and sharing the social practices of writing for publication in academic engineering, and by extension, in other STEM disciplines. For writing instructors as well as disciplinary faculty members working with students on writing projects, these findings suggest the value of considering the role of graphics in text production not only as illustrations but also as heuristics for invention in identifying research findings and shaping rhetorical arguments. Along these lines, Poe et al. (2010) provide an example of an MIT faculty member, Dennis Freeman, who teaches physiology students to use a storyboarding technique that includes these three concepts:

> 1. Data driven scientific research. Organize and locate trends in data before beginning to write the supporting text. 2. Each figure in a report tells its own story. Design figures that make the point that you want to make. 3. In sum, the figures in a report tell the narrative of the research. Consider if the data make a logical sequence from one figure to the next figure. (p. 118)

Based on the literature, Freeman's example represents a rare articulation of such a strategy, but one that aligns well with the findings presented here.

Another implication of this study is to support the suggestion that writing guides and other materials on research dissemination should be grounded in empirical evidence about engineers' actual writing practices (Curry & Lillis 2010, 2013; Harwood 2005). Such guides tend to work from an assumption of an

individual author, to privilege the production of written text over multimodality, and to advocate a linear writing process that relegates the function of graphics to illustrating points made in the text.[5] In fact, a comment by one of Professor Brown's students, Osman, supports this point: "I sometimes feel that the books telling how to write, it's not really based on the practical writing, it's just in theory" (Interview). Others have noted the mismatch between advice guides/writing textbooks and the empirically documented practices of scientists. Indeed, Poe et al. (2010) consider that "part of students' misconceptions about the function of visual representation comes from textbooks" (p. 116).

In addition, this study suggests that research on engineering and scientific writing should widen its lens to include a broader focus on multimodality. It seems imperative for an intrinsically multimodal discipline such as engineering to account fully for the uses of graphics in writing. Finally, the metaphor of story and storytelling embedded in the participants' comments about graphics deserves further attention; I am analyzing additional PEW study data for the ways that engineers use "story" as part of their writing and teaching about writing for publication.

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5. As Bennett (2009) attests, the marketplace is replete with guides to writing and publishing; see Curry (2011) for a review of five general guides to academic publishing. Kamler and Thomson (2008) critique the panoply of dissertation writing guides for doctoral students. A key finding from their analysis is that such guides "package their contents as a series of defined, linear steps" (p. 510).

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