APPLIED RESEARCH

SUMMARY

- Reports on the use of graphics by engineers as a method of stimulating the writing process
- Shows that graphics have a powerful function in stimulating writing ideas
- Describes patterns in graphics types based on the genre, and the most common types used

Graphics and Invention in Engineering Writing

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INTRODUCTION

An indication of how integrally graphic material is used in the production of engineering writing can be seen from a study of the use of graphics by 15 engineers as a method of stimulating the writing process. Each participant answered questions about a variety of genres, so that one participant might discuss, for instance, seven or eight genres of writing. From all 15 participants, 113 responses were recorded, and of that number, in only five cases did the respondent indicate that graphics were not used at any point when writing that genre.

Conversations with the engineers in this study seemed to show that it is natural for them to record information in graphic form and to use graphics during design work. As one participant said of his work habits, he will have a pad and pens available every day for sketching, particularly in the design phase. As a technological offshoot of this way of working, another engineer indicated that he will "rely heavily on the computer for data evaluation" to produce graphs, PowerPoint, Gantt charts, and sketches of both mechanical and electrical drawings.

These engineers also interact with one another using graphics. When asked whether graphics use was a normal part of daily activity, a third person said that drawing and sketching were sometimes more helpful, that this was a "very common interaction among engineers." When asked the same question, about whether he uses graphics to communicate, another respondent answered, "Sure do. All day." Because of the way they work, it seemed probable that when these engineers produce text, they would integrate both ways of symbolically representing information, text and graphics. As it turned out, every engineer in this study used graphics to stimulate ideas when writing.

More substantively, every person indicated using graphics as a source of ideas for writing in multiple writing genres, and for every person this use of graphics could occur both before composing (planning, thinking, making notes) and while composing (creating the text). Perhaps the clearest example was given by an engineer who described the creation of technical memos as a process that usually begins with math calculations, then includes graphs, often with pictures, and finally adds text. It is notable that as he describes this process, the writing comes last, almost as a kind of documentation of what has preceded it.

Engineers often operate as much by visual imaging as by linguistic description, if in fact visuals are not even predominant during design tasks. The feeling of engineers toward the use of graphics is epitomized by an engineer quoted by Kathryn Henderson: "Without the drawing, you know, it's just talk" (1998, 82). To fully function in the workplace, however, engineers have to use written language to interact with people who do not use the same visual imaging that they do. Thus a basic engineering method of symbolically representing ideas, visual imaging, must work with a completely different method, language and writing.

For those who are interested in engineering writing, the interaction between graphics and text is a possible area of research. Taking into account more than the finished text, looking at the process that creates the text, as I am doing here, expands the research concern. From that point of view, it becomes informative to look at how graphics are used by engineers during the writing process as a method of invention.

The rhetorical concept of invention has a long history. As Janice Lauer (2004) points out in *Invention in rhetoric and composition*, there has been (and is) a great deal of disagreement in rhetorical study about the function and use of invention. Drawing on Aristotle, I am defining invention

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as methods for discovering what to say when speaking or writing. Early methods of invention included lists of topics that might generate ideas, along with standard lists of questions (stasis questions). In the Middle Ages, writing manuals (on composing sermons, for instance) added to invention techniques, and still later came techniques involving genre format, such as the format of science research articles. As this article tries to show, visual graphic material can also serve an inventional function, at least for some kinds of writing.

In spite of the potential for research in this area, there are few studies that consider graphics as they are used in the writing of working engineers. One of the works that does address this topic is Henderson's book *Online and on paper: Visual representations, visual culture, and computer graphics in design engineering* (1998). Henderson looks at the uses of graphics by engineers and the importance of graphics for development of ideas. One engineer is even quoted as saying, "I can't think without my drawing board" (27). Although Henderson's book makes clear how integrally engineering thinking is bound up with graphics, Henderson does not focus directly on graphics as invention for writing.

Looking at graphics in engineering at a closer level of detail, Christina Haas and Stephen P. Witte (2001) have described the discussions held by working engineers during the process of revising both text and graphics. That study, which focused on how embodied knowledge gets represented, looked at the writing/revision process as it occurred, with some detail on how text and graphics affected one another. Reports such as this one by Haas and Witte are particularly good for letting us see the detail on how text and graphics can operate together.

To investigate the use of graphics in engineering writing, I talked with engineers at two different companies about their writing. In *Invention in rhetoric and composition*, Lauer writes that "The acts of invention often occur intensely in the early phases of writing but can continue throughout the composing process" (2004, 7). In this study I have paid attention to that process, concentrating on how these engineers used graphics before composing text as well as while composing.

I define graphics as any material that visually represents information on paper or on a computer screen, but that is not standard text. Graphics thus include not only photographs and charts, but also tables or computer printouts. This study concentrated on general writing practices among the engineers I talked to, rather than examining individual pieces of writing in detail. The purpose here was to gain a broader knowledge about how graphics serve an inventional function in engineering writing. Understanding this interaction has a definite importance for technical communicators who work with engineers, and this study attempts to increase that understanding.

PSYCHOLOGICAL EFFECTIVENESS OF GRAPHICS

My study makes it clear that engineers do use graphics for invention, but knowing that they do so cannot lead us to automatically assume that this is the most effective way for them to write. It could be possible, for instance, for engineers to use graphics simply out of habit and personal comfort with that method of representing information. The use of graphics for invention, however, may be based on more than mere familiarity.

The means by which graphics increase text comprehension have been studied, and researchers have suggested various ways that material may be mentally processed. One suggestion that is found repeatedly is the idea of a "mental model" of textual material, a model that may be a physical object but may also be a more abstract representation of ideas. The suggestion that graphics aid in creation of mental models is supported by Valérie Gyselinck (1996), Arthur M. Glenberg and William E. Langston (1992), Mary Hegarty and Marcel Adam Just (1989), F. Ganier and colleagues (2000), and Wolfgang Schnotz (1993).

Schnotz, for example, describes the advantage of graphics for mental models:

> *A text leads to the construction of a propositional representation which then allows to construct a corresponding mental model. A graphic, however, as an external analog representation provides the possibility of a relatively direct construction of a mental model . . . . (1993, 248)*

Schnotz proposes that graphics may aid in constructing mental models because text is stored only in verbal memory, whereas graphics are stored in both verbal and visual memory, providing an advantage not only in occupying more memory, but in creating a memory that already contains a kind of visual model. Ganier and colleagues also suggest that mental processing is quantitatively increased by use of graphics, as they say that text plus graphics provides two ways to access information and clarify ambiguities (2000).

These models of mental processing have implications for the use of graphics as a stimulus for invention in writing. If graphics do provide more accessible mental models, it may be that an increase in access to these models (which can be visual metaphors of ideas) can stimulate new ways of seeing those ideas, or of connections between ideas. A different reason why graphics may be an effective catalyst to invention may be found in *Sketches of thought*, by Vinod Goel (1995). Goel describes the design process by saying that the early stages of that process require an ability to "transform one symbol into another" and "transform one idea into another" (193), which allows the de-

signer to remain open to ideas and possibilities. According to Goel, "dense and ambiguous symbol systems" (194) are more likely to allow such transformation to happen. He contrasts free sketching, which he sees as dense and ambiguous, with drafting, which he believes is not. If Goel is correct, then some graphics, if not all, may operate in writing invention by increasing the likelihood of transforming one idea into another.

BACKGROUND TO THIS STUDY

The information in this article comes from an ethnographic study I conducted over the course of several months with engineers in private industry. Ethnography involves going out to observe another "culture," and in this case, I observed engineers rather than, say, Pacific islanders.

Michael Agar (1980) describes two general attitudes toward data collection in ethnographic work: (1) data can be based mostly on observation rather than what the study subjects say, or (2) data can be taken from conversations with those who inhabit that culture. I followed the second philosophy (which happens to be Agar's philosophy as well) and talked with participants from two companies located in southern New Jersey.

It is also the case that an ethnographic study is shaped by what is learned as the researcher goes on, and my experience bears out this observation. Five participants worked for a company that makes sophisticated communications equipment, often with the government as a client for their products. Because the products made by this company are used in such sensitive situations, every object made is subject to individual testing, with voluminous recording of results, and those written records also go to the client. As one engineer at the company put it, "You're selling paper and the hardware comes for free."

The other 10 participants in the study worked for a local branch of a multinational company that makes consumer products. The local branch used in this study employed about 750 people.

To use Agar's terminology, my respondents at both companies were "opportunistic"; that is, I talked with whomever I could. At the consumer goods company, however, many people were instructed to talk to me by a supervisor who became interested in my study. Of the 15 engineers who provided information for this study, there were 13 males and 2 females, and the experience level of the participants ranged from relatively new engineers (two years of experience) to those with several decades of experience (40 years).

I began the study with the intention of focusing on the use of graphics, an idea that arose from Dorothy Winsor's article "What counts as writing? An argument from engineers' practice" (1992). I began gathering information in a broad way—what Agar calls "informal interviews"—in which respondents can say anything they want, including critiquing the questions of the interviewer (1980, 90). When I began, though I knew that I wanted to investigate the use of graphics, I did not know that my final results would concentrate on graphics as a method of generating ideas for text.

In the end, this study consisted of several steps:

1. I began by asking questions of several engineers at both companies to get an idea of writing practices at each company. These interviews gave me information about both companies and some idea of the writing practices at each one.

2. Based on what I learned from the early conversations, I generated a formal set of questions asking for more detailed information on specific genres that had been suggested by participants. At this point I began to focus more closely on the interaction between text and graphics. This formal set of questions was posed to the same engineers I had talked to in the early conversations.

3. Information gained from the formal set of questions led to the creation of a final, longer questionnaire. It is common in ethnographic work to move gradually from an informal to a formal step, as in this case. This questionnaire focused on a range of possible graphics and on 13 writing genres that I had been told were used at either or both of the companies involved. For this questionnaire, the number of participants was expanded to include 15 people. The information from that final questionnaire provides the data for this study.

In the final interviews, I asked about 13 writing genres, all of them suggested by engineers at one or both of the two companies. I did not ask participants to try to define the suggested genres. Instead I used the language of my respondents and let them decide whether they engaged in writing that would match the genres on the list. Not all participants used every genre. The number who claimed to use a given genre (out of 15 total participants) is indicated here for each genre included in this study:

- Engineering notes (13)
- Test log (7)
- Design review (11)
- Status report (12)
- Test report (9)
- Failure report (3)
- Test procedure (10)
- Equipment procedure (5)
- Repair procedure (4)
- Proposal (9)
- E-mail (15)
- Paper memo (5)
- Paper letter (4)

TABLE 1: LIST OF GRAPHIC MATERIAL TYPES PRESENTED TO PARTICIPANTS WITH THE QUESTIONNAIRE

Numerical/Linguistic

1. Tables
2. Spreadsheets
3. Computer-generated data lists
4. Charts or graphs (line graphs, bar graphs, pie charts, flow charts)

Sketches and Drawings

5. Orthographic (two-dimensional), hand-drawn
6. Orthographic (two-dimensional), machine-drawn
7. Isometric (three-dimensional), hand-drawn
8. Isometric (three-dimensional), machine-drawn
9. Schematics (electrical, pneumatic, and so on)

Illustrations

10. Artistic illustrations (with unnecessary detail or color)
11. Photographs

During the interviews conducted using the final questionnaire, participants were also shown the list of types of graphics in Table 1, so that all answers referred to the same list. Answers about types of graphics were given and recorded by the numbers on this list.

As participants looked at the list in Table 1, I asked which types of graphics they might use with each writing genre to organize ideas prior to composing text, or to help generate ideas while composing the text. Examples of three types of graphics from the table are shown in Figure 1 (isometric drawing), Figure 2 (orthographic drawing), and Figure 3 (schematic).

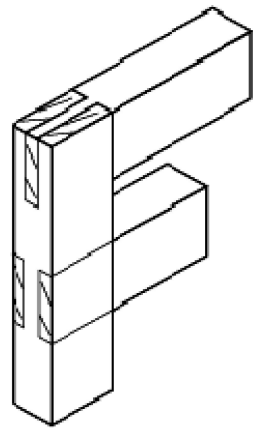

Figure 1. Isometric (3D) drawing. Used by permission from Geoff's Woodwork, http://www.geoffswoodwork.co.uk/ortho_drawings.htm.

HOW THESE ENGINEERS USED GRAPHICS

Looking in detail at how graphics affect writing, I noted immediately that the participants of this study had developed individual ways of working that were more important than general trends. Individual differences were thus likely to override broad patterns. I found no clear patterns at all based on years of experience, nor could I find clear differences between the two companies involved. The types of trends that I found are based on (1) overall number of graphics types used by each writer, (2) particular types of graphics used by each writer based on the writing genre, and (3) most common types of graphics overall.

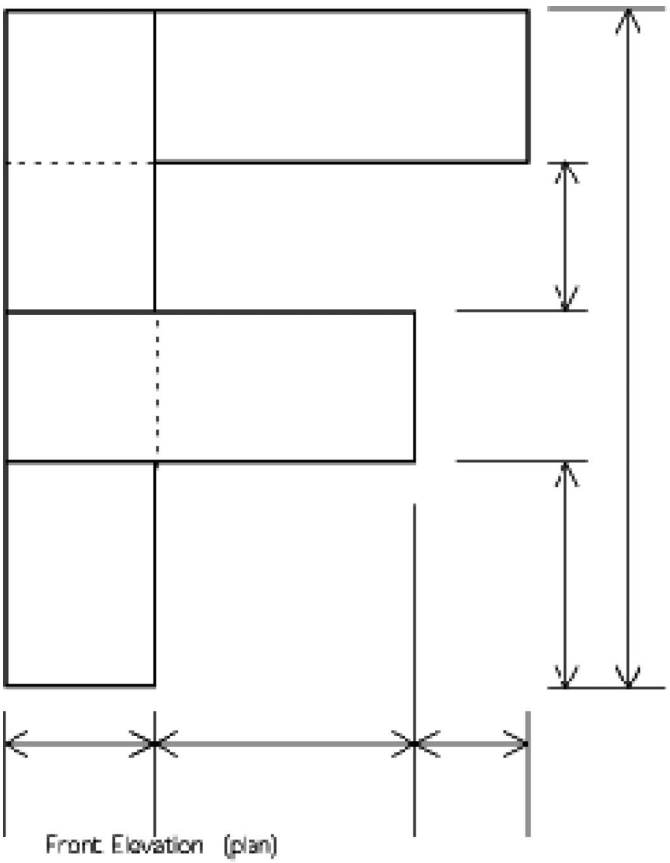

Figure 2. Orthographic (2D) drawing of the same figure Used by permission from Geoff's Woodwork, http://www.geoffswoodwork.co.uk/ortho_drawings.htm.

The first pattern actually emphasizes diverse approaches among the writers, with the number of graphics types used by each individual ranging from very many to very few. This variation seems to reflect personal preferences in the process of producing text. One engineer with 22 years of experience consistently used many types of graphics for invention (Figure 4, Engineer A). In every case, he also used more graphics for invention while composing than he used prior to beginning to write, but in both cases, he tended to use many graphics. A second engineer also tended to use many graphics as invention, but he sometimes used more graphics before beginning to write than he used once he began to compose. In contrast to these two, a third, with 19 years of experience, consistently used either no graphics at all or very few as invention (Figure 4, Engineer B).

Most of the people in the study did not fit as easily into the extremes of many or few. The majority used graphics in a way that apparently varied based on the genre of writing (Figure 5).

A detailed example of this varied approach based on genre is one person's use of graphics before composing for several genres: engineering notes (7 types of graphics), test log (2 types), e-mail (graphics rarely used), status report (none), and design review (8 types). Another example shows an engineer's use of graphics while composing: engineering notes (7 types of graphics), test log (1 type), e-mail (none), test report (3 types), design review (1 type), test procedure (5 types), equipment procedure (none), and proposal (8 types). With these two examples, we see engineers who may use many types of graphics to inspire their writing or none at all, depending on what they are working on.

There are also broad patterns of usage for total numbers of graphics types differentiated by whether they are used before composing or while composing. Three participants said that they use generally (or exactly) the same graphics both before composing and while writing (see, for example, Figure 6).

A variation on this pattern is seen in one person who sometimes used the same graphics for prewriting and composing, but in other cases did not (Figure 7).

As already noted above, one of the engineers always used more graphics while composing than before (Figure 8). There were also many cases, in no particular pattern, of no graphics used for invention.

A second broad pattern, in addition to total numbers of graphics types, concerned the particular types of graphics that were used based on the writing genre. I have categorized the graphics in four groups, based on level of abstraction and on whether the graphics consist of data or an image. A schematic of the types of graphics as I have grouped them is given in Figure 9.

Using these categories, I found cases where the writers gave preferences, based on genre, to graphics that consisted of either data or images. For three genres, I found writers using graphics that consist entirely of data:

- Test logs—Four writers used only data (charts or graphs for all four writers, spreadsheets for two writers, a table for one writer, and a computer list for one writer).
- Test reports—Five writers used only data with no image graphics.
- E-mails—Seven writers used only data for invention.

By contrast, one writer used only image graphics as invention for e-mail. There were also two genres with which some writers used images in preference to data:

- Design reviews—Three writers used only images for invention.
- Repair procedures—Three writers also used only images.

The third broad pattern of graphics usage concerns the most common types of graphics used overall, shown in

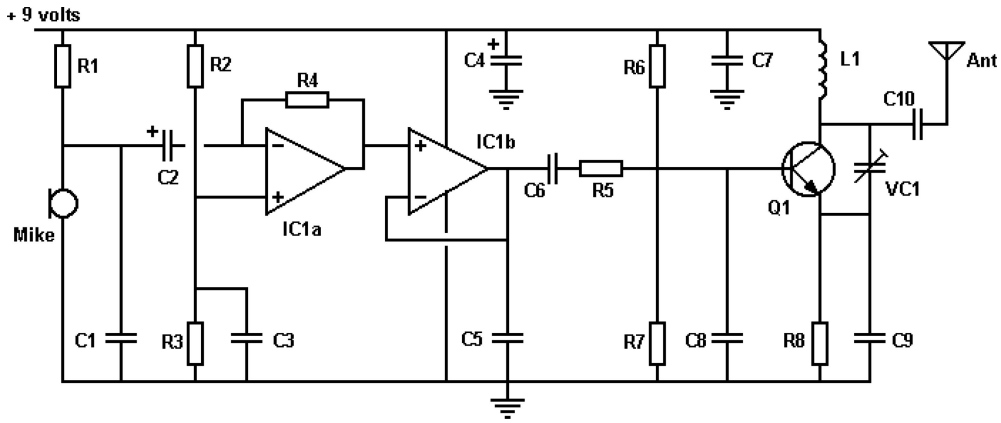

Figure 3. Electrical schematic. Among other possibilities, this might be a pipe network or a train system. (Used by permission from Andy Collinson [design by Kamran Ahmed], http://www.zen22142.zen.co.uk/Circuits/rf/txcct.htm.)

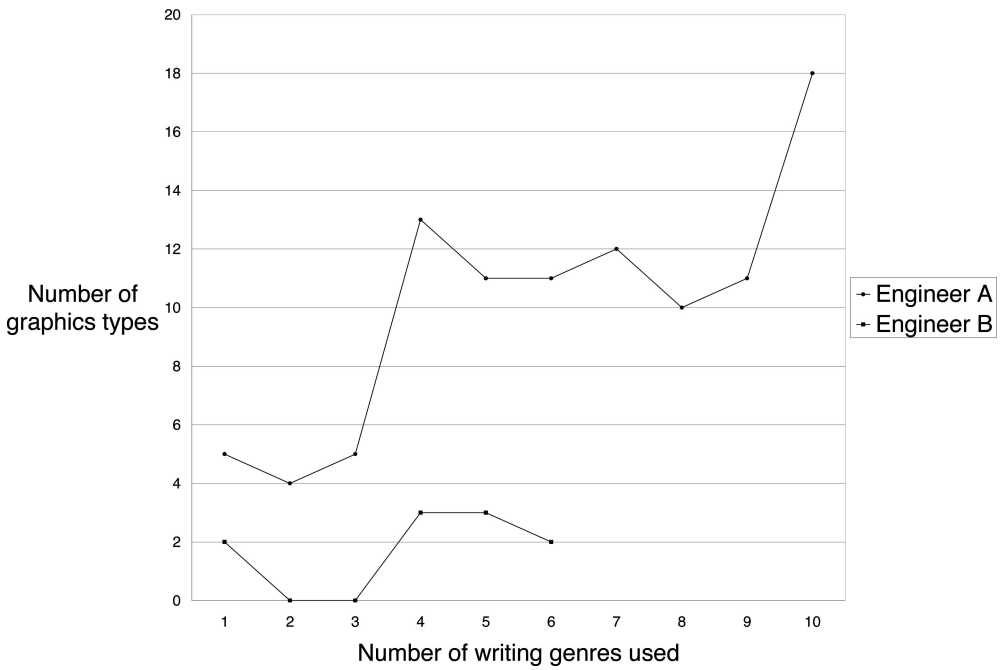

Figure 4. Number of graphics types used for invention by two engineers (high and low numbers).

Table 2. This pattern is different from the patterns based on number and type of graphics used by each writer, as it is a cumulative summary of all writers.

Of all the graphics cited for invention by the 15 writers in this study, the most common graphics used overall were raw data (57 citations) and summaries of data (51 citations), followed by abstract images (42 citations) and summaries of data (41 citations). The most infrequently used graphics were analog images.

When we consider specific graphics, we find that those that were used (for any writing genre) by more than five people were tables, spreadsheets, charts and graphs, orthographic drawings (both hand- and machine-drawn), machine-drawn isometric drawings, and schematics. These seven types of graphics appear to have a relatively high usage in invention, since they are all cited by more than five people.

When another factor is considered, however, the data gives a different result. The two writing genres that used

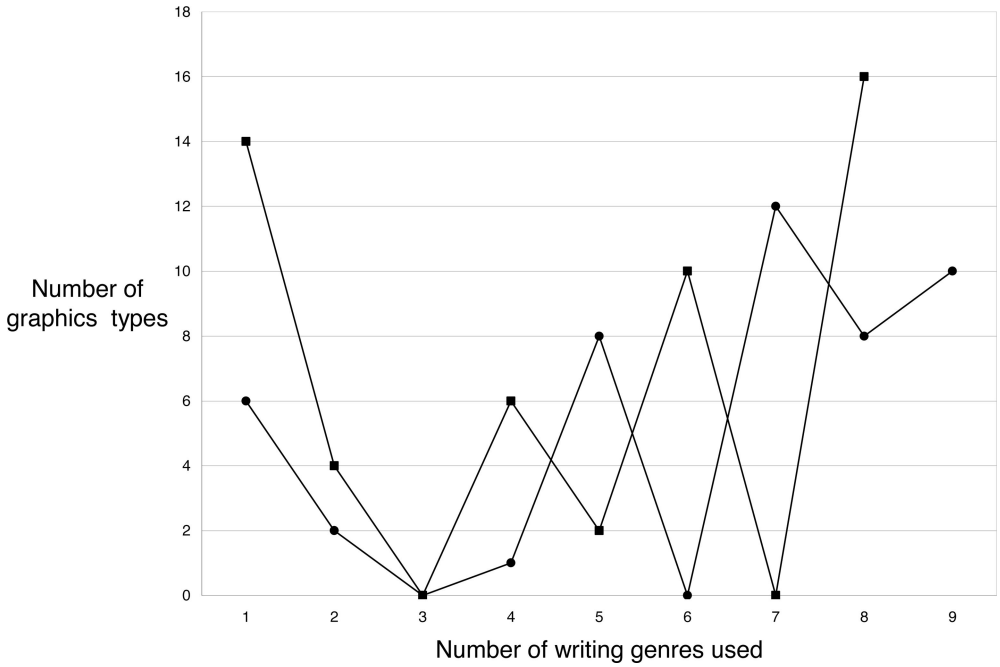

Figure 5. Number of graphics types used for invention by two engineers (mixed numbers).

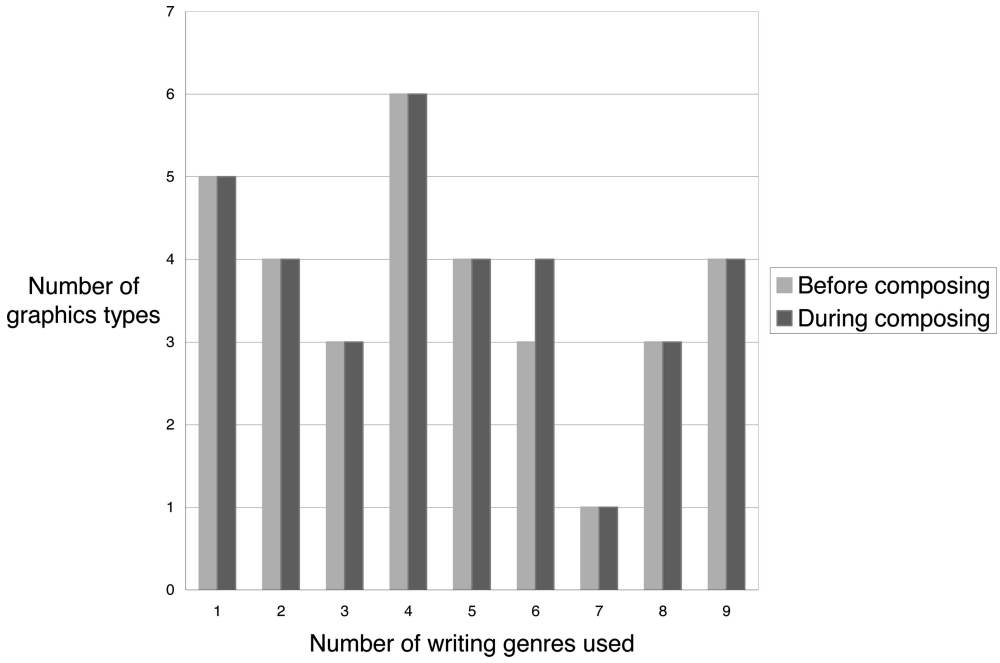

Figure 6. Number of graphics types used by Engineer E both before and during composing (mostly equal numbers).

the most graphics (any type) overall were engineering notes and design reviews, and four of the graphics types just named were used by more than five people only for engineering notes or for design reviews. If we exclude

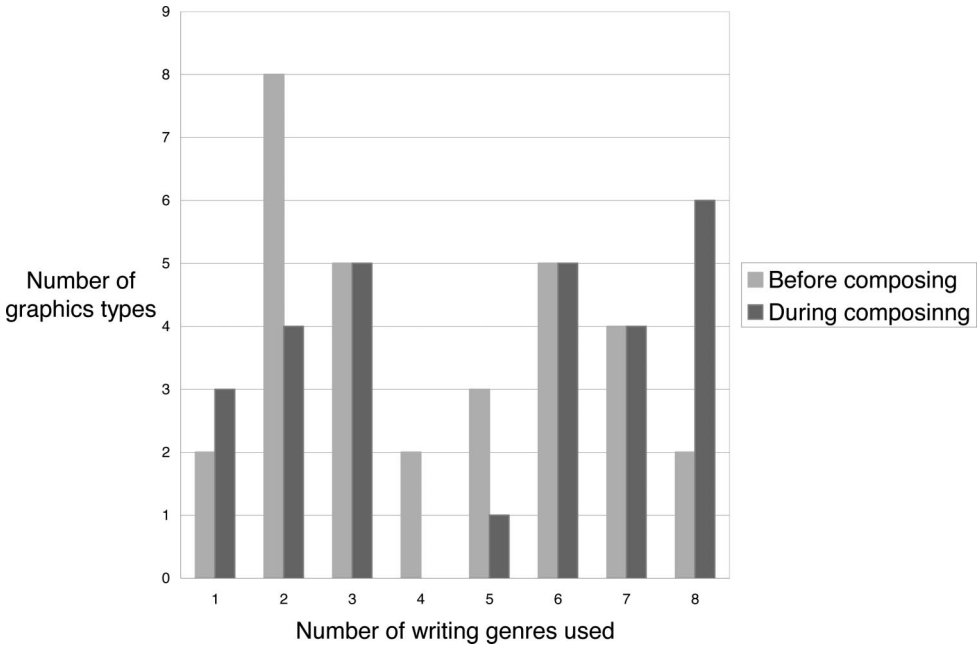

Figure 7. Number of graphics types used by Engineer F both before and during composing (mixed numbers).

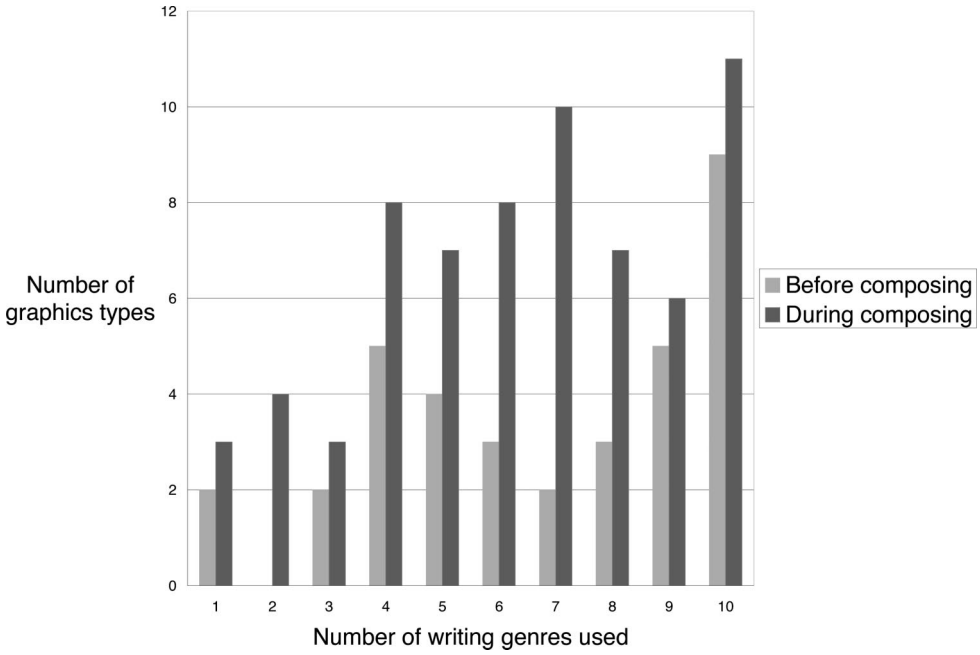

Figure 8. Number of graphics types used by Engineer A both before and during composing (higher numbers during composing).

engineering notes and design reviews, the types of graphics cited by more than five people in the other 11 genres are tables, spreadsheets, and charts and graphs (raw data and summaries of data). Thus, among this group of engineers, there seems to be a trend in invention toward using more data, whether raw or summarized, than images.

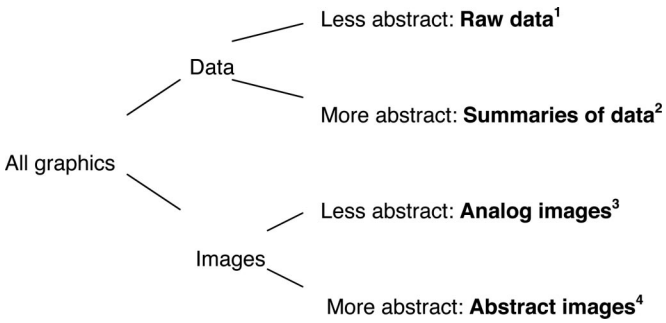

Figure 9. Four categories of graphics in this study. 1 = computer printout data lists, spreadsheets; 2 = tables, charts, and graphs; 3 = isometric (3D) sketches or drawings, by hand or by machine; artistic illustrations; photographs; 4 = orthographic (2D) sketches or drawings, by hand or by machine; schematics (electrical, pneumatic, and so on).

Focus on particular genres

Engineering notes Thirteen of the 15 participants kept an engineering notebook. The relationship of the engineering notes to graphics was especially close. When asked about this relationship, one participant said that sometimes the graphics are the notes. She also said that her notebook consisted of 50–60% graphics (drawings, photocopies, computer printouts, Excel spreadsheets), and another said that his notebook could be 50% sketches. Some participants liked to keep their notes on their computers, typing them up, but one engineer preferred to use paper, to make it easier to add diagrams. Most people said that the engineering notes were done just for themselves, although two engineers (one at each company) said that notes should be kept on any work that might lead to a patent. In engineering notes, the graphics categories most often used were abstract images and summaries of data; raw data and analog images were used only half as often.

E-mails Although e-mail, like paper letters and memos, can be used for many purposes, I treated it as a separate genre based on the fact that it is a unique medium combining writing, speed, and (frequently) informality. For invention, e-mail writers used raw data and summaries of data very heavily, more than with any other genre in this study.

Proposals This genre made particularly heavy use of graphics. One person said that the strategy of proposal writing uses story boards to outline the document and particularly to describe what graphics need to be created; in his experience, very few graphics exist at the beginning of the proposal project. All four graphics categories were used frequently for proposals, but with slightly greater use of images compared with data.

TABLE 2: CUMULATIVE NUMBER OF CITATIONS FOR GRAPHICS TYPES BY ALL WRITERS

Type	Category	Number of citations
Spreadsheets	raw data	57
Charts/graphs	data summaries	51
Machine-drawn orthographics	abstract images	42
Tables	data summaries	41
Schematics	abstract images	34
Photographs	analog images	32
Machine-drawn isometrics	analog images	29
Computer data lists	raw data	25
Hand-drawn orthographics	abstract images	21
Hand-drawn isometrics	analog images	10
Artistic drawings	analog images	7

Repair and equipment procedures There was very light use of graphics overall for writing repair procedures. When graphics were used, they were almost entirely images, with almost no data used. Equipment procedures also made little use of graphics for the writing, and participants gave instances of using no graphics at all. When graphics were used for equipment procedures, they were images only, with no data.

Test reports After e-mail, test reports were the most likely genre in this study to use raw data and summaries of data, with a high frequency for both, and a much greater use of data with test reports compared with images.

Status reports Although this genre sometimes used graphics at a high level of frequency, four participants cited no use of graphics for invention. With the status report, those who did use graphics cited every graphics category, although with very little use of analog images. A possible

impulse for using graphics may be one person's observation that "the manager doesn't want a lot of words."

Design reviews There was an extremely heavy use of graphics in this genre, more than with any other genre in this study, even more than for proposals. For invention, the graphics category used most often was analog images.

After writing

The interaction between graphics and text went far beyond invention in writing. In very many cases, the final writing was also accompanied by graphics, and all 13 genres of writing in this study were cited by participants as potentially incorporating graphics in the final product. There were of course contrasting cases, such as one engineer's writing of a status report, in which he said that he might use six types of graphics for invention but which could have no graphics at all in the final product. In general, however, graphics were said to frequently accompany the writing. Another person said of accompanying graphics, "You'll almost always end up with a figure of some sort."

For a more extensive view of how graphics function with text, I posed the following question: "Of graphics material that is included with a piece of writing, which comes first, the graphics or the text?" Only one response unequivocally declared that the text preceded the graphic. Other responses were that the text "most often" or "a lot of times" came first, or that both text and graphic were created simultaneously. In half the cases, the graphics that accompany the text were said to come before the text was written.

Another way that text and graphics continued to interact is that the text, either while being composed or when completed, served in turn as invention to the creation or modification of the graphics. As one participant put it, "I may be writing and I realize I need additional views, or clarifications." Another engineer gave a view of the process in his statement that he will begin a note, draw a picture, then finish the note. These comments were typical of responses from every participant in the study, who all said that the writing could stimulate the creation or modification of the graphics, just as the graphics could stimulate the creation of the text.

CONCLUSION AND RECOMMENDATIONS

How can the information here be used in the work of technical communicators? As with most ethnographic work, caution must be exercised in generalizing from the participants in this study to other engineers. With other types of training or at other organizations, engineers could have very different ways of working, and only the accumulation of a number of studies may allow us to describe with confidence "how engineers write" with graphics.

In the current study, however, there are two factors that support broader application. First, this study involved two different companies, one doing mostly government work and the other producing common consumer goods. Information thus comes from one company that tests and documents each object they make, without being focused on the marketplace, while the second company must satisfy consumers and operates on a model of mass production. A second factor concerns the engineers themselves, who ranged widely in age and experience. Since diversity in methods of training seems a safe assumption, it may be that the behavior of these engineers is indicative of broader engineering practices.

Among the engineers I studied, individual habits of composition seem more important than strong patterns affecting all the participants, yet we can say with no equivocation that all of these engineers sometimes use graphics as an inventional technique for their writing. From the work that technical communicators do with engineers, they are already accustomed to the fact that inclusion of graphics with documents is a common practice.

What this study can add is an understanding that even in cases where a document may include few or no graphics, it is possible that an engineer may have used graphics as invention, to stimulate and help develop the ideas that went into the document. Therefore, it could be useful for technical communicators, in their discussions with engineers, to bring some of the graphics of invention to the foreground. Talking to the engineers about which graphics they consider important as a source of ideas may improve communication between technical communicators and engineers.

The participants in this study also indicate a variety of personal preferences in using graphics, such as consistently using many or few types of graphics for invention, or varying the number of graphics types in relationship to the writing genre. Knowing this variation in personal preferences can also give technical communicators a greater understanding in talking with engineers. Since personal preferences are strong, the practices encountered from working with one or even several engineers will not necessarily predict how the next engineer will work.

Technical communicators might also keep in mind another finding from this study, that variation in the specific types of graphics used is sometimes dependent on the writing genre, as when we see, for instance, general reliance on data graphics for test reports and image graphics for repair procedures. Since graphics may portray either data or images, as technical communicators discuss the use of graphics with engineers, they should be aware that in a given instance an engineer may be making decisions on that basis. An engineer might use many graphics or types of graphics, but those graphics could all—or mostly—consist of only data or only images.

As readers consider how to use the information from

this study, they should bear in mind that the focus here is on the process that produces writing, not on the writing as a finished product. Graphics may be used as invention for a document even though no graphics accompany the final product. As this study indicates, talking to engineers about the writing process is one way to learn about the kinds of information they use in writing. TC

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