Displays of Knowledge: Text Production and Media Reproduction in Scientific Practice

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by

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I walk into the laboratory and encounter an array of glass beakers, colorful liquids, strange inscriptions, active computer monitors, and a host of unfamiliar objects, instruments, and blinking lights. Coming from an English department, and educated in a PhD program that specializes in the study and teaching of writing, I have entered what seems to be nothing less than a vortex of chaos—a setting I have seen in movies, read about in books, but have never experienced firsthand for any extended period of time. Little surprise, then, that this scene has me reeling; yet it also has me engaged, interested in how I might make sense of the activities taking place in front of me. So I stand there, observing and writing in my field notebook, and watch as a chemist portions out a heap of white powder onto a digital scale. This is a methodical process: each step painstakingly completed, and each detail likewise recorded in a notebook where it is rendered—linguistically, visually, materially—into a meaningful series of actions and effects. Documenting this process becomes, for him, a means to track and reproduce the steps taken to synthesize materials that are either examined in the adjacent optics laboratory or sent to other laboratories, near and far, where collaborators can use them to
conduct their own experiments. Documenting a chemist at work in turn becomes, for me, a way to situate writing and text production in light of the tasks and activities that constitute a typical day in the life of a laboratory scientist.

I begin with this anecdote, first, because I think it nicely illustrates how texts, in this case a relatively common laboratory notebook, perform key functions in the context of day-to-day scientific inquiry. Such exploration lies at the heart of this dissertation, and much will be said about the ways in which scientists represent their work both in the laboratory and in broader disciplinary settings. Yet the above scenario also helps articulate a problem that writing scholars increasingly face in their own work: that is, how best to research and teach the multimodal and multimedia compositions that have become a mainstay in everyday, academic, and workplace writing activity. Just to read this laboratory notebook, for instance, I would need to account not only for extended stretches of linguistic script but also for chemical structures, graphic displays, photographs, schematics, and three-dimensional objects. And that is just a start. Beyond textual representations and their arrangements, which are manifold, I would need access to a vast body of scientific knowledge and technical expertise in order to interpret what these semiotic resources afford, individually and holistically, for the chemist who uses them to document and communicate his research. As a non-scientist, I am thus left to explore for myself how such texts cohere and are rendered meaningful in light of the goals they are designed to serve. As a writing researcher, I am also left to question what, exactly, constitutes writing—as a mode of communication, as a literacy practice—in this particular setting.
Puzzling over the semiotic dimensions of written communication is not, of course, limited only to laboratory notebooks. Indeed, due in part to the growing influence of new media technologies, the concept of writing itself has undergone considerable change over the past two decades: namely, from being associated with a single *mode*—e.g., verbal language—to being associated with multiple *modes*—e.g., verbal, visual, aural—that are deployed with increasing ease and frequency in print and digital texts. Responding to this change, scholars in the field of writing studies have tended to diverge in one of two directions. First, some have argued for a multimodal approach to literacy that theorizes the “semiotic principles [that] operate in and across different modes” co-deployed in various cultural texts (Kress and van Leeuwen 2001, p. 2; see Cope and Kalantzis 2000). Within this framework, writing, characterized primarily as linguistic, is one semiotic mode among others rather than *the* dominant mode of textual communication (see Kress 2000, 2003). Second, others have argued for research that investigates the cultural settings within which writing is enacted as a literacy practice. Within this framework, writing is not characterized as linguistic per se but is approached via the material, technological, and semiotic resources deployed in text production. This dissertation aligns most closely with the latter approach. I thus tend to agree with Paul Prior (2005) when he suggests, following scholars like Witte (1992), Medway (1996), and Haas and Witte (2001), that scholarship on writing and multimodality must focus not on texts alone but on “the whole of practice—on artifacts, activities, and people alike” (p. 29).

This dissertation adds to existing scholarship through a qualitative study of writing in a liquid crystal physics and materials science research institute. The question
that guides this inquiry can be stated thus: **How is writing understood and enacted in the context of scientific research and communication?** Answering this question required an investigation that did not begin with a concrete definition of writing per se—and thus beg the very question I was seeking to answer—but with an exploration into the semiotic modes and practices through which scientists document, analyze, and communicate their research. The aim this project has thus been to approach writing not simply as print-linguistic but rather as co-extensive with the media, technologies, and semiotic systems involved in day-to-day scientific work; taking this approach has in turn led me to account for what writing, so understood, affords for the related tasks of text and knowledge production in the physical sciences. By exploring what writing is to scientists, this dissertation, I will argue, offers new insights into the literacies with which students and workers increasingly engage and for which the field of writing studies is developing new theories, methods, pedagogies, and curricula.

Findings from this dissertation specifically suggest that writing in scientific practice involves a complex negotiation not only of existing semiotic modes—e.g., linguistic, visual, mathematical, computational—but also of various materials, technologies, and inscriptions that scientists create, *in situ*, in order to generate knowledge related to the object(s) of their study. The modes and inscriptions that get assembled in scientific texts, I will show, thus realize meaning potential in specific, localized ways that cannot necessarily be accounted for through text-based analysis alone. I argue, then, following Harris (1995), that writing generates meaning not solely through *difference* within a closed system (ala Saussurean linguistics [1959]) but through
the contextualized production and integration of written signs. The substantive theory of writing that I begin to outline in the following chapters of this dissertation is not, therefore, based on a particular script, mode, or way of inscribing visible marks in graphic space (see Gelb 1952). What I hope to show, rather, is that writing to scientists—and indeed, writing more generally—is less a prescribed way of representing and more a constructive way of creating and deploying semiotic resources that afford best to particular research and communicative situations.

Dissertation Structure

This dissertation is structured as follows:

I. Chapter one introduces the problem and question that guides this study, reviews scholarship related to writing, multimodality, and scientific practice, and introduces the setting within which the study was conducted.

II. Chapter two takes up specific issues of methodology and explains the procedures through which I collected, analyzed, and integrated various data sources into an emergent theory of writing. This theory builds on three case studies of scientific practice and stems from a year I spent studying scientists at work.

III. Chapter three presents a case study involving Dave, a chemist, and the laboratory notebooks he constructs as part of his technical work and textual documentation involving the production of liquid crystal materials.
IV. Chapter four presents a case study involving John and Morgan, two experimental physicists, and the inscriptions they produce and deploy to visualize, analyze, and represent their work textually for a disciplinary audience.

V. Chapter five presents a case study involving Jordan, a theoretical physicist, and the representational practices he undertakes to model, simulate, and communicate findings related to liquid crystal materials.

VI. Chapter six concludes this dissertation by discussing how my substantive theory of writing, building as it does on grounded research in the context of scientific practice, contributes to existing knowledge of writing as a semiotic mode, an integrative literacy practice, and a means of transforming the material and technical dimensions of scientific work into durable, rhetorically persuasive texts.

II. Theoretical Background

*A Framework for Scientific Writing and Text Production*

A growing body of scholarship in writing studies has examined the function and production of scientific texts across a variety of social, institutional, and historical contexts. While diverse in scope, this scholarship tends to share a common focus, or at least an implicit agreement, about what constitutes writing as an object of analysis: whether referring to the experimental article as it evolved out of transactions of the Royal Society (see Atkinson 1998; Bazerman 1988; Gross, Harmon, and Reidy 2002), grant
proposals that are revised to obtain research funding (Myers 1990), or research articles that are designed to accommodate findings to lay and interdisciplinary audiences (Blakeslee 2001; Ceccarelli 2001; Fahnestock 1985/1998). These studies have taken important steps in examining how scientific texts organize human activity and shape the ways in which scientists communicate their work rhetorically.

What existing studies have yet to do, however, is examine scientific writing as it is enacted in day-to-day laboratory work and text production. Ethnographies of laboratory science have taken a step in this direction by exploring scientists’ *in situ* representational practices (see Knorr-Cetina 1981, 1999; Latour 1987; Latour and Woolgar 1979/1986; Lynch 1985; Traweek 1988), but these studies tend to focus on writing as a way to investigate science as a social practice rather than exploring the multi-semiotic dimensions of writing as it is produced and deployed in goal-oriented scientific activity. Thus, while a wealth of research has examined scientific “writing” and writing in “scientific practice,” none has explored a scientific community with the intent to locate and theorize writing as it is understood and enacted in the context of scientific research and communication.

As a way to frame my inquiry, this dissertation builds on three bodies of scholarship that have investigated questions related to writing, multimodality, and scientific practice. 1) The first is scholarship that examines writing as a situated rhetorical activity. Through a focus on writing as it is enacted in context, these scholars explore the diverse ways in which texts are constructed and respond to the needs of writers responding to real world exigencies. 2) The second is scholarship that examines
the various semiotic resources through which writers make and communicate meaning textually. Building on Halliday’s systemic-functional linguistics and social semiotics, these scholars account for the ways in which modes realize meaning potentials both as a function of structural relationships and through choices individual writers make in specific communicative situations. 3) The third is scholarship that examines writing and visual representation in the context of laboratory work. Taking ethnographic or ethnomethodological approaches, these scholars have examined the ways in which scientists assemble texts and in doing so transform the material, technological, and symbolic dimensions of their inquiry into culturally-valued forms of knowledge. Such assemblages, I will argue, constitute multimodal objects of analysis par excellence and provide unique insight into writing as a situated rhetorical activity, a semiotic practice, and a means for understanding how and the extent to which multimodality provides a useful construct for explaining the changing dimensions of writing and literacy in an age of new media.

Writing and Text Production

Roy Harris’s integrational linguistics (1995, 1996, 2000) provides a useful starting point for asking and answering questions about writing as a mode of literate communication. Specifically, he situates writing within a semiological framework that treats written signs as products of rather than prerequisites to communication. This is a small but important distinction. For if writing involves the production rather than just the transcription of signs—specifically, signs-as-spoken-language—then writing need not be
equated only with verbal communication, and meaning need not be a result of difference within a closed system (see Saussure 1916). Such thinking, Harris suggests, counters an evolutionary view of writing (see Gelb, 1952) and breaks with the “old tradition of treating writing systems as indices of cultural progress or cognitive advancement, the tradition which judges writing systems by their ‘accuracy’ in transcribing the spoken word, the tradition which invariably treats the alphabet, either tacitly or overtly, as the ultimate human achievement in the history of forms of writing” (2000, p. 15). Indeed, once focus is shifted from “what writing makes possible” to “what makes writing possible” (1995, p. 11), writing systems—e.g., alphabetic, ideographic—become one way, not the only way, to understand how texts are created and imbued with meaning.

Harris’s integrational linguistics, and his semiological approach in general, is useful for interrogating the concept of writing-as-linguistic, but it can be further developed by studying actual situations within which writing is enacted as a literacy practice. Site-based writing research helps address this need. Witte’s constructivist semiotic (1992), for instance, grew out of research across a variety of settings where he studied writing as part of everyday activity—from the classroom to the boardroom. Like Harris, he views writing more broadly than the linguistic sign: “studying the production and use of ‘writing’ from a perspective that privileges spoken or written linguistic systems of meaning-making and ignores other systems of meaning-making can hardly yield a comprehensive or culturally viable understanding or ‘writing’ or ‘text’” (p. 240). Unlike Harris, however, Witte constructed a theory out of grounded research that
accounts for specific writing practices and the ways in which meaning results from localized cases and diverse contexts of writing activity.

Addressing issues of context is essential given the range of semiotic modes, and practices, that constitute writing across diverse cultural settings. As Medway (1996) explains in his study of architects at work, “It is...immaterial to the ‘writer’ whether language, drawings, or graphs are employed; the choice is made in light of the advantages and disadvantages that each offers and of the constraints and expectations obtaining in the particular cultural milieu” (p. 475). This is an inclusive yet grounded view that, like Witte’s, does not attempt to colonize all forms of representation as writing per se but, rather, looks to the activities within which writing and texts are embedded to determine what writing is and, thus, what it does to help facilitate technical and knowledge-productive work: whether with architects or, in the case of this dissertation, with physical scientists.

Haas and Witte (2001), in a study that investigates the production of an engineering standards document, also investigate non-linguistic dimensions of writing and text production. This study specifically explores how a group of engineers draw upon multiple semiotic resources—e.g., linguistic, visual, gestural—to produce a text that effectively responds to an obdurate physical reality. As Haas and Witte suggest, focusing on the multimodal character of texts helps connect situated acts of meaning to the broader social and material realities to which those texts respond in particular ways: “when writing is conceived of as an embedded and embodied practice, understanding links to the
subsuming and circumscribing human activities of which writing is a part becomes paramount” (p. 447).

Hull and Nelson (2005) take a similarly situated approach in their investigations into writing, multimodality, and digital text production. Rather than adopting an explicitly multimodal framework, however, these authors approach multimodal composition from the perspective that it might actually be considered a (new) form of writing. As they suggest, because “a culture and a time’s mediational means …are intimately connected with our capacities to think, represent, and communicate, it would seem hugely important to widen our definition of writing to include multimodal composing as a new available means” (pp. 251-52). Hull and Nelson speculate that a theory of writing might be widened to include multimodal composition, but they also suggest that a theory of writing as such may not be entirely adequate to account for the effect of new media technology on composing practices.

The studies discussed here tend to share in the belief that writing is as complex as the settings within which it is enacted as a literacy practice. One strength of this approach lies in the work these researchers have done to investigate a host of cultural contexts—from boardrooms to architectural and engineering drafting sessions—and thus develop rich, grounded accounts of writing as a situated rhetorical activity. I would like to build on and extend these accounts, however, by engaging with writing in a setting where the very nature of “reality” is under investigation. Medway does of course examine the relationship between conceptual designs and technical realities in his study of architects; Haas and Witte likewise provide provocative insight into the relationship
between textual representation and an always-changing material world. Yet in each of these studies the participants are dealing with a relatively identifiable set of circumstances: whether a blueprint or a water channel. With scientific research, however, physical reality itself is often a question that must be answered. It is the focus of investigation. A study of writing in scientific practice, then, while it can draw upon existing studies of workplace writing activity, must grapple with a different set of epistemological questions related to the construction not only of physical structures—e.g., instruments, equipment—but also of theoretical entities whose “existence”—in the present, in the future—is often the object of investigation and material production.

**Multimodality and Scientific Communication**

Grappling with the epistemological dimensions of scientific writing does, however, have some precedent in research that arises out of Halliday’s systemic-functional linguistics and social semiotics (Halliday 1994, 1978 respectively; see Halliday and Hasan 1989; Hodge and Kress 1988). Multimodal discourse analysis (see Kress and van Leeuwen 2001; see Iedema 2003; Ventola et al. 2004) in particular has been instrumental for theorizing the semiotic dimensions of scientific communication and, generally, for pushing at the boundaries of literacy in what Kress (2003) and others have referred to as a “new media age.” In their work with visual design, for instance, Kress and van Leeuwen analyze different scientific texts and ask, “What is the effect of
the mode of representation on the epistemology of science?” (1996, p. 37). The authors attempt to answer this question—for scientific and other cultural texts—by developing a “grammar” that explains how modes realize meaning potential through the ideational, interpersonal, textual meta-functions described by Halliday (1994). These meta-functions correspond and function in relation to the register of any given communication situation: field/ideational (something happening); tenor/interpersonal (how actors are positioned within the field); and mode/textual (how modes are organized to achieve a particular meaning or message). Attention to context here is paramount; yet context in this framework refers primarily to texts and the way they realize meaning potentials based on the rhetorical choices writers make in constructing a message for particular audiences.

O’Halloran (2005; see 1998, 2004) also operates within a systemic functional framework in order to investigate how meaning is made and communicated in scientific texts. Specifically focusing on mathematical discourse, she argues that “an understanding of the functions of mathematical symbolism, visual images and other semiotic resources permits a re-evaluation of the role of language in constructing a naturalized view of the world” (p. 15). For her, the language of mathematics has direct implications for how reality is constructed and understood symbolically and not just linguistically. Such a move is critical for exploring writing in the sciences not only due

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1 Beyond texts produced by expert scientists, Kress et al. (2001) and Jewitt et al. (2001) have explored multimodality in the teaching and learning of science. Examining the relationship between teachers and students, these authors conclude that learning science is not simply a transmission of information but rather a dynamic engagement where students respond to and transform existing knowledge given the writing tasks and semiotic resources at hand.
to the diverse and multiple resources scientists bring to bear on their work, but also to the ways that work is communicated to lay audiences.

O’Halloran’s approach is also similar to research Lemke (1998) has undertaken to explore multimodal and multimedia representation in physics communication. Similar to her work, he adapts Halliday’s systemic-functional linguistics in order to analyze scientific texts, in his case, articles taken from the journal *Physics Review*. Lemke analyzes these articles in terms of presentation, orientation, and organization—terms that map roughly with Halliday’s ideational, interpersonal, and textual meta-functions. While I cannot go into depth, here, about the entire scope of his project—one that now spans decades—I would argue that his work provides a useful link between multimodal text analysis and scientific text production as a situated rhetorical activity: that is, while Lemke tends to focus on texts rather than the practices involved in producing them, his research does account for the multiple ways in which scientists represent their work and communicate it to disciplinary audiences.

Similar to the research discussed in this section, my dissertation examines the function and production of scientific texts. Yet, rather than starting with texts as an object of analysis, I attempt to situate them in light of *in situ* scientific work; like Kress and others, then, my aim is to develop a framework within which to understand multimodality and meaning potential, but I am starting from a different position: with people, goals, and available resources being deployed toward particular ends in the context of scientific research and communication. Thus, while the scholars mentioned here provide a rich view of scientific discourse through a focus on texts as multi-semiotic
objects of analysis, this approach can be extended by examining meaning making as part of specific cultures, disciplines, and communities of practice in the sciences. This is especially important for scientific communication given the copious technical work within which visuals become functional (as signs) in context and when deployed textually.

*Writing and Representation in Scientific Practice*

Multimodality has become a constructive way to research and analyze scientific discourse, but writing researchers have generated an equally valuable body of work that illustrates the way in which scientists construct knowledge through writing and text. This scholarship has examined, for instance, the historical development of scientific genres (Atkinson 1998; Bazerman 1988); expert composing practices (Berkenkotter and Huckin 1995; Rymer 1988); use of analogy (Gibson 2008; Graves 2005; Little 2008); and the rhetorical shaping of information for expert, lay, and interdisciplinary audiences (Blakeslee 2001; Paul, Charney, and Kendall 2001; Fahnestock 1985/1998, 1989; Myers 1990). Scholars have also examined how non-linguistic systems shape the logic of scientific claims and thus the means whereby scientists lay claim to the knowledge they produce (Arsenault, Smith, and Beauchamp 2006; Fahnestock 1999, 2005; Gross 2006b; Gross, Harmon, and Reidy 2002; Richards 2003). The importance of this work notwithstanding, however, research in the field of writing and rhetoric studies has yet to examine writing and representation as enacted in the context of scientific research and communication.
Scholars in the social sciences, on the other hand, have long been interested in the role of writing and representation in scientific work. This body of scholarship thus extends research on scientific writing and rhetoric into a realm that does not focus solely on linguistic signs or genre-specific texts as objects of analysis. Laboratory ethnographies, for instance, have shown how scientists visualize their objects of study in order to render their work immutable and mobile *inscriptions* (see Latour and Woolgar 1979/1986, 1987, 1990). These studies offer something that multimodal and writing theorists do not: A picture of visual-cum-multimodal communication in scientific contexts. Latour, for instance, spent years researching in the Salk Institute and examined the ways in which scientists produce inscriptions to communicate the outcomes of their work (Latour and Woolgar, 1979/1986; see Latour, 1987). Knorr-Cetina has likewise spent decades conducting laboratory ethnographies in physics and biology and has produced similar findings about the way scientists “manufacture” knowledge through various symbolic and textual forms (1981, 1999). Lynch, through a focus on laboratory work, examines visual inscription as a way to understand science as a (labor) practice that can be explored by looking to the talk that centers on scientific artifacts (1985; see 2006). Lynch and Woolgar’s (1988) collection on representation in scientific practice encapsulates these approaches and provides a theoretically and methodologically rich view of scientific visuals and the communities, cultures, and practices of which they are part.

This dissertation specifically draws upon Latour’s concept of *inscription* in order to situate writing as part of a larger system for producing and generating knowledge in
the form of texts. This does not mean that I attempt to characterize all forms of
inscription as writing per se; what I would propose, instead, is a framework that examines
writing via the spectrum of inscriptions that scientists deploy in their work. Pauwels
(2006) offers an example of one such framework. According to him, scientific
inscriptions function in a variety of ways—e.g., visualizing that which is too slow or fast,
big or small, to observe through normal human perception—all of which contribute to the
production and circulation of referential knowledge. Pauwels specifically focuses on the
productive apparatus of scientific visuals—e.g., the media, technologies, sign systems—
and the normative cultures within which they give meaning and shape to the physical
world. A fundamental aim of scientific visualization, he suggests, is to produce “social
objects” (p. 12) that enable inter-subjective discussion and debate among scientists. In
other words, referents—whether physical or mental—must be made visible so that
relationships can be perceived, constructed, analyzed, and understood both in and outside
the laboratory. Pauwels’s concept of visual literacy in science is (thus) process-oriented
insofar as it would link visuals with their “contexts of production” (p. 21).

In the case studies presented in this dissertation, processes of visualization help
confirm the meaning-constructive work of scientists in the laboratory and the way they
communicate that work to themselves and to disciplinary audiences. Similar to Pauwels,
then, I examine scientific literacy via the ways in which scientists make their work visual,
analyzable, and accountable to themselves and their communities. Yet in contrast to him,
I look to scientific practice as a way to explore the concept of literacy rather than looking
to the concept of literacy as a way to explore science as a practice. In doing so, I take
heed from Lynch (2006) and his approach to visualization in science: that it involves the construction of “reality” but does not dispense with external reality entirely. As he suggests, “while much can be said for the idea that graphs, photographs, and so forth do not simply reflect natural properties, much also can be said for the idea that they do not simply reflect properties of mind, society, or culture (p. 37). This work begins to bridge the realist/constructivist divide and offers a useful counter to scholarship that views science as fundamentally rhetorical and open to the type of analysis that scholars like Gross (1990/1996, 2006a) seem to advocate. Following Pauwels, Lynch, and others, I focus in this dissertation not on scientific texts alone but on text production as relates to the inscriptions that scientists produce and deploy in their work.

These three bodies of scholarship together provide theoretical grounds for examining writing in the context of scientific practice. More precisely: the first views writing as multimodal insofar as text production is understood as a situated rhetorical activity; the second views writing as linguistic and, thus, as one semiotic resource among others that can be deployed in making and communication complex meanings; and the third views writing as inscription and, thus, as a means whereby scientists make their work visible, analyzable, durable, and persuasive. Choosing any one of these directions makes an epistemological commitment to writing as an object of study and, accordingly, to the way in which writing is defined as a research and teaching subject. Simply put, where a study of writing begins will shape both the type of findings it will produce and the ways in which those findings are warranted on methodological grounds.
In this dissertation, I do not start with writing as a predefined object of study. Indeed, *writing* is a question for which I am seeking an answer. Nor do I start with a workplace setting that has precedent in existing writing research. A study of writing in a physics laboratory, I have found, raises many questions that have not yet been worked out in the existing research. Finally, I do not take a critical approach to science, as is often the case with studies that examine scientific writing and discourse. I do, however, attempt to add a useful empirical and theoretical dimension to what is currently known about writing, literacy, and multimodality by exploring these concepts in the context of scientific practice.

III. Research Setting

*A Writing Researcher Enters the Laboratory*

Just a fifteen minute walk across campus from the English department, the liquid crystal physics and materials science institute (hereafter Institute) positioned me to spend a great deal of time in close proximity with scientists and to re-think many of my own assumptions about writing, text, knowledge, and the very nature of physical reality. Indeed, what I thought I knew about writing was immediately “made strange” as I was forced to contend with a broad spectrum of inscriptions (see Latour 1987, 1990; Latour and Woolgar 1979/1986) that scientists used and produced as part of their work: renderings on white boards, glass fume hoods, and vials; images projected on screens; theoretical and three-dimensional models; computational simulations; and various other forms of representation the likes of which I had never encountered as a writing researcher.
and teacher. What I found, however, while new to me, was a setting where I could ask useful questions about the writing and multimodal text production in the context of a distributed practice involving the production of new materials, instruments, technologies, and, ultimately, physical realities. Writing for me, then, is understood in light of the practices in which it was used and produced to achieve the objectives of scientists working in this space.

Yet my interest in the institute extended beyond its value for researching writing per se. Indeed, this particular setting was partly responsible for inventing the very technology—liquid crystal displays—that have helped to enact a media shift from page to screen and a concomitant shift in the way writing scholars view literacy as a practice. While this historical tidbit does not play a central role in my investigation, it does provide insight into the way in which scientific knowledge relates to technological development in one particular setting. The Institute itself is home to an interdisciplinary doctoral program in chemical physics, and the faculty, a mix of professors trained in physics and chemistry, teach as well as manage their own research groups. The study of liquid crystals invites collaboration between physicists and chemists in many ways, not least for the expertise that each field can bring to bear on the production, characterization, and technological development of this phase of matter (see Collings 2002; Palffy-Muhoray 2007). In addition to in-house collaboration, scientists from diverse fields and disciplines regularly visit the Institute to research, collaborate, and give lectures. Indeed, it is not uncommon for a biologist to give a lecture one week, an electrical engineer the next, a physicist the next, and a chemist the next. Within this setting I was thus able to learn
much about the rhetorical shaping of information across scientific disciplines (see Blakeslee 2001).²

The design for my study, however, was oriented primarily toward the writing practices of one research group.³ The group is headed by Dr. Maxwell, a senior physicist and one of the Institute’s associate directors. Group research varies but is structured around two interrelated activities. First, these scientists produce materials that either have a liquid crystal phase or that might be combined with other materials in the design and development of new technologies, from liquid crystal displays to flat lenses. Second, they study and characterize, through experimentation, theoretical modeling, and computational simulation, the optical properties of the materials they produce. While members of the group change—some are visiting scientists and post-docs, some are students on rotation—nine to twelve people have been consistent throughout this study. Participants ranged from full professor to visiting professor to post-doc to advanced graduate student to first year graduate student to undergraduate intern (see Table 1.1). In sum, the group is a diverse bunch, though I would add that such diversity is brought together through networks of activity related to Dr. Maxwell’s interests, his grants, and the Institute itself both as a community and a physical research space.

² I obtained permission through Kent State University’s Institutional Review Board and from the scientists themselves to conduct this research. Names have been changed to protect the confidentiality of scientists and their participation in my study. I use the term “confidentiality” here as it is in keeping with Kent State’s terminology for conducting research involving human subjects that are identifiable to the researcher.
³ Despite this focus, I also spent a significant amount of time attending group meetings for Drs. R. and J. Schrodinger. These scientists both specialize in theoretical physics, though R. focuses more on computation and visualization and J. more on the “pen and paper” work of mathematics. Attending these group meetings offered their own unique insight into physics research and communication and provided a useful check against the work I was observing in Dr. Maxwell’s group.
Table 1.1  
*Main Participants, Position/Rank, Discipline, Primary Observed Activities*

<table>
<thead>
<tr>
<th>Name</th>
<th>Position/Rank</th>
<th>Discipline</th>
<th>Primary Observed Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Maxwell</td>
<td>Professor, head of laboratory, associate director of Institute.</td>
<td>Experimental Physics</td>
<td>Direct and track laboratory activity. Run group meetings.</td>
</tr>
<tr>
<td>John</td>
<td>Dr. Maxwell’s graduate student.</td>
<td>Experimental Physics</td>
<td>Set up and follow through on experiments in the laboratory.</td>
</tr>
<tr>
<td>Jordan</td>
<td>Dr. Maxwell’s graduate student.</td>
<td>Theoretical Physics and Computation</td>
<td>Set up and follow through on experiments in the laboratory and simulation work on computer.</td>
</tr>
<tr>
<td>Morgan</td>
<td>Dr. Maxwell’s Post-Doctoral Fellow.</td>
<td>Experimental Physics</td>
<td>Construct equipment, set up experiments, take part in experiments, arrange laboratory so that it is in working order.</td>
</tr>
<tr>
<td>Sarah</td>
<td>Dr. Maxwell’s Post-Doctoral</td>
<td>Experimental Physics</td>
<td>Construct equipment, set up experiments, take part in experiments.</td>
</tr>
<tr>
<td>Dave</td>
<td>Dr. Maxwell’s Post-Doctoral</td>
<td>Chemistry</td>
<td>Mix, measure, synthesize and provide material for experiments</td>
</tr>
<tr>
<td>Victor</td>
<td>Visiting Scientist.</td>
<td>Experimental Physics</td>
<td>Interface with experiment through computers. Visualize data through computer programs.</td>
</tr>
<tr>
<td>Roland</td>
<td>Graduate student on rotation.</td>
<td>Experimental Physics</td>
<td>Construct equipment, set up experiments, take part in experiments.</td>
</tr>
<tr>
<td>Brad</td>
<td>Undergraduate student intern.</td>
<td>Technology Studies</td>
<td>Construct equipment, set up experiments, take part in experiments.</td>
</tr>
<tr>
<td>R. Schrodinger</td>
<td>Professor</td>
<td>Theoretical Physics and Computation</td>
<td>Direct group meeting and advise on student PowerPoint presentation. Demonstrate simulations of liquid crystal and related materials.</td>
</tr>
<tr>
<td>J. Schrodinger</td>
<td>Professor</td>
<td>Theoretical Physics</td>
<td>Direct group meetings; give lectures to students and other faculty during meetings.</td>
</tr>
</tbody>
</table>
For approximately one year, I was part of the group’s day-to-day activities. To name a few, I attended daily morning meetings where the group gathered to drink coffee and discuss the nuts and bolts of laboratory activity and individual research projects; I observed activity that crossed between the two main laboratory spaces (chemical and laser labs); I observed office activity, including data analysis and work with computer simulations; I attended weekly group meetings where laboratory members shared their work and discussed their progress; I attended “brainstorming sessions” where different laboratory members worked together to solve a common problems; I attended impromptu meetings where laboratory members presented and revised their work prior to giving posters or Power Point presentations at local and national conferences; I attended weekly seminars from visiting scientists; and, basically, I was involved as a participant observer in any number of everyday activities: from producing materials to constructing equipment to conducting experiments to preparing and running theoretical simulations.

Through my research, which takes the form of observational field notes, interview and meeting transcripts, and a range of visual and textual inscriptions, I was able to identify three practices within the group that contribute to its overall research output: 1) Material Production; 2) Physics Experimentation; 3) Theoretical Physics Modeling and Simulation. Each of these practices provided a useful case for examining what forms writing takes, the ways in which writing is enacted in the production and characterization of liquid crystal materials, and, in general, the ways in which knowledge is produced, deployed, and circulated in the laboratory, the Institute, and the liquid crystal physics research community. Most importantly, perhaps, defining these practices as discrete case
studies enabled me to define writing more explicitly, and thoroughly, according to the research and communicative goals of scientists and the different types of expertise they bring to bear on the objects of their study.

This dissertation begins with a case study involving Dave, a chemist, and the relationship between his technical work and textual documentation practices. I argue here for a “material” concept of writing and literacy that accounts for the semiotic resources—e.g., chemical structures, three-dimensional objects—that Dave deploys in his work. I follow this chapter with a case study involving John and Morgan, experimental physicists, and the relationship between visualization and text production in experimental physics research. I argue here for a “visual” concept of writing and literacy that connects in situ laboratory representation with the function and production of scientific texts. Finally, I present the final case study involving Jordan, a theoretical physicist, and the relationship between theoretical models, computational simulations, and a discursive text. I argue here for a “computational” concept of literacy that accounts for the various ways in which writing can be said to construct and enact new conceptual realities.

Individually, each case study provides new and interesting insights into the material, visual, and computational dimensions of writing as a literacy practice. And together, these case studies illustrate how scientists produce and stabilize referential knowledge related to liquid crystal materials as an object of study. The following chapters are devoted to grounding, analyzing, and teasing out the implications of this claim.
Chapter 2

Methods, Analysis, and Findings:
Steps Toward a Substantive Theory of Writing

I. Introduction

Research Design, Revisions, and Scope

Writing scholar Charles Bazerman, in an article titled “Theories of the middle range in historical studies of writing practice,” discusses the need for research that negotiates a middle ground between theories of writing that have little grounding in human activity and empirical studies of writing that have little theoretical purchase beyond the settings within which they are embedded. Drawing on sociologist Robert Merton’s “theories of the middle range” (1949/1968), he specifically calls for studies that “identify empirically reseachable social phenomena and processes that, as they became confirmed and elaborated, might emerge into theories of somewhat larger sweep” (2008, p. 300).

Following in the spirit of Bazerman’s call, one aim of this dissertation is to develop a “substantive theory” of writing based upon qualitative study in a liquid crystal physics research institute (see Glaser and Strauss 1967). More specifically, through methods of

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4 According to Glaser and Strauss (1967), substantive theory is “developed for a substantive, or empirical, area of sociological inquiry such as patient care, race relations, professional education, delinquency, or research organizations” (p. 32). The substantive area for this dissertation is a scientific research institute that specializes in the production, characterization, and technological development of liquid crystal materials.
participant observation, inscription collection, and in-depth interviews, I explore how writing is variously understood and enacted in the context of scientific research and communication. The design for this study has thus aimed to provide a “thick description” (Geertz 1983) of writing activity based upon field notes taken while observing practical scientific work, inscriptions and texts collected from scientists themselves, data gathered through numerous interviews, and, in general, my own experience as a researcher becoming immersed in an unfamiliar scientific culture (see Table 2.1).^5

<table>
<thead>
<tr>
<th>Method</th>
<th>Aims</th>
<th>Output</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>Observe scientists at work; document their practices; gain insight into the way in which visual inscriptions function as part of their inquiry and text (re)production.</td>
<td>Field Notes. ~250 single spaced, typed pages, plus an additional ~400 pages handwritten, across three stages of inquiry: 6, 4, and 2 months.</td>
<td>Comparative analysis of field notes; open, axial, and selective coding across stages of inquiry. Theoretical memo writing.</td>
</tr>
<tr>
<td>Visual Artifacts</td>
<td>Collect inscriptions and texts that scientists produce and deploy in their laboratory work and text (re)production. Examine relationship between visual and text production across laboratory spaces.</td>
<td>Hundreds of my own photographs and visual renderings of laboratory work; dozens of inscriptions and texts collected from participants themselves.</td>
<td>Comparative analysis of inscriptions and texts; situate comparisons in relation to field notes on laboratory work and analysis of output of that work.</td>
</tr>
<tr>
<td>Interviews</td>
<td>Collect scientists’ talk in order to analyze self-perceptions of writing</td>
<td>Seven interviews for a total of ~6 hours of talk.</td>
<td>Open, axial, and selective coding based on multiple</td>
</tr>
</tbody>
</table>

^5 Following Latour, I use the term *inscription* to describe the immutable, mobile, reproducible, and combinable forms of representation that scientists can assemble for the purpose of textual communication (1990, pp. 44-47). In later chapters, I make more nuanced distinctions between *inscription* and *text* in order to tease apart the relationship between visuals produced in the laboratory and those integrated into specific textual genres.
My research developed progressively across three phases of data collection and analysis. As shown in Table 2.2 below, the first phase, lasting approximately six months, involved an intense period of data collection and analysis where I spent time in the Institute on a near daily basis. The second phase, lasting approximately four months, involved me making explicit connections between texts, inscriptions, and practices that began to coalesce around emergent analytical categories. The final phase, lasting approximately two months, involved me making more selective visits to the Institute to check and confirm my findings, and, where necessary, refine my thinking. This research has been guided by the Grounded Theory approach to data analysis (Glaser and Strauss 1967; Strauss 1988). Briefly, this approach is designed for research that attempts to build theory—in this case, a substantive theory of writing and multimodal text production in a scientific research setting—that can be traced to specific data points and analytical procedures. The process of building theory, as I discuss in more detail below, involves working closely with data, engaging in open, axial, and selective coding, developing core categories, and generating hypotheses that can be examined and refined through ongoing theoretical sampling and comparative analysis. Grounded Theory proved essential given my initial lack of familiarity with the site and the length of time I was able to spend conducting my investigations there.
Table 2.2
Research Timeline and Activity

<table>
<thead>
<tr>
<th>Timeline/Activity</th>
<th>Months 1-6</th>
<th>Months 7-10</th>
<th>Months 11-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methods</td>
<td>Immersion in site (30+ hrs/week), observations, artifact collection, analysis.</td>
<td>Ongoing immersion (20+ hrs/week), observations, interviews, artifact collection, analysis.</td>
<td>Confirmation, interviews, artifact collection, analysis.</td>
</tr>
<tr>
<td>People/Actors</td>
<td>Maxwell’s Group; Schrodinger Group; Jensen Group; Institute as a whole (in spaces like seminars, offices and hallways).</td>
<td>Maxwell’s Group; Schrodinger Group; physics community (conference site).</td>
<td>Maxwell’s Group</td>
</tr>
<tr>
<td>Activity Spaces</td>
<td>Optics lab, chemical lab, offices, morning meetings, group meetings, seminars, local and national conferences, poster sessions, guided tours.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tasks/Activities Observed</td>
<td>Production of material, experimental, computational systems; text production/assembly; faculty lectures; faculty and student presentations; various writing and inscription (print, digital, whiteboard); computing; solving equations and brainstorming; building equipment; reading and interpreting (linguistic, mathematic, visual, material).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analytical Work</td>
<td>Open coding of field notes; theoretical sampling in site; move toward axial coding; memo writing. Transcribe field notes.</td>
<td>Axial coding of field notes; theoretical sampling; move toward selective coding and core categories of practice; memo writing.</td>
<td>Selective coding of field notes based on emergent categories of practice; move toward conceptual integration; memo writing.</td>
</tr>
<tr>
<td>Outputs</td>
<td>Transcribed and coded field notes; in situ inscriptions and texts; analytical visualizations; memos.</td>
<td>Taxonomy of inscription via spaces, people, tasks, and emergent practice categories; interview transcripts; memos.</td>
<td>Selective practice observations and analytical categories; interview transcripts and analysis; memos.</td>
</tr>
</tbody>
</table>
The objective of my research was to investigate writing as co-extensive with the media, technologies, and semiotic systems that scientists deploy in their research and communication. Initially, I anticipated that such inquiry could be usefully completed within approximately four months of visits to the Institute; this period, I surmised, would give me enough time to gather and begin coding multiple data sources, test and revise my initial hypotheses, and begin developing a substantive theory that would offer new insights into writing and multimodal text production in scientific practice. It did not take long to discover, however, that four months would not be nearly enough time to explore the range of tasks and practices with which scientists engage in their day-to-day work. Even to focus on recognizable forms of writing—e.g., laboratory notebooks, Power Point presentations, research articles—would take me only so far in situating and understanding writing as an embedded practice and object of study. Indeed, without some understanding of what those forms of writing are designed to represent, or what ends they are designed to serve, I would have little more than a surface-level description of objects and actions and not a thick description of scientific writing activity (Geertz 1983; see Witte 2005).  

It was not difficult, however, to extend my stay with the group. This was due, in part, to my ability to establish credibility as a researcher and confirm to the group that my study was legitimate—and, if nothing else, a reasonably accurate rendering of their work in the laboratory. As an outside observer, and an non-scientist, there were actually

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6 Geertz’s concept of “thick description” is best explained, perhaps, through the difference he articulates between blinking and winking: while the mechanism is the same—i.e., a fluttering of the eyelid—the significance of the act differs greatly. A thick description would be able to differentiate between these acts by uncovering the complex layers of meaning in a particular culture or site of human activity.
moments during my investigation when I needed to be forthcoming with my questions as well as my findings—more so, perhaps, than I would have originally preferred given my initial interest in keeping some objective distance between myself and the scientists I was observing. Approximately two months the project, for instance, Dr. Maxwell asked me to present my work-in-progress at a group meeting. This was not so different a task than what was required of group members on a weekly basis: that is, sharing work, showing progress, discussing problems, brainstorming solutions and new ideas. I was of course glad to comply—and in fact intrigued by the response I would receive—but was also hesitant about revealing too much too soon and, thus, unnecessarily shaping the way in which the group perceived my presence in the laboratory and in their lives. Yet what started out as a potential problem of objectivity—i.e., the relationship between myself as research and the scientists as research subjects—actually evolved into a rich, in-depth inquiry where I would become deeply involved with the group and the cultural practices that shape their research and communication.

Getting more deeply involved in the culture of science was also encouraged by Dr. Maxwell in other ways. Not long after I presented my research to the group, for example, he suggested that I apply to the American Physical Society’s March Meeting, an annual conference that brings together thousands of scientists from around the world for a full week of presentations, meetings, and collaborations. Proposing for this conference meant that I would prolong my stay in the Institute for at least an additional three months; this also meant, however, that I would gain an even greater appreciation for the work that goes into presenting—e.g., visually displaying, orally communicating—
one’s findings to a scientific audience. Thus, while my initial plan was to spend four months with one group of scientists, I ultimately ended up spending the equivalent of approximately one year’s time in and out of the Institute, among multiple groups, conducting my research, crafting presentation material, attending revision workshops, getting advice and critique from scientists, and eventually participating in a national physics conference where I presented my work in a session titled “Physics Education: In and Outside the Classroom.” The scope of this project, then, while initially a relatively bounded study, evolved into a prolonged inquiry during which I became immersed in the culture of Dr. Maxwell’s group, the Institute, the scientific community, and the ways in which scientists in general write and assemble texts as part of their research and communicative work (see Appendix A, Table A.1).

Methodological Grounding and Dilemmas

Throughout this project, I engaged in open, axial, and selective coding of field note transcripts, visual and textual inscriptions, interview transcripts, and theoretical memos I had written. Open coding involved making repeated passes through my data to generate initial categories for comparative analysis.7 During the first few weeks of my study, for instance, I described various objects that scientists worked with in the laboratory. Three categories emerged from this descriptive analysis: materials (e.g., chemicals), instruments (e.g., lasers), and inscriptions (e.g., graphic displays). These categories were then dimensionalized in relation to the tasks in which they were involved.

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7 According to Glaser and Strauss (1967), the “comparative method is designed to aid the analyst…in generating a theory that is integrated, consistent, plausible, [and] close to the data” (p. 103).
I would document, for example, when a scientist would scribble notes on a sticky pad (inscription) while working on a laser (instrument) that would be used to experiment with a sample (material). Examining tasks in turn led to additional categories that could be examined along the “axes” of the goals they were designed to serve: for instance, producing, experimenting with, or simulating liquid crystal materials. Axial codes extended open codes by focusing data collection and analysis on specific tasks and, eventually, emergent core categories or practice. Selective coding occurred later in my study, after these core categories—i.e., material production, physics experimentation, physics modeling and simulation—became the focal case studies for this dissertation. In other words, once I began focusing on production, experimentation, and theoretical modeling and simulation of materials, I examined these practices more selectively based upon objectives, people involved, tools used, and so on. This general approach is designed to “saturate” codes and categories and ultimately to generate a substantive theory that can be traced to the data points through which it emerged.

The process of coding data maps roughly with the three research phases I outlined above. More specifically, I conducted open and axial coding during the first six months; axial and selective coding during the following four months; and selective coding and conceptual integration during the final two(+) months. One dilemma I faced during this time, however, was that I needed to understand, first, the actions I was observing—i.e., beyond simple, object-based description—before being able to situate writing within
specific practices.\footnote{More specifically, I take heed from Witte (2005) who discusses the “boundary problems” involved in focusing on activity, or practice, as a unit of analysis. My aim in this project has been to build toward practice in a principled way rather than start with practice as an arbitrary construct for understanding scientific research and communication.} *Practice* within the context of this dissertation is a conceptual category that emerged through ongoing data collection and analysis and that eventually formed the basis of my case study development. Thus, while I was able to describe the range of inscriptions and texts that were located in the laboratory—e.g., notebooks, whiteboard markings, academic posters—those observations remained at a descriptive level until I could “figure out” what constitutes the practice of science in the group and the Institute—an ongoing challenge, and one, I found, that will motivate my research and thinking for years to come.

Yet even to describe the work of scientists is no simple undertaking. Indeed, an exhaustive description of objects alone—e.g., materials, instruments, inscriptions—would number in the thousands housed in and across laboratories, offices, hallways, classrooms, meeting rooms, and so on. More than objects themselves, the very nature of scientific inquiry tends toward principled interpretation of phenomena that scientists themselves do not always understand completely. A challenge for me, then, was to make sense of this unfamiliar world in a non-arbitrary way. One key turning moment in this process was the point at which I began to investigate the concept of *material*.\footnote{The term “material” here refers the liquid crystal materials—e.g., elastomers, gels, films—that these scientists produce and characterize in the laboratory.}

Quite simply, I began “following” material samples—e.g., from laboratories to offices and group meetings—which enabled me to examine how these objects were produced, characterized, and represented by members of the group. This approach,
which I discuss in greater detail below, resulted in three core categories of practice around which I based my subsequent investigation: production, experimentation, and simulation of liquid crystal materials. These categories in turn provided the foundation for three case studies that form the core of this dissertation: Dave, a chemist, producing materials and recording his work in a notebook; John and Morgan, experimental physicists, experimenting with materials, visualizing data, and producing a multimedia presentation; and Jordan, a theoretical physicist, modeling and simulating material systems. While much data collection and analysis preceded this material focus, it is worth noting here that liquid crystal materials themselves are central to the work of science in this site: that is, the group generates its own objects of study (samples), means for producing and characterizing those objects (instruments, experimental procedures), and means for conceptualizing new materials, methods, and physical realities (models, simulations).

Laboratory Spaces

Group research tends to take place in and across three main spaces (See Figure 1.1). These include the chemical laboratory as a site of synthesis and material production; the optics laboratory as a site of physics experimentation; and the office as a site of physics modeling and computational simulation. Early in my research, I spent time documenting the objects found and actions performed in each space before making a more analytical move to focus on the way in which various forms of inscription and text were involved in the completion of specific tasks. Taking this approach led me to
identify a division of labor between members of the group. I use the term division cautiously, however, because scientists in this setting often take part in a number of tasks and activities: for example, I observed Jordan, a self-described theoretical physicist, synthesizing materials and conducting experiments as well as running simulations. Yet despite conducting different types of research, each group member tends to spend more or less time in one or more of these spaces: Dave in the chemical laboratory, John in the optics laboratory, Jordan in his office, and so on. Identifying these spaces as sites of specific tasks, and examining the work completed there, helped me trace and, eventually, begin to understand the nature of writing and text production as it was enacted in light of scientists’ research and communicative objectives.

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10 I would add here that members of Dr. Maxwell’s group often assist each other on projects, collaborate on productive and experimental work, and spend time mentoring younger students who rotate in and out of the group on a regular basis.
II. Analytical Procedures

A Task-Based Analysis

Noting the way in which scientists traveled between spaces, the amount of time they spent in each one, and the actions they were performing, I was able to hypothesize more explicitly about the aims and outcomes of their work. Yet at this point, my research was still operating at a more or less descriptive, object- and action-based level involving materials, instruments, and various forms of symbolic inscription (see Appendix A, Table A.2). As a way to narrow my analysis and data collection procedures, I thus turned to Bracewell and Witte’s (2003) twin constructs of tasks and ensembles as units of analysis for identifying and studying the relationship between text production and use in the context of laboratory work. This meant that I would identify, generally, “problem situations” (tasks) and the ways in which scientists, working individually and collaboratively, set about solving those problems using a range of instrumental and semiotic resources (ensembles). I could only make this move after spending several weeks in the laboratory—producing, transcribing, and coding field notes—since it took no small amount of time to understand who these scientists were, what work they were performing, how that work contributed to overall group output, and, essentially, what constituted a “problem” (situation) for them in light of broader research objectives.

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11 I created Table 2.4 early in my investigation for the sake of documentation and also to begin examining relationships between objects and actions, and, eventually, tasks and practices. The left column of this table includes actions I observed, and the right column includes a general description of those actions.

12 As Bracewell and Witte suggest: “We define the task as the set of goals and the actions that implement these goals, which are developed in order to achieve a solution to a complex problem within a specific work context…. [T]he work ensemble, serves to link the task to social and material means that achieve the development and application of the solution in the material world. We define the work ensemble as the smallest group of people who collectively uses sign systems in conjunction with other tools and technologies to realize an appropriate solution to a complex problem within a specific work context” (p. 528, italics theirs).
Tasks performed in the laboratory are myriad and range from the explicitly technical to the highly analytical to the seemingly mundane. During my first week in the laboratory, for instance, I observed Morgan and Dave changing out dye in a laser. This is a relatively straightforward task that involves draining and disposing of the existing dye, adding the new, and negotiating various instrumental components: pump, tubes, switches, and so on. The task-as-problem-situation, in this case, was one I could observe: that is, an ensemble of people using various tools to solve a problem. What I could not immediately observe, however, were the reasons why tasks such as this needed to be completed. I later discovered, for example, that John needed the dye changed in this particular laser so he could run an experiment. So, while the apparent “problem” of this task, to me, was changing the dye, this problem makes fuller sense in light of the ends to which the dye and laser would be put in the context of John’s experimental practice. Usefully, then, I discovered that tasks-as-problem-situations were variable according to what I actually knew about the broader objectives of individual scientists and the group as a functioning research unit.

During this time I continued to transcribe and code my field notes, write theoretical memos, observe in the laboratory, talk with scientists about their work and, basically, just spend time “hanging out” in the laboratory. As a way to streamline my data collection procedures—and get a handle on the amount of data I was collecting—I

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13 I would note here that the time spent in the laboratory—just being there—is not insignificant, even if it is not exactly documentable. I found, for instance, that there is something of a “gestalt” effect that comes out of observing scientists at work and becoming part of their culture—an experience akin to suddenly realizing what is happening on a new level than what had previously experienced. In other words, I developed an understanding of their research through my immersion and not just through the visible data I was collecting.
also developed a simple heuristic for investigating task situations (see Figure 2.2, Appendix A). This heuristic provided me with a useful template for bounding tasks and exploring a set list of variables that I could observe and document in my field notebook. These include objectives (short- and long-term), participants (primary, secondary), mediational means (material, instrumental, symbolic), outcomes (material, instrumental, symbolic), and links to other tasks. With the dye-changing task, for instance, I could identify the short-term objective (replacing the dye), participants (Morgan as primary, Dave as secondary), mediational means (dye, various tools, binder with technical instructions), outcomes (new dye, functioning dye laser), and links to other tasks (John could set up and run his experiment).

This task-focused inquiry was useful for investigating who was doing what type of work (as well as where and how). Yet it was also somewhat cumbersome given the nature of laboratory practice: that is, scientists are constantly in and out of the laboratories and are almost always working on multiple tasks at once. Indeed, it is not at all uncommon for someone to drop what he or she is doing and take up some other task—whether on their own or at the request of Dr. Maxwell. Accounting for the fluidity of these task situations—and their sheer number—was a challenge, but it eventually led to a clearer sense of where different members of the group were focusing the majority of their work. Some, for instance, spent more time synthesizing and producing material samples for experimentation (Dave); some spent more time building and running experiments (John, Morgan); and some spent more time constructing theoretical models and computational simulations (Jordan). Through this focus, I discovered that each of the
tasks I was observing were oriented in some way toward liquid crystal materials: whether their production or experimental and theoretical characterization.

Once I began focusing on liquid crystal materials as a central object of study for research in the laboratory, it did not take long to realize that each group member contributed his or her own expertise to their production and/or characterization. It did not take long, either, to realize that tasks had different objectives and outcomes. Consider, for instance, Dave’s work in the chemical laboratory. Much of his inquiry is directed toward the synthesis of liquid crystal materials and production of material samples. At any point in this process, the tasks he performs may have a material, instrumental, or symbolic objective: for example, synthesizing chemicals (material), working on a centrifuge (instrumental), or using various inscriptions to document his work (symbolic) (see Table 2.3). Table 2.3 is designed to show how material, instrumental, and symbolic task objectives are carried out in particular spaces and how they led to emergent practice categories. More specifically, observing tasks undertaken across different laboratory spaces, and documenting their outcomes, led me to identify the practices within which they were situated. Tasks in this way can be understood not as isolated problem situations but as means—something akin to building blocks—to achieve research objectives involving the production, experimental characterization, and computational simulation of liquid crystal materials.
<table>
<thead>
<tr>
<th>Task Objective &amp; In Situ Example</th>
<th>Observed Tasks</th>
<th>Practice Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Produce material in chemical laboratory. Measure, weigh, and synthesize chemicals toward development of new materials and procedures.</td>
<td>Production</td>
</tr>
<tr>
<td>Characterize material in optics laboratory.</td>
<td>Experiment with material samples toward development of new experimental method.</td>
<td>Experimentation</td>
</tr>
<tr>
<td>Simulate material in office.</td>
<td>Simulate material systems toward understanding of material properties.</td>
<td>Simulation</td>
</tr>
<tr>
<td>Instrumental</td>
<td>Construct system for production in chemical laboratory. Assemble system for synthesizing materials chemically.</td>
<td>Production</td>
</tr>
<tr>
<td>Construct system for experimentation in optics laboratory.</td>
<td>Assemble system for characterizing materials experimentally.</td>
<td>Experimentation</td>
</tr>
<tr>
<td>Construct system for computation in office.</td>
<td>Assemble system for modeling and simulating materials computationally.</td>
<td>Simulation</td>
</tr>
<tr>
<td>Symbolic</td>
<td>Document production in chemical laboratory. Record procedures; solve equations; analyze data; display and communicate findings through texts (e.g., Notebook).</td>
<td>Production</td>
</tr>
<tr>
<td>Produce visual data through experiment in optics laboratory; analyze data in office.</td>
<td>Record procedures; write code; solve equations; analyze data; display and communicate findings through texts (e.g., PPT).</td>
<td>Experimentation</td>
</tr>
<tr>
<td>Produce simulation in office; generate and analyze data in office.</td>
<td>Record procedures; write code; solve equations; analyze data; display and communicate findings through texts (e.g., Article).</td>
<td>Simulation</td>
</tr>
</tbody>
</table>
Practice categories were further dimensionalized according to variables described in the task heuristic (see Appendix A, Figure A.1) and the task objectives outlined in Table 2.3. Table A.3 (see Appendix A) illustrates how the various components of the practice context—people, primary spaces, practice objectives, tasks, and outcomes—relate to the specific practices of production, experimentation, and simulation. John’s work, for example, can be investigated in itself according to variables that circumscribe the practice context. Yet the variables involved in experimental practice can also be compared against the variables involved in the practices of production and simulation. On the one hand, each practice constitutes a unit of analysis insofar as it involves different people, different objectives, different tasks, and different outcomes. On the other hand, each practice strives toward a similar goal involving the production, experimental characterization, and computational simulation of liquid crystal materials. More precisely, these researchers share an interest not only in material per se—e.g., as a tangible phenomenon—but rather on a dynamic referent that circulates between each practice and is stabilized through these practices that, together, contribute to a holistic characterization of liquid crystal materials as objects of study.

What I have attempted to articulate up to this point is a methodological progression that has informed my substantive theory of writing in liquid crystal physics research. More precisely, the progression looks something like: 1) description of objects and actions; 2) identification of tasks and ensembles as units of analysis; 3) a focus on the material, instrumental, and symbolic objectives of tasks-as-problem-situations; 4) the emergence of practice categories; 5) the integration of practice contexts and variables; 6)
and, finally, an emergent concept of research and writing activity in the group that involves the production, analysis, and circulation of materials as physical and conceptual referents.

III. Findings

Findings from my research result from a task-based analysis that eventually coalesced around three categories of practice: production, experimentation, and simulation of liquid crystal materials. Each practice, as discussed above, requires a unique set of resources—material, instrumental, symbolic—for carrying out specific tasks that contribute to the achievement of the group’s research and communication objectives. This section discusses, briefly, findings that relate to the role of writing and text production in this process. More specifically, with Dave, I discuss the relationship between the technical work and textual documentation involved in material production; with John and Morgan, I discuss the relationship between visual inscription and multimedia communication in physics experimentation; and with Jordan, I discuss the relationship between computational simulation and textual representation in theoretical physics. Looking at these practices together, I then propose a model for writing research that links text production to the material, technical, and semiotic dimensions of laboratory work.

I begin this section with a conceptual model for visualizing the relationship between core categories of practice and the ways in which they contribute referential knowledge related to liquid crystal materials (see Figure 2.3). As Figure 2.3 shows, the
material-as-referent is represented (and thus circulated) in different ways:Dave produces notebooks in order to track material production and confirm the output of his technical work as knowledge;John produces a multimedia presentation in order to communicate his experimental findings to a disciplinary audience;and Jordan drafts a research article that will either end up as part of his dissertation or published in a journal (or both). I have designed this model to articulate the general relationship between practices, their various components, and the way in which each contributes to a holistic understanding of liquid crystal materials. What follows is an attempt to show how the material and technical dimensions of scientific practice enter into circulation—in the laboratory, in broader disciplinary contexts—through specific inscriptions and texts.

Figure 2.2. Model of Practice Context, Text Production, and Referent Circulation
**Material Production**

Dave produces his own means of production (i.e., production system) and documents those means, and the product of his work, in a laboratory notebook. The contents of his notebook—and the distillation of his work—can be used in any number of ways, but the primary objective of this text production process is to generate durable (immutable, mobile) knowledge related to the procedures involved in chemical synthesis. Knowledge, here, takes the form of both action and object: procedural knowledge and the materials produced. The notebook thus serves as a negotiated space where Dave can document his work and warrant the material sample as an epistemic outcome. I have been able to trace this relationship—between material procedures and textual integration—through the procedure of thin layer chromatography (TLC) and the visual inscription it produces: a TLC plate (see Figure 2.4).

*Figure 2.3. Context of Material Production and Textual Integration, Top View*
Figure 2.4 illustrates the situation I investigated as Dave (D) produced material samples, tested them through TLC, and rendered his procedures and outcomes in a laboratory notebook. The aim of this process is twofold: 1) to generate samples that can be characterized under controlled conditions, and 2) to generate a text that documents and warrants—using available semiotic resources, like the TLC plate—the sample as a knowledge object. The laboratory notebook specifically provided a means for me to analyze the relationship between the material and instrumental dimensions of production and the symbolic means through which Dave represents his work textually. This led, in turn, to what I call a “material” dimension of scientific writing and literacy that links the context of production to situation of use—a relationship that further exemplifies the constructive relationship between scientists and the knowledge objects they produce in and through their work.

Physics Experimentation

John produces his own means of production (i.e., experimental system) and communicates that production, and the outcome of his research, in a multimedia presentation. Knowledge, here, results from the technical work he performs in the laboratory with Morgan—i.e., the construction and enactment of the experiment itself—and the textual re-presentation of that work for a disciplinary audience at a national physics conference. I have been able to trace the relationship by focusing on the laboratory as a site of visualization that creates materials and sets up grounds for text production (see Figure 2.5). Visualization in the laboratory, I argue, enables John to
transform the material and technical dimensions into analyzable data; the visuals deployed in his text in turn provide a means to legitimate this visual production and thus the experimental method that John is presenting as a research finding.

Figure 2.4. Context of Experimental Visualization, Top View

Figure 2.5 illustrates a process through which John (J), working with Morgan (M), generates a visual image in order to provide himself with an analyzable data source. This process requires a great deal of technical work—e.g., constructing and arranging instruments, orienting the interface between sample and light source—that culminates in a so-called Fringe Image. Looking to the role of visuals in experimental practice—from notebook renderings to the Fringe Image to quantitative displays—has enabled me to
examine how John grapples with the material, technical, and symbolic dimensions of laboratory work and represents that work in a multimedia presentation. I argue here for a “visual” dimension of scientific writing and literacy that accounts for the non-linguistic means whereby scientists conduct their inquiry and represent findings to a disciplinary audience. Accounting for the production and use of visuals in scientific practice adds an important dimension to textual analysis: that is, in tracing the use of visuals from the laboratory to a public presentation highlights the rhetorical choices scientists make in communicating their work.

Theoretical Modeling and Simulation

Jordan produces his own means of production (i.e., computational system) and represents that production, and the product of his work, in the form of a research article. Knowledge, here, results from the mathematical work involved in constructing theoretical models, the computational work involved in creating and running simulations, and the technical work involved in orchestrating various hardware and software toward specific ends (see Figure 2.6). The outcome of this process is a simulation that Jordan can use to produce analyzable data. Similar to John, the method here is an object of interest insofar as it helps characterize the material in question. For Jordan, however, the material he is characterizing may not have a physical referent per se. Thus, while Dave and John are dealing with materials objects, Jordan is dealing with a different type of material reality: one that he models mathematically and simulates computationally.
Figure 2.5. Context of Theoretical Modeling and Simulation, Top View

Figure 2.6 illustrates the context in which Jordan (JN) conceptualizes, represents, models, and simulates materials as his object of study. My research has investigated the various ways in which he utilized writing, broadly understood, to visualize and carry out this work: for example, as a means to model his object of study mathematically, enact it computationally through a simulation, and represent it textually in the form of a research article. I have been able to trace this process by examining simulations as a way for Jordan both to test his theoretical models and generate data related to the computational system that he has created. I argue here for a “computational” view of writing and literacy as it is enacted as part of theoretical physics research and communication. Accounting for “writing” in this way offers an intriguing complement to research that examines writing in light of new media literacy.
Each of these practices has their own unique objectives. For Dave, this involves producing useable material samples; for John, this involves producing a method for characterizing material samples; and for Jordan, this involves producing a computational simulation for exploring the dimensions of material systems. Within each practice, I have found, are equally unique inscriptions—something akin to “outliers”—that scientists produce in order to generate data and to “index” their productive, experimental, and computational systems. More specifically, The TLC plate in Dave’s work enables him to confirm the validity of his sample as a knowledge object; the Fringe image in John’s work enables him to confirm the technical dimensions of his experiment and thus the method he has developed; and the simulation in Jordan’s work enables him to generate data that can be used to test his theoretical model. Looking to these “indexical referents” (my term) offers a way to connect the material, technical, and semiotic dimensions of laboratory work to the texts that scientists produce to document, warrant, and communicate their research (see Appendix A, Table A.4).

Table A.4 begins to show how each practice involves a discrete set of components, procedures, indexical referents, textual outputs, and what I call epistemic outcomes. The indexical referents are a key point of interest, here, because they provide a link between the tasks involved in laboratory work and the texts that circulate knowledge to various audiences (see Figure 2.7). Building on Latour’s (1993) concept of “circulating reference,” Figure 2.7 models the way in which each practice produces an

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14 I use the term “system” here to describe the apparatuses that Dave, John, and Jordan create to produce and characterize liquid crystal materials. This concept of system is fluid and dynamic rather than closed in the sense that the boundaries of each system often change. Either way, each scientists must hold his or her results and findings accountable to the means (i.e., systems) through which they were produced.
indexical referent and a text that, together, contribute to the group’s holistic knowledge related to liquid crystal materials. More precisely, these indexes provide a “frame of reference” for visualizing, objectifying, and analyzing various material and conceptual phenomena. Each index accordingly becomes, for the scientists involved in this study, a basis for interpreting the material, instrumental, and symbolic dimensions of their work; it also becomes a way to generate texts that enable the circulation of referential knowledge both in and outside the group.

For Dave, the TLC plate provides a frame of reference for the work involved in synthesizing chemicals and creating a material sample. More specifically, the procedure of thin layer chromatography, the output of which is a TLC plate, provides him with one way to confirm the validity of his sample. The plate also provides a link between material and text production insofar as it moves directly from the laboratory into the laboratory notebook (see Figure 2.8). In this way, it “indexes” a whole set of objects and relationships involved in production. Dave can “read” this network of relationships
through the TLC plate and the multimodal ensembles he deploys alongside them in his notebook. Chapter 3 examines this relationship in greater depth.

For John, the Fringe Image (hereafter Fringe) provides a frame of reference for interpreting the material and technical procedures that went into constructing and enacting the experimental system through which it is produced. It also serves as a visual datum and thus provides a link between visualization procedures in the laboratory and the way in which John transforms that work into a multimedia presentation (see Figure 2.9). The Fringe, however, unlike Dave’s TLC plate, does not get included in John’s presentation directly. Rather, it gets “absorbed” into a series of other visuals that perform particular rhetorical functions for communicating findings to a disciplinary audience. I discuss this relationship in greater depth in Chapter 4.

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15 By “absorbed” I mean that the Fringe gets measured, quantified, and transformed into graphic displays.
For Jordan, the simulation provides a frame of reference for interpreting the computational system through which it was produced (Figure 2.10). It is also a method for generating data related to a theoretical model. That data gets analyzed and rendered into various graphic forms and, eventually, included, along with a two-dimensional image of the simulation, in the draft of a theoretical manuscript. The simulation in this way provides a link between different forms of writing—e.g., programming code, linguistic script—*in situ* computational work, and textual integration. I discuss this relationship in greater detail in chapter 5.

![Figure 2.9. Simulation as Indexical Frame of Reference](image)

I will discuss each of these case studies in greater detail throughout the remainder of this dissertation. Yet there is a point I would like to make here: namely, that writing and text production in scientific practice can be traced through the construction of material, experimental, and computational systems, the enactment of procedures, the production of indexical referents, and the integration of those (and other) inscriptions into genre-specific texts. The output of this work, as I attempt to model below (see Figure 2.11), is a system that generates different types of knowledge related to the production
and characterization of liquid crystal materials. This model also begins to show “directionality” of texts: horizontally (starting with the material and technical dimensions of systems) and vertically (from the semi-private and idiosyncratic laboratory notebook to the more public multimedia presentation to the potentially more widely circulated theoretical manuscript).

Figure 2.10. Model of Text and Knowledge Production
IV. Discussion

Findings from this dissertation suggest that writing in scientific practice tends to involve a range of material, instrumental, and symbolic forms. Text production, I will argue, must therefore be understood in light of the material conditions, technical work, and semiotic resources that scientists bring to bear in their research and communication. The argument of my dissertation can be stated thus: How we understand literacy relies to a great extent on the way we understand writing as a mode of communication and as a situated rhetorical activity. For the physical sciences in particular, writing is a material, visual, and computational means of generating and coming to grips with objects—physical, conceptual—and for communicating research that investigates the various material, instrumental, and symbolic dimensions of those objects. Writing in this way is at once technical, rhetorical, and epistemic activity: it is all three of these insofar as it is involved in technical work that leads to knowledge outcomes that lead to the communication of those outcomes to specific audiences—from the laboratory to the conference hall to the scientific community more broadly. The remaining chapters of this dissertation are devoted to unpacking and teasing out the implications of this argument.
Chapter 3

Materiality and Modality in Chemical Physics Research:

The Laboratory Notebook as Locus of Technical and Textual Integration

I. Introduction

Chemists Hans Fredrich Ebel, Claus Bliefert, and William E. Russey, in their book *The Art of Scientific Writing*, emphasize to scientists the importance of written communication for sharing information, publishing findings, and, generally, taking part in the research that animates their respective fields. Among the types and contexts for writing the authors discuss—from reports to dissertations to journal articles—they pay early and detailed attention to the laboratory notebook, describing it as the “‘germ cell’ of the scientific literature” (p. 16). I mention this quote not just to reinforce what might be evident to many scholars of writing and rhetoric: namely, that writing is an essential component of scientific knowledge production and communication. What interests me here, rather, is how Ebel and his co-authors, through a biological metaphor, characterize the laboratory notebook as progenitor to a larger and more complex body of scientific writing. This is no trivial statement. It is a telling one, however, in that it speaks to the role texts play not just in the communication of findings but also in the seemingly mundane, day-to-day work of scientists at the laboratory bench.
This chapter, drawing on a yearlong study of writing in a liquid crystal physics research laboratory, explores just how and the extent to which texts, the laboratory notebook in particular, enable scientists to transform the material conditions of laboratory practice into durable *inscriptions* (Latour 1987, 1990) that document, warrant, and circulate research outcomes. Situating such texts in their contexts of production is not a new concept for writing researchers. Indeed, the field of writing studies has long been interested in exploring the relationship between everyday writing activity and the broader systems within which texts organize and reproduce local action (Bazerman 1997). This research has shown, among other things, that writing tends to be as diverse in form and function as the cultural settings within which it is enacted as a literacy practice: whether in local communities (Brice Heath 1983), academic disciplines (Geisler 1994; Haas 1994; Prior 1998; Russell 1997), professional workplaces (Haas and Witte 2001; Medway 1996; Spinuzzi 2003; Winsor 1999), or the biological and physical sciences (Bazerman 1988; Blakeslee 2001; Myers 1990). Still needed, however, are studies that investigate the production and use of writing that does not, as Witte (1992) suggests, “privilege linguistic systems of meaning-making” (p. 240). This is one reason why the scientific laboratory notebook strikes me as a compelling object of analysis: it is a recognizable text that has received little attention as a multimodal product and organizing force in scientific work.  

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16 Writing and rhetoric scholars have studied the laboratory notebook (e.g., see Gross 2006 and Campbell 1990 for analyses of Darwin’s notebooks), but this work has not explored the practices through which specific texts are produced and deployed in the context of scientific work.
I specifically focus in this chapter on a case study involving Dave, a chemist, the tasks he undertakes to produce materials for physics experimentation, and the notebook he constructs as a means to record and communicate his work. I warrant this focus on two grounds. First, the notebook illustrates the range of inscriptions scientists deploy in their technical work and textual documentation: from quantitative displays to naturalistic images to three-dimensional objects. Accounting for these inscriptions, I will argue, is a necessary move to understand what constitutes writing in the context of scientific practice. Second, analysis of Dave’s notebook in particular reveals how this text, in tandem with the technical work he performs, fulfills a dual objective: that is, it facilitates the production of material objects while conferring epistemic status on those objects through a holistic, multimodal rendering of materials, procedures, and outcomes. Tracing the way inscriptions move between the tasks of material production, on the one hand, and the tasks of text production, on the other hand, I demonstrate how material becomes textual and how the textual in turn shapes the way scientists conceptualize, produce, and warrant the material outcomes of their work.

II. Multimodal Literacy and Situated Text Production

Over the past two decades, the growing influence of new media technology has compelled many writing scholars to revise their approaches to research and teaching. And some have specifically turned to multimodality as a framework for theorizing the

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17 “Materials” in this context refer to synthesized chemical compounds that serve as “samples” for research. A “sample” is typically understood as a known quantity of some material that can be characterized through controlled experimentation.
multiple semiotic modes deployed in print and multimedia communication (Baldry & Thibault, 2006; Cope & Kalantzis 2000; Jewitt 2005, 2006; Kress 2000, 2003; Kress and Van Leeuwen 2001). This construct has proven especially generative in the writing classroom as instructors respond to students’ increasingly sophisticated knowledge of digital text production (Anderson et al. 2006; Devoss, Cushman, and Grabill 2005; Shipka 2005). Yet multimodality, while useful as an analytical tool and pedagogical resource, has not been adopted without scrutiny. In a 2005 special issue of *Computers and Composition*, for instance, Paul Prior suggests that neither researchers nor instructors “can account for multimodality and affordances without a focus on the whole of practice—on artifacts, activities, and people alike” (2005, p. 29). Prior hits upon an important point that, I would argue, embodies an approach Witte (1992) advances for situated writing research: namely, a theory of multimodality must account for the diverse contexts within which texts are used and produced if it is to have broad applicability as a framework for studying literacy as it is enacted in the world.

Witte’s “Context, text, and intertext” has been instrumental for theorizing writing as a situated, meaning-constructive activity. In this framework, context refers to the sites, and the situations, within which texts are produced and interpreted; text refers to the objects of production and interpretation; and intertext refers, broadly, to the means by which individuals come to understand texts in relation to other texts and utterances (see Bakhtin 1981; Kristeva 1986). This triad, Witte suggests, moves beyond a Saussurean theory of signs where meaning is realized through difference within a closed system and adopts, instead, a Peircian view where meaning derives from the writer or reader’s ability
to integrate context and text with his or her existing knowledge. Meaning in this way is not transmitted via pre-existing signs, or language in particular, but through active construction of signs within specific settings. This is one reason Witte does not privilege linguistic systems: these are but one way make meaning textually. Nowhere is this more apparent, perhaps, than in the physical sciences where multiple and diverse sign systems are deployed both in day-to-day research and in the communication of findings to expert and lay audiences.

A constructivist approach to writing and text, because it attempts to account for non-linguistic meaning making, is essential for studying writing and literacy in sites where multiple sign systems are the norm rather than the exception in textual communication. Medway (1996), for instance, presents a study of architects who utilize many forms of writing in their design work. Similar to Witte, he examines writing that does not necessarily take the form of extended discourse; he is most interested, however, in the “modes of operation in which the end is a new physical reality and the means is the construction of a written representation that will shape the fabrication process” (p. 474). Specifically, Medway examines how writing and other, visual modes enable architects to bring new conceptual realities into existence prior to, and apart from, any physical structure that may result from such conceptualization. This, for him, is one way to differentiate between writing as technical and writing as epistemic: that is, architectural writing/design does not just facilitate the production of buildings but actually brings new knowledge into the world prior to any attempt at technical construction. Informed by Medway’s work, the study I present here investigates how a notebook, in tandem with
laboratory work, functions as a technical and knowledge-productive form of documentation. My research extends Medway’s account, however, insofar as the notebook is less a “blueprint” for the production of material samples and more a means of visualizing, and thus warranting, the production process and its material outcomes. Writing in this case, I will argue, does more than bring conceptual realities into the world; it quite literally serves as a basis for confirming the existence of those realities through a process of multimodal visualization.

Haas and Witte (2001), in a study that investigates the production of an engineering standards document, also illustrate the relationship between texts and the material realities they purport to represent. Yet in contrast to Medway’s architectural designs, the standards document must be produced with a specific context in mind—the relationship between channel easement a river bank—and therefore must deal with an obdurate reality that, while represented in the text, exists apart from that text in a very real sense. The engineers must, then, through their writing, come to grips with the proposed easement and the existing embankment. The authors specifically examine the embodied nature of text production and how gesture enables the engineers to produce a successful document. While I am unable, within the scope of this chapter, to take up issues of embodiment, Haas and Witte’s work nonetheless provides a key point of departure for examining the relationship between text production, multimodality, and the material world. As they suggest, examining “representational processes can link studies of material and cultural conditions to the real-time processes and practices of individual writers and groups of writers” (p. 446). This is one major concern of the study I present here: that is, linking
the material conditions of everyday scientific practice with the material and symbolic production of the notebook as a resource for documenting and communicating that practice.

As a way to link context of production with situation of use in the workplace, Bracewell and Witte (2003) have proposed two constructs, tasks and ensembles, that help connect the particulars of *in situ* literate practice with the more abstract systems of activity within which that practice is embedded. Bracewell and Witte describe tasks and ensembles thus:

> We define the task as the set of goals and the actions that implement these goals, which are developed in order to achieve a solution to a complex problem within a specific work context…[T]he work ensemble, serves to link the task to social and material means that achieve the development and application of the solution in the material world. We define the work ensemble as the smallest group of people who collectively uses sign systems in conjunction with other tools and technologies to realize an appropriate solution to a complex problem within a specific work context. (p. 528, italics theirs.)

While a brief discussion of this piece oversimplifies a complex argument the authors make about writing, literacy, and human activity, focusing on tasks and ensembles as units of analysis helps explain how the notebook functions in the context of scientific work. More specifically, the notebook serves as a locus of integration for the tasks Dave performs: from the production of inscriptions included in the notebook, to the production of the notebook itself, to the general production of materials used in physics experimentation. This production process, understood via tasks and ensembles, offers a basis for exploring the material and symbolic dimensions of writing as it shapes and is shaped by scientific activity in this setting.
III. The Case of Material Production

This chapter focuses on the case of material production and examines, specifically, the way in which a chemist’s notebook functions in the documentation of technical procedures and in the legitimization of material samples as an epistemic outcome of technical work. While separation of material production from physics experimentation or theoretical simulation is arbitrary on some level—indeed, all are intimately tied together in the overall context of the group’s output—it is analytically useful to focus on materials production as a practice in its own right. First, the results from this case study help define what writing is in this site—a mode of communication that takes on various material and symbolic dimensions—and what writing does in this site—a means whereby texts and materials are produced and legitimated, often in tandem, as epistemic objects (Rheinberger 1997; see Knorr-Cetina 1999).18 Second, material production requires a form of specialized knowledge (chemistry) that differs from, yet is integral to, experimental and theoretical physics research in the group. Delineating these practices not only helps bound various research, spaces, and types of meaning making; it also helps make me a theoretical move from grounded qualitative inquiry to a more systemic understanding of chemistry and physics as scientific practices in the Institute.

Physicists in the group often create materials for their own experiments, but I focus here on Dave, a post-doctoral fellow with a PhD in chemistry and the only certified chemist in Dr. Maxwell’s employ. The bulk of Dave’s work consists of producing

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18 Rheinberger suggests that epistemic objects are “the material entities or processes—physical structures, chemical reactions, biological functions—that constitute objects of inquiry” (p. 28).
material samples for the group, for collaborators in the Institute, and for collaborators in other laboratories. Production of samples in this case is not just a material means to an experimental end; it is also an indispensible way to maintain professional relationships and contribute to a body of disciplinary knowledge within the liquid crystal physics community. Yet this can happen only if a minimum of two criteria is met. First, the end result of material production must be a “good” sample, one that is usable, testable, replicable, and, essentially, knowable; second, and following from the first criterion, the production process must be documented textually to confirm whether or not samples are indeed “good.” My research has examined the writing, visual inscriptions, and texts that are produced in and mediate this work.

IV. Methodology

Examining the relationship between the technical work and text production in a chemical physics research laboratory presented at least two challenges in my study. First, I had to identify and describe the range of inscriptions and texts that Dave deploys to synthesize and produce material samples; second, I had to identify the ways in which those inscriptions and texts relate to material samples as epistemic objects that can be further characterized through physics experimentation. Three methods formed the basis of my data collection procedures: observation, inscription collection and visual documentation, and in-depth interview (see Table 3.1). I discuss each of these methods in greater detail below.
Table 3.1
Methods, Aims, Outcomes, Analysis

<table>
<thead>
<tr>
<th>Method</th>
<th>Aims</th>
<th>Output</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>Observe Dave at work; document his practices; gain insight into the way in which visual inscriptions function as part of their inquiry and text (re)production.</td>
<td>Field Notes. ~150 single spaced, typed pages, and ~200 hand written pages, across three phases of inquiry: 6, 4, and 2 months.</td>
<td>Comparative analysis; open, axial, and selective coding across stages of inquiry. Theoretical memo writing.</td>
</tr>
<tr>
<td>Inscriptions</td>
<td>Collect inscriptions and texts Dave uses and produces in laboratory. Examine relationship between inscriptions produced in laboratory and deployed textually.</td>
<td>Hundreds of my own photographs, graphic renderings or Dave’s work; dozens of Dave’s photographs and renderings of his own work.</td>
<td>Comparative analysis; situate visuals in the laboratory in relation to field notes on laboratory work and analysis of textual output of that work.</td>
</tr>
<tr>
<td>Interviews</td>
<td>Collect Dave’s self-perceptions about writing and the role of writing in their work; collect language that (dis)confirms and checks my own analysis and hypotheses.</td>
<td>One interview with Dave for a total of ~45 minutes of talk.</td>
<td>Open, axial, and selective coding based on multiple passes through transcribed text. Comparison with procedures for data collection and analysis.</td>
</tr>
</tbody>
</table>

Observations

Throughout the first phase of my inquiry, I spent an average of ten to twelve hours per week making observations in a “chemical laboratory,” the space where Dave produces material samples.19 Observations take the form of field notes written in the laboratory that were later transcribed and supplemented with additional notes and

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19 This constituted under half the time I spent per week in the institute, on average, dividing my attention between the optics laboratory, offices, meetings, lectures, and so on.
theoretical memos. My initial strategy for taking field notes was to construct an inventory of observable inscriptions, texts, objects, and actions; through ongoing comparative analysis, coding, and theoretical sampling, I was then able to make more focused observations related to specific tasks, a move that enabled me to tease out relationships between writing, text, and the practice of material production. The first week I was in the laboratory, for instance, I observed Dave working in the chemical laboratory with his notebook laid out beside him. From a descriptive viewpoint, I was able to examine this text, which is produced in the laboratory, with other texts that are used in the laboratory but produced elsewhere. While a small distinction, it led me to develop categories that centered on the types of texts that mediated Dave’s work, especially those that are produced and/or used in tandem with material samples. I made a similar move with inscriptions produced in the laboratory that ended up in the notebook; doing so eventually led me ask questions about the relationship between inscriptions, for instance thin layer chromatography plates, and the manner in which they contributed to the notebook as a functional text. I discuss this relationship and analytical movement in greater detail below.

Visual Documentation and Inscription Collection

In addition to taking field notes, I also produced and collected visual and textual inscriptions. I did this for two reasons. First, I wanted to document the work scientists were doing so that I could study that work on my own, outside the laboratory; this was crucial for gaining a foothold on the scientific concepts that inform scientific work in this
site. My method involved producing my own graphic renderings and taking digital photographs (see Appendix B, Figures B.1-B.3). This method, akin to visual or multimodal ethnography (see Pink 2007; Dicks et al. 2006), was useful for describing and analyzing the often ephemeral inscriptions recorded on whiteboards and the often complex chemical and physical processes that are enacted in time and space. Second, I wanted to have a material record of the work that scientists were producing. Toward this end, I began collecting various inscriptions, texts, and material objects that the scientists offered to me (as copies) or that I photographed on my own. These included visual displays, drafts of papers, notebooks, photographs and images, photographs of material samples, and various other inscriptions and texts involved in scientific research performed in this site. Essentially, the production and collection of visual inscriptions offered a useful means to analyze 1) what inscriptions look like, the forms they take, and the media through which they are realized; 2) how texts are composed, through inscriptions, over time/space; and 3) how texts and inscriptions ultimately mediate and circumscribe the practice of material production.

*Interviews*

Interviews in this study served two distinct but interrelated purposes. First, they enabled me to supplement my analysis through recorded talk. Having a record of scientists’ own language proved essential for investigating the ways in which they perceive their work and writing as part of that work. Second, interviews enabled me to

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20 Figures 3.1-3.3 offer a first-person view of the chemical laboratory as a research space (for Dave and for me).
learn about scientific concepts. Similar to visual inscriptions, I could take interviews home, transcribe them, and study the practices that form the basis of scientists’ inquiry. Generally, because interviews were more open-ended than formal, I was able to collect discourse about a variety of subjects that, while directed by my questions, gave way to participants reflecting and commenting on their research and writing. This was a helpful tactic given my aim in conducting interviews: that is, because I used them to supplement my analysis, I had different questions for different people. So when interviewing Dave, for instance, the chemist largely responsible for the production of material samples, I could ask questions related to his process, his textual documentation practices, and the relationship between technical work and material outcomes.

V. Analysis and Results

In this section, I examine how Dave’s notebook functions in the day-to-day work of material production. I make this point in three ways. First, I discuss how I came to focus on the notebook in light of the constellation of other texts deployed in the laboratory; second, I examine the range of inscriptions produced in the laboratory and how they are integrated into the notebook; and third, I show how, through this integration, the notebook legitimizes material samples as epistemic objects. I make this final move, specifically, by examining the technique of thin layer chromatography (TLC) and how the result of this technique, a TLC plate, links the notebook with material processes Dave performs in his technical work: that is, the plate is both a material result of chemical processes and a symbolic inscription that does textual work. Through
analysis of the process by which a material object becomes textual, I trace the relationship between the notebook, the tasks involved in synthesizing and testing materials, and the general practice and outcomes of material production.

Early in my study, I observed a great deal of action involving the notebook as a recognizable text (see Appendix B, Figures B.4-B.6). I observed, for instance, that Dave would have this book open next to him as he prepared raw chemicals and synthesized them into compounds. The task in this case would be fairly methodical: He would have a “recipe” for his synthesis, one that came from his notebook, a so-called recipe book, a journal article, or some combination of texts; he would weigh out the individual substances; he would combine the substances in a vial or some other receptacle; he would perform a technique to mix substances in order to synthesize them and form a compound; and he would, finally, attempt to characterize this compound using different techniques, for instance thin layer chromatography or nuclear magnetic resonance spectroscopy. While performing these tasks, Dave would typically record his steps in the notebook either by hand with a pen—using inscriptions that ranged from linguistic script to schematics to chemical structures—or by taping in print-outs from word processing or other scientific software programs after his work was completed in the laboratory (see Appendix B, Figures B.7 & B.8).

The task in this case, one which the notebook helps address, is to record processes and procedures so that the output of Dave’s work—a material sample—can be checked against the textual record he has produced.

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21 Figures B.4-B.6 offer a first-person look at how the notebook functions *in situ.*

22 Figures B.7-B.8 offer a first-person look at the different inscriptions Dave uses to document his work.
Observing simple tasks such as synthesizing materials and recording steps in a notebook turned out to offer critical insight into the relationship between text production—the notebook itself—and material product—a sample that would travel into the optics laboratory, or some other space, where it could be further characterized (see Appendix B, Figure B.9). I was able to trace and thereby come to grips with this relationship, first, by observing the notebook as a mediating artifact and outcome of Dave’s work, and, second, by examining the individual inscriptions through which the notebook was constructed.

Tracing the inscriptions, for instance, many of which are produced apart from the notebook itself, led me to focus specifically on those “outliers,” like TLC plates, that were not immediately recognizable as forms of writing or visual display (see Appendix B, Figure B.10). This was a logical step for me: to understand scientific “writing” meant accounting for those textual forms that, while seemingly atypical, were regularly deployed as part of Dave’s meaning making processes in the laboratory (see Figure 3.1 below). Figure 3.1 depicts Dave’s research space and attempts to illustrate the relationship between him, TLC as a procedure, and the TLC plate as an inscription that gets integrated into his notebook. The TLC plates specifically led me to inquire into the tasks through which they were produced; learning about thin layer chromatography as a technique in turn brought me back to the notebook where I could examine how the TLC plates realized and/or embodied particular meanings in themselves as well as in relation to other inscriptions deployed in that graphic space.
Most texts found in the chemical laboratory provide a necessary resource for the day-to-day tasks involved in the work of normal science (see Kuhn 1996) and are designed to address particular problem situations in the laboratory. The methodical work of materials production, for instance, demands technical precision and conceptual clarity for the work to be completed efficiently and well; it also demands that the researcher have durable and portable resources for undertaking and recording the processes and outcomes related to his or her work (See Table 3.2).
Table 3.2
*Texts, Production and Use, Relation to Material Output*

<table>
<thead>
<tr>
<th>Text</th>
<th>Production and Use</th>
<th>Relation to Material Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Notebook</td>
<td>Produced in the lab through handwritten sign systems, digital printouts, and three-dimensional objects. Print resource.</td>
<td>Holistic reference that confirms the validity of material samples Dave has synthesized. Produced across time and space, this text is the primary source of documentation and serves as a record of Dave’s work.</td>
</tr>
<tr>
<td>Recipe Book</td>
<td>Used in the lab; may be revised based on the work Dave records in his notebook. Print resource.</td>
<td>Reference that provides procedural knowledge for synthesizing materials and producing samples. Similar to the notebook, but does not record successes and failures of work.</td>
</tr>
<tr>
<td>Manuals</td>
<td>Used in the lab, usually in relation to equipment and instruments. Print resource.</td>
<td>Reference for constructing equipment and instruments used in the practice of materials production.</td>
</tr>
<tr>
<td>Catalogs</td>
<td>Used in the lab to order chemicals, equipment, and various instruments. Print and online resource.</td>
<td>Reference for ordering raw materials that will be transformed into samples and for ordering instruments and equipment that help enable that process.</td>
</tr>
<tr>
<td>Journal Articles</td>
<td>Read/Used in the lab. Print and online resource.</td>
<td>Reference for envisioning, checking, and supplementing work on materials.</td>
</tr>
<tr>
<td>Website</td>
<td>Produced in office based on notebook entries. Digital resource.</td>
<td>Dissemination of work related to material samples and procedures. Similar to notebook in describing procedures and outcomes; different in the material means it draws upon for doing so.</td>
</tr>
<tr>
<td>Labels</td>
<td>Used and produced in the lab. Print resource.</td>
<td>Identification and dating of materials and various processes.</td>
</tr>
</tbody>
</table>
Inscriptions

Inscriptions serve a similar purpose as texts and can be linked to them in different ways. First, one can look at a text, for example a notebook, and examine the inscriptions deployed in that graphic space; this is one entry point for understanding the notebook as a durable, readable document. Another place to begin is to examine the ways in which inscriptions are produced and deployed as part of tasks. This means, for instance, that a visual TLC plate (an inscription) produced through the technique of thin layer chromatography (a task) is an object in itself that has meaning given the task through which it was produced. Yet, this meaning is only partial; for once the inscription gets integrated into the notebook, it becomes part of different multimodal ensembles (see Kress and van Leeuwen 2001) where it takes on new meaning in relation to other inscriptions. In this case, the product of thin layer chromatography, the TLC plate, is a sign that connects to, and is the output of, actual procedures and techniques that Dave performs in time and space; those procedures and techniques are inscribed in the notebook through objects, in this case the TLC plate, that construct particular meanings both materially (as objects produced) and textually (as objects integrated with other inscriptions). Linking inscriptions to tasks enabled me to trace the relationship between technical documentation and technical work as both are brought to bear on the production of materials and the notebook itself (see Table 3.3).
<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Role in Task</th>
<th>Relation to Material</th>
<th>Textual Affordance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Linguistic Script (alpha numeric)</strong></td>
<td>Document procedures, integrate inscriptions textually in notebook, label materials</td>
<td>Descriptive Depiction. Provides a link between scientists, materials, procedures, and output.</td>
<td>Durable means of integrating and re-contextualizing methods, materials, and various inscriptions.</td>
</tr>
<tr>
<td><strong>Graphs (Visual Displays)</strong></td>
<td>Product of analysis, taped into and hand drawn in notebook</td>
<td>Relational Depiction. Shows relations as a product of some factor.</td>
<td>Quantitative visualization.</td>
</tr>
<tr>
<td><strong>Photographic Images</strong></td>
<td>Record procedure and/or results. Taped into notebook.</td>
<td>Material Depiction. Relates to outcome (temporal).</td>
<td>Naturalistic visualization.</td>
</tr>
<tr>
<td><strong>Formulas</strong></td>
<td>Describe materials used and produced; taped and handwritten into notebook</td>
<td>Procedural Depiction. Relates to raw materials.</td>
<td>Chemical visualization.</td>
</tr>
<tr>
<td><strong>Chemical Structures</strong></td>
<td>Describe materials used and produced; taped and hand drawn in notebook</td>
<td>Procedural Depiction. Relates to synthesized compounds.</td>
<td>Structural visualization.</td>
</tr>
<tr>
<td><strong>Thin Layer Chromatography Plates</strong></td>
<td>Product of procedure; taped into notebook</td>
<td>Procedural Depiction. Provides a way to check procedure and outcome.</td>
<td>Material visualization.</td>
</tr>
<tr>
<td><strong>Spectra Displays</strong></td>
<td>Product of procedure; taped into notebook</td>
<td>Procedural Depiction. Provides a way to check procedure and outcome.</td>
<td>Quantitative visualization.</td>
</tr>
</tbody>
</table>


**Texts and Inscriptions in Action**

Looking at the notebook offers a rich sense of what scientific writing and meaning making looks like in this site. Yet looking to the notebook alone misses out on a great deal of technical work that goes into producing inscriptions for the purpose of documentation, characterization, and legitimization of material samples as epistemic objects. To add to this descriptive account, I thus examine how the notebook connects, via the TLC plate, with specific tasks that are integral to successful material production. Doing so lends insight not only into the textual integration of various inscriptions but also into the ways inscriptions and texts mediate, emerge from, and thereby inform the construction of materials objects and conceptual realities in this site.

**The Laboratory Notebook**

As a functional text, the notebook does an undetermined amount of work in the context of scientific inquiry. Here, however, I focus on three points of interest. First, notebooks are often composed by a single person though they just as often record the outcomes of collaborative work. That works gets distilled into a series of procedures, visual representations, and written descriptions so that the resulting text, while stylistically related to the person who composed it, actually moves away from individual action and description and toward the processes and methods that inform and warrant that action. This, I would argue, constitutes a move to “objectify” the process and place emphasis on the “known,” that is, that which is document-able and replicable.
Second, even if a notebook is composed by a single person, it is designed so that scientists who are familiar with the subject matter could use it as a reference for themselves. The notebook in this case is a durable and conventional text that, insofar as it “objectifies” the production process, invites other readers into that process as if they could follow the same procedures and get the same results. This is, perhaps, a key function of the notebook: it enables replication of experimental processes, and, thus, provides other scientists with a means to re-produce procedures either to obtain the “same” results, or, conversely, to check those results against their own methods and procedures for obtaining them.

Third, as a genre the notebook serves a dual function insofar as it organizes activity but is also the product of that activity. In other words, there is a convention to keeping a notebook, and there are, accordingly, reasons to expect that the notebook itself structures social action (see Miller 1984). Yet no two notebooks that I have seen in the laboratory appear the same. This is due, in part, to the nature of the work—from chemistry to physics—but also to the way that the notebook functions as an individualized discursive (and non-discursive) space for recording, rendering, and documenting a host of procedures, objects, and outcomes.

For Dave in particular, the notebook provides a space for recording the materials, procedures, and outcomes of his work. The notebook in this way serves as a reference that can be examined at length either during or after its production to determine whether and how a specific outcome has been achieved. In what follows, I illustrate this process and focus specifically on the technique of thin layer chromatography in order to
demonstrate how inscriptions become part of the notebook, how the notebook in turn re-contextualizes inscriptions, and how, ultimately, each contributes to the production of material samples. TLC plates provide a useful object of analysis because 1) they are the material and symbolic result of a technique that helps identify the content of samples; 2) they are part of an interpretive process whereby Dave comes to understand the material as an epistemic object; and 3) they are part of a notebook that draws together the material and technical conditions of the laboratory into a durable and mobile textual space.

**Thin Layer Chromatography**

Thin layer chromatography is a technique chemists use to identify the character and number of components in a synthesized compound. For Dave, this is a central means for examining whether the material he creates turn out to be what he expects it to be— one of his primary objectives as a chemist working in the laboratory: “you want to make sure that what you say [the material] is is what it is” (Transcript, p. 2). While somewhat abstract on the face of it, Dave’s statement is aptly describes a common part of laboratory life. As Latour and Woolgar (1986; see Latour 1987) have discussed, inscriptions move the scientist’s attention away from the material object of study but, in doing so, enable him or her to achieve a greater understanding of that object. For Dave, the TLC plate draws his attention away from the material sample and becomes a way to interpret, and thereby understand, the material in a more precise way. The procedure itself is fairly typical in chemists’ work and involves adding a synthesized compound to the TLC plate
and examining the way it separates (see Figures B.11-B.13). Dave describes the procedure thus:

Dave: So...you have a thin layer of sand, but it’s not actually sand; it’s very small silicone oxide particles glued to a surface, metal or glass. And if you put a small drop of a chemical reaction at the bottom, and if you put it in, and then take that piece of paper—it basically looks like a piece of paper—and you put it in a jar with some solvents such as water, or in alcohol, or Toluene, or gasoline, or something....basically it will migrate on the surface of it. So, I’m trying to think of something analogous, if you take a newspaper, and you spill some water on it, you will notice the ink start to smear out. Well, the way the TLC is set up, is that instead of smearing out, the chemical will start to migrate toward the top of the small piece of paper. And, different chemicals will migrate at different rates. So as you go along, you can see is, do I have two, three, or four different chemicals in my mixture, or do I have just one chemical? And you can also identify which chemical is which using the TLC plates. So if you imagine [...] you want to make some chemical, and you have these two starting materials that you want to connect together, and then you have your product. So on a TLC plate—let’s say it’s a one inch wide TLC plate—you put a tiny drop of the one starting material on the left hand side, a tiny drop of the other material on the right hand side, and then hopefully your product in between them.

CW: Product is what?

Dave: The final reaction. So you mix the two together, you’re hoping to connect A and B together to make C, so A is on the left hand side, B is on the right hand side, and hopefully C is in the middle. Then you put this in a development chamber, and the things migrate up the surface of the TLC plate, and hopefully that chemical A on the left hand side will go one quarter of the way up, chemical C [sic: meaning B] will go, let’s say, three quarters of the way up, and your final product, you hope, maybe, and this isn’t always the case, will be in the middle halfway up. And you can also see, OK, if everything’s gone perfectly, in the middle, all of chemical A and all of chemical be are reacted so you won’t see any of chemical A or chemical B left because they have been consumed, just like the gas in the car is consumed: you have an empty tank. But if the reaction has not run completely, then you can see if there is some leftover A, or leftover B, and that will also show up. So that’s a quick—it takes about five minutes to do—it’s a quick check to see if your reaction is going or not. And that’s what chemist’s commonly use.

Several points can be taken from this excerpt. First, thin layer chromatography enables Dave to engage with material samples and interpret their molecular content.

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23 Figures 3.12-3.14 offer a first-person view of this process.
Such techniques are necessary for his work in that their visual outputs enable him to come to grips with what he cannot observe through normal human perception. This in itself suggests how representations are a constructive part of his work, or, at least, a means by which he comes to understand his object of study: that is, one can examine the material output of thin layer chromatography as a way to gain insight into the task, the means by which it is undertaken, and the way in which it is documented textually through the TLC plate. This is not to suggest that the work of science is like any other interpretive process; it is to suggest, however, that scientists themselves are adept at creating and using tools—paper, otherwise—that enable them to probe various dimensions of the material objects they produce and study in their work.24

I would also point out how Dave explains the process of thin layer chromatography to me as a non-scientist. During the interview, we sat looking at his notebook and the TLC plates taped onto the page. Prompted by my questions, Dave used the notebook and these inscriptions to describe, through analogy, a material process that he has completed many times. Specifically, he talks about newspaper and draws a connection to the materiality of the plate itself: it is a surface, like a newspaper is a surface, but it is different in its materiality and thus in its effects. The first has ink on paper, and the second has silica on a piece of glass. He also suggests the way in which the reaction works on the plate itself. Like an engine burning gasoline, the chemicals are “consumed” and leave a residue that he can interpret. This interpretation is part of Dave’s literate performance: one that involves the act of inscribing on the TLC plate, first

24 See Klein (2001) for a discussion of “paper tools” in chemistry.
of all, but one that also involves an interpretation, or reading, of the plate once the
reaction has taken place. The reading in this case is a highly trained skill that few people
outside the profession would be able to understand. Yet for Dave, this is part of his daily
work as a chemist: examining the relationship between materials and the techniques he
deploys to test them. The TLC in this case is the embodiment of a technique as well as a
site of reaction; as such, it quite literally represents the material sample—or some part of
it—while revealing necessary details about the sample’s content. In other words, the
sample is applied to the plate as the sample, but the result—what Dave reads—is less the
sample than an interpretation of the relationship between the sample, the chemical, the
plate, and Dave’s experience that tells him how to interpret what he sees.

TLC and Textual Integration

While the TLC plate serves as a site of interpretation for Dave, it is not an end in
itself. Indeed, only when the plate is integrated into the notebook does it take on the
more holistic meaning that enables Dave document his process fully, and, thereby, create
a durable resource for communicating the outcomes of his work. Knowing something
about TLC as a technique and the TLC plate as an outcome of technical procedures, it is
now possible to move into the notebook itself as a way to see how that work is
documented textually. The move, here, is to trace how the material becomes textual and
how the textual in turn becomes symbolic, at least in part, through its materiality.

Consider a typical page from Dave’s notebook (see Appendix B, Figure B.14). A
simple (or not so simple) description of this page would reveal a number of inscriptions
Dave deploys as part of his documentation practices. It would include, from top left, linguistic script in the form of the notebook font, handwritten linguistic script, chemical structures, a list of starting materials, compounds, and procedures, a TLC plate, and more handwritten linguistic script. Not every one of these inscriptions has a “life of its own” outside the notebook like the TLC does. Even so, these inscriptions function together as an ensemble where meaning is realized through but is greater than the sum of its parts (see Hull and Nelson 2005). The affordances of each inscription, in this case, rely not only on the way they function apart from or are inscribed in the notebook; they also rely on the way they function together based upon their materiality and semiotic potential as inscriptions deployed in the same graphic space.

*Notebook Inscriptions*

Linguistic script serves many purposes in the notebook. Most obvious, perhaps, is the way it integrates (see Harris 1995, 2000) the other semiotic modes inscribed in the text. For instance, Dave includes a printout of the procedures by which he deployed the materials involved in his synthesis. This step-by-step rendering provides a durable means for explaining his activity and contextualizing other semiotic resources. Compare this with the chemical structures pictured near the top of the page. This inscription ostensibly has a direct relationship to the material itself and visualizes how different substances might synthesize under particular conditions. Representing those structures linguistically would be less efficient than rendering them as a visual structure in the sense that, first, a linguistic description would take up more space, and, second, the linguistic description
may not provide as useful or immediate an image as the conventionalized structures themselves. Each inscription, then, affords something for the task at hand. In this case, the chemical structures provide a means to visualize the materials—and how they might synthesize—at a molecular level; the linguistic script, however, complements this visualization through a more descriptive record of the procedures undertaken in the actual synthesis.

Once Dave gets to the procedures, he returns to linguistic script and forms a list. (He uses a different medium here as well. Print documents function, he says, to keep his notes clean.) While perhaps an obvious move, it leads toward a concept of modal affordance: As he said in his interview, “The idea of the lab notebook is, it’s supposed to be that, if I were to die tomorrow, meet my untimely demise, someone should be able to use the lab notebook to repeat my work” (Transcript, p. 4). This means, in part, that the information must be durable in the sense that someone else can read and, over time and space, understand specific procedures. Visual modalities—e.g., chemical structures—might prove useful but do not in themselves contextualize procedures in the way that linguistic text can. Such visuals do, of course, contribute to the overall textual meaning: in this case, the visual structure illustrates what one can expect to happen at a molecular level. This affordance in turn enables Dave, or any trained reader, to link the “known”—e.g., the starting material—with other “knowns”—e.g., the TLC plate—that lead to an overall rendering of the production process and its material outcomes.

In addition to the procedural documentation, which shows the materials used, how they were synthesized, and the techniques to which they were submitted, Dave includes
the TLC plate as evidence of the technique itself. The TLC plate in this way is operating at multiple levels at once. First, it represents a conventional process whereby materials are characterized; second, it represents the product of that characterization that is both a means of testing and a textual inscription; third, as an inscription, it integrates with other inscriptions in the text, in this case, the chemical structures, the linguistic procedures, and so on. This is a key connection between the notebook, as text, and the practice of thin layer chromatography: the inscription used to characterize a sample in time and space becomes part of an ensemble where that time and space is rendered textually as a way to confirm that the sample is what he expects it to be.

The notebook as text thus functions in at least two significant ways. First, it is a means for documenting technical procedures. This occurs through multiple inscriptions, some of which are the direct result of procedures—e.g., the TLC plate—and some of which are added into the notebook directly by Dave as a way to contextualize those procedures and outcomes in relation to the overall process of textual and material production. Second, the notebook, once produced, becomes both a resource for future research—a durable product that other scientists can utilize—and a means whereby Dave can show that the product of his work is what he expects it to be. Said another way: once Dave has produced a sample, and once he has documented that process textually, he has two resources for confirming that he has done “good” work. The sample, on the one hand, constitutes the material output that can be taken up by physicists and further characterized through their experimental systems; the notebook, on the other hand, constitutes a durable textual resource that can be used by chemists or physicists either to
confirm existing samples as epistemic objects or to produce more samples based upon replicable procedures.

Worth noting here is that the notebook provides for the possibility of replicating material production. In this way, it serves as a key resource for producing more materials as well as distributing the knowledge gained from Dave’s work to scientists working in other laboratories. Text production in this sense serves the purpose of documenting laboratory work so that the work itself—procedurally, materially—can be understood within a framework of existing knowledge; in another sense, text production is the means through which scientists can confirm their work as scientific insofar as it is rendered into a series of methodical procedures, like thin layer chromatography, and outcomes, like the TLC plate, that can be brought together into the notebook and referred to at later points in time.

Figure 3.2 (below) provides a simple model that attempts to illustrate these relationships. On the left is Dave, a scientist, and on the right is the text that he produces to document and confirm the material output of his work. Between scientist and text are the different objects, processes, and steps involved in synthesizing (SYNTH) and testing materials and integrating findings into his notebook. The arrows depicted in this model signify the recursive nature of this process: that is, the setup, synthesis, TLC procedure, and TLC plate together provide Dave with material and semiotic resources for recording his work textually; the text in turn gives context to his work and provides a durable resource for confirming the validity of his procedures and the materials he produced.

25 This also occurs via the Web space Dave has created for disseminating his and the group’s expertise and general work related to liquid crystal materials.
While this model oversimplifies a highly complex and often idiosyncratic process, it does begin to show the integrated relationship between material and text production in Dave’s laboratory work.

VI. Discussion and Implications

Examining the relationship between Dave, his notebook, and the practice of material production illustrates both the materiality of literate practice and how non-linguistic modes play a key role in scientific meaning making. Medway’s (1996) work, discussed at the outset of this chapter, can help explicate this relationship. The architects in his study bring new conceptual realities into the world prior to the physical structures their designs would help construct. The scientist in my study, however, performs something of an inverse move: that is, he literally brings new materials into the world—ones that do not occur in nature—while confirming their material and conceptual
“reality” through a series of technical procedures and textual documentation practices. While Dave does have a “blueprint” for creating material samples, the notebook itself is not just a set of guidelines. Indeed, it is a dynamic text that is produced in tandem with technical procedures. Examining how the technical and the textual are connected through the TLC plate, I have shown how this scientist visualizes, interprets, and visually renders his work into a durable resource for himself and others. This is a complex literacy practice that is best understood by looking not only at the texts scientists produce but also at the way those texts are implicated in the technical and knowledge-productive work they perform.

This study contributes to writing scholarship in at least three ways. First, investigating text production in a scientific context reveals how written and visual inscriptions are involved in specific, goal-oriented activity. In this case, Dave, a chemist, uses his notebook to document and visually represent technical procedures that enable him to warrant the material output of his work. Tracing the relationship between technical work and technical documentation shows how texts in this site are not just the product of a discourse-based literate performance but of a complex, distributed process involving specialized knowledge—technical, scientific—that takes years to learn and develop. Understanding literacy in this way is a positive move to account for the contextual factors involved in individual and collaborative acts of meaning making. More specific to a laboratory setting, accounting for the relationship between technical work, textual documentation, and scientific knowledge highlights a dynamic process
through which meaning is negotiated and constructed semiotically as much as it is realized through a closed system of signification.

Second, studying multimodal texts like the laboratory notebook as part of scientific practice complements and helps extend research that focuses on texts alone as units of analysis. Multimodal frameworks developed by Kress (2000, 2003) and others (see Baldry and Thibault 2006; Kress and van Leeuwen 1996, 2001; Lemke 1998) do provide useful and necessary insight into the ways in which meaning is made and communicated through multiple semiotic modes; yet a focus on texts without a focus on the practices through which they are produced offers only partial insight into the meaning(s) they convey. Consider once again the TLC plate that Dave integrates into his notebook. As an inscription, it offers distinct affordances for documenting the procedures involved in chemical synthesis: namely, by providing a tactile object that can be integrated alongside other inscriptions and semiotic modes deployed in the same graphic space. In this way, it enters into a discourse that involves other, discipline-specific forms of representation such as chemical structures and visual spectra. More than that, though, the TLC plate indexes a procedure that is used to confirm material samples as epistemic objects. Examining this inscription textually ultimately offers insight into what three-dimensional objects afford for meaning making and communication; what such analyses do not necessarily uncover, however, are the complex technical strategies and techniques through which these inscriptions are produced and, thus, how they can be interpreted in light of the broader tasks, practices, and discourses in which they are deployed in the field of chemistry.
Finally, situating laboratory notebooks as part of Dave’s work offers insight into scholarship that attempts to teach, research, and, generally, theorize the production and interpretation of multimodal texts in technical and scientific contexts. First, examining multimodal text production in specific settings highlights the problems to which texts respond—e.g., determining the content of a material sample—and the semiotic resources that scientists (in this case) deploy to address those problems. Rather than the text being a target object, as is the case in much classroom teaching, texts are instead situated in relation to broader activities and practices in which they perform key functions. Second, scientific writing and text production often involves the “accommodation” (see Fahnestock 1985) of information to different audiences: whether expert or lay public. How scholars of writing studies understand this communication—and potentially help facilitate it—relies to a great extent on how we understand the modes through which it takes place and what those modes afford, and what they communicate, for the people using them to construct and disseminate knowledge. Likewise, how non-experts in general perceive and understand technical and scientific information relies to a great extent on the way in which they understand not only content per se but also how that content is shaped by the modes through which it is constructed and communicated. Moving beyond a focus on linguistic discourse, as I have attempted to do in this chapter, ultimately helps to account for the range of signification practices that experts deploy in their work and, thus, the way in which technical and scientific information can be communicated efficiently and well.
Chapter 4

Visualization and Text Production in Experimental Physics

I. Introduction

Luc Pauwels, in the opening chapter to his edited collection *Visual cultures of science*, emphasizes the centrality of visual representation to scientific research, communication, and knowledge production. One aim of this volume, he suggests, is to outline a framework for scientific visualization that accounts for the “complex interdependencies that exist between the nature of the referent, the social, technological, and cultural context of production, the choices with respect to medium and style of representation, and the purposes and uses that need to be achieved” (p. 24). Pauwels tends to focus his efforts not on the discursive output of scientific research—e.g., images found in published articles—but rather on the processes through which visuals are used and produced as part of *in situ* representational practices. Taking this approach, he argues, provides grounds for exploring what visuals afford in context and how, accordingly, they are imbued with meaning when assembled textually. While Pauwels does not explicitly discuss text production as part of this framework, his approach nonetheless raises a provocative question for writing research: namely, how does the
practice of scientific visualization relate to the function and production of multimodal scientific texts? 26

Answering this question involves more than close rhetorical analysis of visuals or scientific documents alone. Indeed, it requires that I venture into the spaces where scientists conduct their work: the laboratories, offices, meeting rooms, conference halls, and other sites where inquiry becomes visible and scientific texts take shape. Such an undertaking responds to and builds on two diverse yet related bodies of scholarship. The first analyzes the role of visuals in scientific discourse, and the second examines the role of visuals in laboratory practice. 27 While diverse in their aims, theories, and methods, each of these scholarly traditions has looked to scientific representations—e.g., bubble chamber images, brain scans, molecular structures—as a way to unveil the social, rhetorical, and sometimes political dimensions of science as a material and cultural practice (see Lynch and Woolgar 1990; Galison 1997; Pickering 1995). What these scholars have yet to explore fully, however, and what I am interested in investigating here, is how and the extent to which in situ visualization informs the process of text production in a modern scientific workplace.

This chapter presents a case study involving two physicists, John and Morgan, and the visual inscriptions they deploy in their experimental research and communication. Observing these scientists at work has enabled me to accomplish two related objectives:

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26 Following Pauwels (2006; see Trumbo 2006), I define scientific visualization as the “complex processes through which scientists develop or produce (and communicate with) imagery, schemes, and graphic representations, computer renderings, or the like, using various means (ranging from simple pencil on paper to advanced computers or optical devices) (p. 1). This definition is more inclusive than exploring the concept of visualization according only to computational work.

27 I discuss this scholarship below and explain its potential value and limitations for the study I present here.
first, to examine the production and use of visual inscriptions as part of in situ laboratory work, and second, to investigate the way in which visual modes—e.g., schematics, photographs, animations—are used to document and communicate that work to a disciplinary audience. Investigating the whole of this practice provides insights into the rhetorical choices scientists make when representing their research and, thus, what (and how) different semiotic resources afford for the related tasks of text and knowledge production in the physical sciences. I ultimately argue that looking to the relationship between visualization and text production in scientific practice offers an important dimension to research that examines scientific meaning making through more formalized methods of textual analysis.

The structure of this chapter is as follows. First, I discuss scholarship that has examined the role of visuals in scientific research and communication. Second, I discuss the setting and participants involved in this study. Third, I explain the methodological and analytical procedures through which I studied the relationship between visualization and text production in a physics research setting. Finally, I illustrate how the study of visualization in laboratory practice can help to contextualize the choices one scientist in constructing a multimedia text for presentation at a national physics conference. I conclude this chapter by discussing how site-based research on scientific text production sheds light on the material, technical, semiotic, and rhetorical dimensions of scientific communication.

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28 I differentiate between “visual inscription” from “visual mode” in the sense that, for the sake of analysis, all inscriptions are visual but convey information through different modalities (e.g., schematic, photographic, etc.). In this chapter, I also use the terms “visual” and “visual inscription” to reference inscriptions that are not script-based (e.g., linguistic, computational, mathematic).
II. Writing, Inscription, and Scientific Text Production

Writing scholars have often explored how texts function as an organizing force and point of contact between scientists, scientific organizations, and various publics. Diverse in scope, this scholarship has generated studies related to the historical development of scientific genres (Atkinson 1998; Bazerman 1988); expert composing practices (Berkenkotter and Huckin 1995; Rymer 1988); use of analogy (Gibson 2008; Graves 2005; Little 2008); and the rhetorical shaping of information for expert, lay, and interdisciplinary audiences (Blakeslee 2001; Fahnestock 1985; Myers 1990). Scholars have also examined the ways in which non-linguistic systems shape the logic of scientific claims and thus the means whereby scientists lay claim to the knowledge they produce (Arsenault, Smith, and Beauchamp 2006; Fahnestock 1999, see 2005; Gross 2006b; Gross, Harmon, and Reidy 2002; Richards 2003). These scholars have specifically generated useful insights into the role of visuals in published or soon-to-be public texts. The importance of this work notwithstanding, however, research in the field of writing and rhetoric studies has yet to examine the contexts within which the very substance of scientific texts—e.g., images, graphs, schematics—are produced and take shape.

Yet exploring the role of visual inscription in scientific work is not an uncharted area of study. Bruno Latour, for example, is one of the most well-known proponents of “laboratory ethnography,” a method of investigation designed to explore how scientific claims are made, how “black boxes” get closed, and how one can “swim upstream” to explore the processes of inscription and reification through which scientific knowledge is produced, warranted, communicated, and maintained (Latour 1987, 1993, 2005; see
Latour and Woolgar 1979/1986). Exploring “science in action,” he suggests, is one way to flesh out the “rhetoric” of science: “we must eventually come to call scientific the rhetoric able to mobilise on the spot more resources than older ones [are able to mobilize]” (1987, p. 61). Inscriptions—his term for the semiotic resources scientists produce to make their research analyzable and communicable—are essential to this mobilization and enable researchers like him (and me) to examine how scientists transform the materiality of their practice into immutable and mobile texts (see Latour 1990).

According to Latour’s way of thinking, scientific text production involves not just a linguistic write up of findings but rather an “assembly” of inscriptions. Viewing texts in this way—i.e., as “assemblages” rather than literary or discursive objects—creates a space for analyzing the relationship between laboratory work and the way it gets represented visually and textually for a specific audience or rhetorical purpose. Visual inscriptions in particular—e.g., images, graphs, spectra—are useful foci because they can often be traced to experimental and analytical procedures in the laboratory. Pauwels (2006) provides further insight into this process. A fundamental aim of scientific visualization, he suggests, is to produce “social objects” (p. 12) that make possible inter-subjective analysis and deliberation among scientists. These objects often depict that which is too slow or fast/big or small to observe through normal human perception; they thus play a central role, he suggests, in producing, stabilizing, and circulating knowledge related to physical and conceptual referents. In looking to visualization as a situated

29 For similar approaches, see Knorr-Cetina (1981, 1999), Lynch (1985), and Traweek (1988).
30 See Arsenault, Smith, and Beauchamp (2006) for a useful discussion of Latour’s concept of “graphism.”
practice, Pauwels ultimately provides useful insight into the ways in which scientists give meaning and shape to the physical world.

In this chapter, however, I take Pauwels’s research a step further by focusing not only on visualization per se but also on the ways in which visuals function both in the laboratory and in the production of a rhetorically persuasive text. I have found, in taking this approach, that visuals tend to function in at least one of two ways. First, they provide a visual and material resource for interpretation and analysis and, thus, for the production of other inscriptions, like graphs, that get integrated into scientific texts. Second, they provide a means of documentation through visual modalities—e.g., schematics, photographs, animations—are used to represent the technical and methodical dimensions of experimental work. Examining visuals in these two ways—as a resource for analysis and inscription production, as a resource for documentation and representation—I take tend to agree with Lynch’s (2006) claim that visual production as a “labor process that sets up, and creates materials for, individual perceptions and judgments” (p. 29). I would modify this statement only slightly for my own inquiry: visualization is a labor process that sets up, and creates materials for, scientific text production.

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31 I liken this process to the concept of “semiotic transduction,” a term used to describe the transformative process through which the content of one semiotic modality is expressed through another semiotic modality (see Kress 2003; Fortune 2005). While beyond the scope of this chapter, additional research and analysis might explicate this concept more fully as it relates to visuals and visualization in science.
III. The Case of Experimental Physics

Spending approximately one year studying physicists at work, I encountered a great many inscriptions and texts both in and outside the laboratory. These include but are not limited to renderings on white boards; monitors with still and moving displays; laboratory notebooks; academic posters; journal articles; and so on. Yet despite the range and sheer multitude of inscriptions and texts that circulate in the laboratory, there are few observable writing processes that culminate in specific documents such as research articles or laboratory reports. These documents do exist, of course, but the scientists I observed did not typically rely on a set schedule, at least during regular working hours, to produce them as part of their day-to-day work. I did, however, learn a great deal from studying “minor” (see Witte 1992) forms of writing such as whiteboard renderings: namely, that making research visible, immutable, and mobile is essential to problem solving and text production. Just as important, I also learned that writing in physics is more complex than sitting down in front of a computer to type up the findings from one’s research.

This chapter focuses on two physicists and the processes through which they construct an experimental system, generate visual data, and communicate findings from their research. John and Morgan work in a liquid crystal physics and materials science research institute (hereafter Institute) and are members of a group headed by Dr.
Maxwell, a senior physicist and one of the Institute’s associate directors. For approximately one year, I researched and took part in the daily activities of scientists working in this group, a study that led me from laboratories, meetings, offices, seminars, and conference halls to various other spaces where scientific research and communication takes place. The group tends to focus, generally, on producing and characterizing liquid crystal materials. Three main practices contribute to this research activity: production of materials, physical experimentation involving materials, and theoretical modeling and computational simulation of materials. This chapter focuses on physics experimentation, though I recognize that discussing this practice apart from other laboratory activity makes a somewhat artificial—if ultimately necessary—distinction between the types of work performed and knowledge produced by members of the group.

John is an advanced graduate student who has been working in the laboratory and on his doctorate in chemical physics for approximately five years. His interests and expertise are oriented primarily toward physics, although his knowledge of chemistry enables him to create materials that he can use and test experimentally. Morgan holds a PhD in physics and is a post-doctoral fellow who, like John, engages primarily in experimental work. The experiment discussed in this chapter belongs to John in the sense that it will potentially be included in his dissertation; yet collaboration is a common part of laboratory work and, thus, the experiment “belongs” to no single person in any strict sense. Take Morgan for instance. As one of the most experienced scientists in the group and an expert technician, she is often responsible for maintaining the laboratory as

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34 Liquid crystal material is a broad term that I use to denote the range of materials that these scientists produce and characterize in their work: from liquid crystal elastomers to gold nanorods.
a working research space so that she can keep her own and others’ experiments moving forward. This involves, for instance, working on a laser that John uses in his experiment. Yet Morgan collaborates with John in more than just an indirect technical sense; she also works with him directly when he runs his experiment in order to obtain data. Examining how these scientists work together, and the role visual inscriptions play in this process, helps illustrate the collaborative nature of scientific work and text production as it is situated in and distributed across laboratory practice.

IV. Methodology

This study examined visualization in experimental physics research as a way to explore the function and production of multimodal scientific texts. In taking this approach, I faced two major challenges. First, I had to contend with the complex technical and experimental processes through which scientists produce visuals as part of their work. These processes are observable in the laboratory; yet much analysis was required to examine the uses to which visuals were put once they were produced. Second, I had to contend with the relationship between processes of visualization in the laboratory and the visuals John used to communicate his research findings. I faced these challenges in various ways, but mainly by tracing the relationship between visuals produced in the laboratory and visuals deployed in a multimedia presentation. Three methods formed the basis of my data collection procedures: observation, inscription collection and visual documentation, and interviews (see Table 4.1).
### Table 4.1

**Methods, Aims, Outcomes, Analysis**

<table>
<thead>
<tr>
<th>Method</th>
<th>Aims</th>
<th>Output</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>Observe scientists at work; document their practices; gain insight into the way in which visual inscriptions function as part of their inquiry and text (re)production.</td>
<td>Field Notes. ~100 single spaced, typed pages, and ~200 hand written pages, across three stages of inquiry: 6, 4, and 2 months.</td>
<td>Comparative analysis; open, axial, and selective coding across stages of inquiry. Theoretical memo writing.</td>
</tr>
<tr>
<td>Inscriptions</td>
<td>Collect inscriptions and texts that scientists produce and deploy in their laboratory work and textual (re)production. Examine relationship between visuals used and produced in the lab and in text production.</td>
<td>Hundreds of my own photographs, graphic renderings or John’s work; dozens of John’s photographs, graphic renderings of his own work.</td>
<td>Comparative analysis; situate visuals in the laboratory in relation to field notes on laboratory work and analysis of textual output of that work.</td>
</tr>
<tr>
<td>Interviews</td>
<td>Collect scientists self-perceptions about writing and the role of writing in their work; collect language that (dis)confirms and checks my own analysis and hypotheses.</td>
<td>Two interviews with John and Morgan for a total of 95 minutes of talk.</td>
<td>Open, axial, and selective coding based on multiple passes through transcribed text. Comparison with procedures for data collection and analysis.</td>
</tr>
</tbody>
</table>

### Observations

This study began with me spending an average of twenty to twenty-five hours per week in a non-linear optics laboratory and observing physicists at work. A challenge for me during this time was not to locate inscriptions in the laboratory but, rather, to understand how inscriptions were being produced and deployed as part of broader experimental objectives. I addressed this challenge by focusing on discrete, observable tasks and the various semiotic and instrumental resources that scientists deployed to complete them. During my first week in the laboratory, for instance, I observed Morgan
and Dave (a chemist) replacing dye in a laser that, I later found, was a key instrument in John’s work. Specifically, the dye had to be replaced because it did not allow for the range of optical frequencies required to undertake his experiment. While writing was produced during this task—e.g., Morgan used sticky notes to reference information from different binders—it was the technical work that led me to ask questions about what actually constitutes the practice of experimentation and, thus, how visual inscriptions mediate and result from this practice. Through observation, I discovered that the technical work involved in creating an experimental system is integral to producing good data; how data are visualized, and rendered “good” or “valid,” involves a series of inscriptions, some of which are produced through the system itself.

Inscription Collection and Visual Documentation

Collecting visual and textual inscriptions, and visually documenting experimental practice, was essential to my study in at least two ways. Not only did these procedures supplement my written field notes and provide a much-needed complement to vast amounts of descriptive linguistic data; they also enabled me to examine the actual inscriptions that scientists produce and deploy in their work. In this chapter, I examine several types of visual inscription that John generated for the purpose of research, documentation, and communication. These visuals serve different purposes for him as a scientist and offered me valuable insight into his overall literate performance. They demonstrate, for instance, how his experiment takes shape physically, and, thus, how the method it is designed to enact can be discussed and warranted textually. Consider the
optics table where John conducts his experiment (see Appendix C, Figure C.1) and the laboratory notebook where an early version of that experiment is depicted schematically (see Appendix C, Figure C.2). The concept of visual inscription, here, exists on different levels—physical and textual—and begins to illustrate the relationship between the experiment as a physical system and John’s ability to render it visually and textually for the purpose of documentation and communication.

*Interviews*

Interviews in this study enabled me to investigate and ask questions about scientists’ work and representational practices. I designed interviews to facilitate conversation through descriptive and structural questions, a strategy that helped me move from object-oriented description to process-oriented understanding of writing and experimental activity in the laboratory (see Spradley 1979). In an interview with John, for example, I asked what he considers writing to be and what role he saw it playing in his work. His response led to an explicit discussion of what writing means to him as a physicist and in turn led me to inquire further about his representational practices. Exploring scientists’ self-perception of writing and communication, and examining these perceptions in light of the practices I observed, proved generative for investigating and understanding the role of visual inscription in the laboratory and in John’s multimedia presentation.
V. Analysis and Results

One challenge I faced in this study was to understand visual inscriptions in light of John and Morgan’s experimental objectives. I addressed this challenge, specifically, by focusing on the ways in which visuals function in the context of laboratory tasks (see Bracewell and Witte 2003). This strategy served me well: that is, identifying tasks—what I consider to be “building blocks” of experimental practice—enabled me to take a fine-grained approach to investigating how visual inscriptions function both in the conduct and communication of experimental research. In this section, I discuss how I moved from identifying inscriptions as objects—a primarily descriptive account—to explaining how these objects can be situated, and better understood, within a broader and more distributed process through which John and Morgan construct, enact, analyze, and present findings from an experiment.

Visual Inscriptions in Laboratory Life

After the first few weeks of spending time in the optics laboratory, I found myself adrift in a sea of observational field notes. These notes were primarily descriptive in the sense that I was documenting the range of objects and instruments I could describe on a superficial level but the function of which was more elusive. My early attempts at description, for instance, enabled me to differentiate between types of lasers (e.g., argon, dye); yet this work did not tell me the ends to which these instruments were being deployed as part of scientists’ experimental objectives. During this time, I also noted the range of inscriptions and texts that scientists used and produced while working with
objects and instruments at the laboratory bench. I could observe, for instance, when
Morgan would jot down notes on a scrap of paper while working on a laser or when John
would go to the white board and write out an equation, or draw a curve, to work out a
problem or communicate a point of interest related to his experiment (see Appendix C,
Figure C.3). Observing this work led me to construct taxonomy of inscriptions, texts, and
perceived in situ affordances as a way to gain deeper insight into experimental activity
(see Appendix C, Table C.1).

The taxonomy represented in Table C.1 helped me to document and examine the
form and function of different inscriptions and texts; it also led me to hypothesize about
their affordances in light of the actions that I could observe. Yet this taxonomy still did
not explain the significance of inscriptions and texts in light of John and Morgan’s
broader experimental objectives. I thus began to identify more explicitly how they were
deployed in day-to-day laboratory tasks.35 Tasks in this setting are as diverse as they are
numerous, but generally exist along two dimensions: those enlisted in constructing an
experiment, and those enlisted in enacting the experiment in order to obtain useable
data.36 For constructing the system, tasks include changing out dye in the dye laser;
creating or obtaining a material sample; constructing a cuvette in which to suspend the
sample in a medium; arranging instruments on the optics table; setting up software for
capturing and transferring visual data, and so on. For enacting the experiment, tasks

35 I use “task” here based upon Bracewell and Witte’s (2003) constructs “tasks and ensembles” as units of
analysis for exploring the relationship between context of production and situation of use in workplace
writing activity.
36 I arrived at these two categories after weeks of watching scientists tinker at the lab bench and then dim
the lights to run their experiments. I would mention, however, that construction and enactment is often an
overlapping and recursive processes that occur in tandem.
include warming up and inspecting lasers; checking to see that instruments are arranged properly; modifying variables in order to obtain multiple data sets; capturing visual data with a camera and software program, and so on. Approaching experimental tasks in this way led to a related dichotomy between inscriptions and texts: those used and produced in constructing the experimental system, and those used and produced in enacting of the experiment. This analytical move enabled me to bracket off many of the inscriptions and texts that did not relate to experimental work in a direct, observable way (see Appendix C, Table C.2).37

Analyzing inscriptions and texts along a construction/enactment axis resulted in a more precise view of the relationship between these analytical dimensions. As demonstrated in Table C.2, for instance, just two inscriptions were used only in the enactment of experimental work: the frequency sheet and the Fringe image. The frequency sheet was created by Morgan to provide an efficient resource for working with the argon laser; John also used it while running his experiment. The Fringe image, however, so-called by John, proved especially unique in the sense that it was the only direct, observable product of experimental work and a source of ongoing interpretation and analysis for these two physicists in the laboratory. This image (Figure 4.2) specifically helps to represent the interface between lasers and material sample (Figure 4.1). Both Figures 4.1 and 4.2 are naturalistic in the sense that this is how one would perceive them if standing in the laboratory during an experimental run. The Fringe

37 For this table, I remove the inscriptions and texts that did not relate, in an observable way, to experimental tasks (e.g., sign-out sheet). For a direct comparison, see Table 4.2. Questions raised about the potential significance of these outliers, while relevant, is beyond the scope of my present discussion.
image, however, results from the interface depicted in Figure 4.2 and is thus an image of
an image. I arrange them below so that they can be “read” from left to right and so the
reader can see this as a visualization process where the Fringe image constitutes visual
data.

![Figure 4.1. Laser/Material Interface. Figure 4.2. Fringe Image](image)

Identifying the Fringe image (hereafter Fringe) helped me create meaningful
connections between the various tasks I had observed up to that point. Indeed, it had
something of a gestalt effect on the way I could understand the inter-relatedness of tasks
involved in experimental activity. The time John spent arranging instruments on the
optics table, for instance, was not just isolated work but rather a carefully designed
approach to visualizing the Fringe as a data source. Yet this image did more than
crystallize for me the relationships between various tasks; it also provided a starting point
from which I could hypothesize its presence in John’s experiment. Specifically, going
backward in time, or “upstream” (see Latour 1987), I could investigate how different
tasks were functioning toward the production of this image (e.g., prescribing it and the
method for producing it). Conversely, going forward in time, or “downstream,” I could examine how this image, as a visual datum, could be analyzed in light of the experimental method John and Morgan were developing (see Table 4.2).

<table>
<thead>
<tr>
<th>Task Situation</th>
<th>Purpose</th>
<th>Inscriptive Forms</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Production</td>
<td>Create sample for experimentation.</td>
<td>Notebook and inscriptions it contains; sample itself.</td>
<td>Object/Sample that can be characterized.</td>
</tr>
<tr>
<td>Experimental Construction</td>
<td>Create system and material/technical conditions for testing sample.</td>
<td>Naturalistic images, diagrams, monitors, software, optics table itself.</td>
<td>Apparatus for producing visuals, characterizing sample and collecting data.</td>
</tr>
<tr>
<td>Experimental Enactment</td>
<td>Run experiment and generate data that leads to analysis of theory and method.</td>
<td>Fringe Image captured at various levels of dilution (for measuring and producing quantifiable results).</td>
<td>Visual datum that can be measured, analyzed, and transformed into a graphic display.</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>Quantify and test visual data against theory; produce graphic display.</td>
<td>Images; equations; tables; various software.</td>
<td>Graphic Display.</td>
</tr>
<tr>
<td>Power Point Assembly</td>
<td>Share, discuss, and disseminate findings.</td>
<td>Linguistic script, diagram, images, animations, mathematic expressions, various symbols and displays.</td>
<td>Verifiable findings that can be shared with audience and used as a point of debate.</td>
</tr>
</tbody>
</table>

Table 4.2 outlines some of the observable task situations that lead to and extend from the Fringe image. More specifically, these tasks are necessary for John to design, construct, and communicate findings related to his experiment. In the following sections, I take the reader through a material and technical process that culminates in a series of visual inscriptions and, eventually, a scientific text. Illustrating this processes explains,
first, how the material and technical work of physics experimentation is made visual and, second, how the production of visuals—in the laboratory, for the purpose of documenting laboratory work—provides grounds for producing a text and presenting research findings to a disciplinary audience.

VI. Swimming Upstream

Material Production

Epistemic objects, according to Rheinenberger (1998/2005) are “the material entities or processes—physical structures, chemical reactions, biological functions—that constitute objects of inquiry” (p. 28). This definition accounts well for material samples that John and Morgan produce and use for their experiment. These materials are unique for at least two reasons: first, their molecular content—e.g., when in the shape of rods—can be oriented through the application of an electric field and thus be used in various technologies (e.g., liquid crystal displays); and second, they do not necessarily occur in nature. John and Morgan must accordingly produce them in the laboratory. Producing materials itself generates knowledge related to the sample in question (see Chapter 3); yet these objects are also “unknown” variables: that is, while their production is well-documented, the resulting (epistemic) object is “known” only insofar as it can be made accountable to experimental investigation. This means, in part, that the object-as-referent is not stable but, rather, is subject to ongoing experimentation. Such work, for John and Morgan, takes place in light of other goals as well—in this case, developing a new experimental method.
Experimental Construction and Enactment

One key objective of John and Morgan’s work, in the context of this study, is to develop a viable method for measuring the susceptibility of liquid crystal material to electric fields. This means that John, as the primary investigator in this experiment, must create a documentable and reproducible system that culminates in the interface between light (laser) and matter (sample) under controlled and measurable conditions. One regular task for him, beyond creating the setup itself, is to modify different variables and methodically produce a visual image that can be used as a reference in the laboratory and data for analysis. This is a constructive process in which John marshals the objects around him toward specific goals. The ostensible focus of his study, in this case, is a dynamic system rather than any single object in the setup as such. Likewise, the focus of my study, in accounting for John’s technical work, moves beyond the Fringe per se to include the ways in which visuals and texts enable him to coordinate, interpret, and communicate findings from his research.

The experimental system enables John to produce visual data that can in turn be used to analyze and confirm the success of his method (which is embodied in the system itself). The completion of this work, of course, does not occur overnight. Indeed, experiments take time, resources, and a range of expertise to design and construct; such processes also must be documented for the purpose of replication, problem solving, and communication. John relies on a laboratory notebook, for instance, to illustrate the components and outputs of his experiment. Consider a schematic that depicts the

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38 I use the term “liquid crystal material” here in a general sense. What John is attempting to measure involves not just material but actually nanoparticles in the shape of rods.
arrangement of instruments on the optics table (see Appendix C, Figure C.2). This visual serves as a counterpart to John’s technical work in the laboratory and provides him with an ongoing resource for generating new and better results. One visual result of experimentation, of course, is the Fringe image itself (see Appendix C, Figure C.4). This illustration shows how John perceives the Fringe in the laboratory and analyzes it according to the theory that underlies his experimental work. Hand drawn illustrations such as this are a common part of John’s documentation practice and are often supplemented by other visual inscriptions (see Appendix C, Figure C.5).

Together, these and other visual inscriptions found in the notebook contribute to the construction of an experiment and John’s ongoing efforts to modify it in order to obtain the data he needs and wants. Importantly, the different modes he deploys afford in different ways for the tasks involved in experimental construction and enactment. The schematic, for instance, provides a “logic” that defines various components of the system—e.g., lasers, mirror, sample, voltage—and their relationship to one another. This relationship is further defined by the visual output: the Fringe that results from their enactment. Representations of the Fringe, as shown in the above Figures, also vary. The hand drawn illustration, for instance, represents John’s own attempt to visualize what he perceives in the laboratory. Yet these illustrations do not alone suffice for John’s practice of documentation. This is why, perhaps, he includes a photograph of a Fringe: it gives him, and any potential reader of his notebook, access to the “real-time” image as it was produced, viewed, and interpreted in the context of laboratory work.
The main visual output of John and Morgan’s work in the laboratory is the Fringe, an image that provides them with a visual means to analyze the relationship between lasers, material sample, and other components of the experimental system. This image specifically constitutes a visual datum that John can interpret as he manipulates variables of the system and generates a useable data set; the Fringe in this way becomes evidence that something is taking place at a molecular level in his sample as it reacts to the electric field being applied to it. What that something is, however, depends on at least two factors. First, it is shaped by the way John dilutes the sample, changes the composition of the Fringe, and in doing so provides himself with a measurable unit of analysis between image captures. Second, it is shaped by other variables in this system: from the frequency of the laser to the dye to the mirrors, and so on. The image is thus dynamic insofar as it represents the relationships between components in the experimental setup; yet it is also dynamic in the sense that John changes it so he can better understand the susceptibility he is attempting to measure through his method. The constructive part of this activity lies in John’s ability to “read” not just the objects at his disposal but also the interstices between those objects and how they manifest in a visual output (see Figure 4.3).
Figure 4.3 is my own illustration, based on field notes, of how John (J) and Morgan (M) work together to enact the experiment and produce the Fringe. As evidence, the Fringe functions as a point of contact between these two physicists and the various components of the experimental system. Consider for instance the following exchange between them taken from my field notes:

- **John comes in**—turns on laser and dye again—about 10 minutes to warm up—then turns lights down for Morgan

- **Morgan working on part of spectrometer that’s getting sent back**

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39 I was not able to audio record talk in the lab due to an agreement I had with the group, but my notes nonetheless provide an accurate depiction of bench talk, especially in brief dialogs like this one. See Lynch (1985) and Woolgar (1990) for ethnomethodological discussions of conversation in laboratory work (i.e., shop talk).
• John comes back in, setting up for laser—control pad

• Morgan: “Is it stable?”

• John: “Yep.”

• Morgan: “Aligned?”

• John: “It’s aligned; I did it this morning.”

• John: “Look at these fringes....”

• Morgan: “Beautiful.”

• John: “Thank you.”

• John: “OK, it’ll work.”

This exchange, while brief, illustrates the way in which the Fringe becomes a “social object” (Pauwels 2006) that John and Morgan can use to interpret the technical stability of the experiment. Said another way, the Fringe becomes a point of interpretation and a way for these scientists to determine, through observation and discussion, that the system—and by extension, the method—is doing what they want and expect it to be doing. While their perceptions and observations are only a starting point—indeed, data must be collected, quantified, and analyzed—the image provides a way for them to engage with material objects and instruments that constitute the system itself as a technical ensemble and, eventually, a re-presentable object of knowledge in itself.
VII. Swimming Downstream

*Data Analysis and Visual Display*

Once the Fringe has been produced, John can capture this visual data and transfer it to his office where it can be quantified, analyzed, and, eventually, transformed into a graphic display. A number of software programs mediate this process. LabView, for instance, is an engineering workplace program that John uses as a tool for analysis and visualization. This software offers John a way to interact with his data graphically and through the construction of object-oriented, analytical relationships (see Appendix C, Figures C.6 & C.7). Like LabView, Maple is a software program John uses to analyze his data, but in this case through algebraic computations (see Appendix C, Figure C.8). The “writing” does in his analysis—e.g., working with code—is a common part of scientific inquiry and shapes the relationship between John, his data, and the components of the experimental system. More specifically, software like LabView and Maple enable John to interact with his visual data and, thus, explore further the means and methods through which it was produced.

One result of all John’s analytical work is a graphic display that gets interpreted and used to make decisions about the material, the system, the method, and any subsequent steps he might take to make informed decisions about how to proceed with his work (see Appendix C, Figure C.9). And once the graphic display is produced, John can interpret the data he has generated, modify his experiment if and where needed, and re-run it *ad infinitum*. Yet experiments do end (see Galison 1988). This depends on many factors—including time, funding, dissertation writing—and can last anywhere from
months to years. Indeed, experiments may only “end” in a partial sense, meaning that they can be replicated, adapted to different conditions, and used to generate new data that confirms or falsifies existing findings.

So far in this chapter, I have discussed a selective part of John and Morgan’s experimental practice. While a brief and admittedly oversimplified take on a complex process, it does begin to illustrate the spectrum of visual inscriptions involved in the practical work of experimentation. It also helps to conceptualize the relationship between visualization and text production (see Figure 4.4). Figure 4.4 is a simple model that represents just some of the variables involved in the production of John’s experiment and his multimedia presentation. On the left are the scientists, John and Morgan, and on the right is the presentation-as-text. Between scientists and text are the various resources they orchestrate in order to design, construct and enact an experiment, analyze data, and render the visual output of their work into a persuasive form of communication. The arrows depicted in this model signify the recursive nature of this process: that is, visual production in the laboratory provides materials for the text, and the text in turn gives context both to the visuals and the method through which they were produced. While this model oversimplifies a complex process, it does begin to show the extent to which text production is distributed across John and Morgan’s experimental work in the laboratory.
A close investigation of this process reveals that the Fringe provides a visual datum and a material resource for analysis and for the production of visual displays. The displays themselves ultimately make it into the presentation; the Fringe, however, drops out or, said another way, is absorbed and transformed into other, more durable inscriptions. Interestingly, while the Fringe does not get represented in John’s presentation, the experiment itself does: through a schematic, photographs, and an animation. On the one hand, then, visual production \textit{in} the laboratory shows how scientists manage the material and technical complexities of their work in order to produce usable data. On the other hand, visual documentation \textit{of} the laboratory shows how scientists use the material and technical complexities of their work to support their claims to knowledge. The remainder of this section is devoted to unpacking the implications of this relationship.
The Scientific Presentation

Scientific presentations, similar to other scientific genres, rarely if ever traffic in verbal language alone. Indeed, these talks typically involve a range of media—from software like Power Point to whiteboards—not only to present findings but also to establish common (visual) ground between audience and the material being displayed. Including a visual component in one’s presentation is in fact commonplace in the physical sciences: given the amount of information presented, it comes as little surprise that visuals play a powerful role in helping an audience engage with one’s work. I specifically focus, here, on visual modalities found in of John’s presentation and the way he uses them to invoke the material, instrumental, and aesthetic dimensions of his experiment. This is a key move for John to make: because he is developing and arguing for a new experimental method, the work he actually does in the laboratory—e.g., creating materials, measuring their susceptibility to the application of an electric field—is of paramount importance for connecting with his audience.

John deploys multiple semiotic resources in his presentation (see Table 4.3), but I focus on visual modes (i.e., non-linguistic, non-mathematical) and the work they perform in representing his experiment, and his method, as valid and verifiable knowledge. I use the term “visual mode” here to emphasize the way in which different visual inscriptions afford different ways for making and communicating meaning for John in his presentation. The visuals included in his presentation include a schematic and color.

40 Stephen G. Benka, editor-in-chief of Physics Today, offers an interesting take on scientific presentations, and communication more generally, in the December 2008 issue. As he says, each talk is “an experiment designed to bring the audience from a mixed state of knowledge to a final state of understanding…” (pp. 50-53). Additional analysis of scientific presentations as a genre, while beyond the scope of this chapter, would no doubt reveal interesting insight into scientists’ writing and communication practices.
photograph that appear in two separate “Experimental Setup” slides; an animation that occurs across two “Alignment” slides; and another color photograph that appears in the “Conclusion” slide.  

Table 4.3
*Modality, Structural Location, Relation to Laboratory, Semiotic Affordance*

<table>
<thead>
<tr>
<th>Inscription</th>
<th>Slide Location</th>
<th>Relation to Laboratory</th>
<th>Semiotic Affordance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linguistic Script</td>
<td>Motivation, Conclusion</td>
<td>Shows how John’s method fits in with existing research.</td>
<td>Contextualizes experiment.</td>
</tr>
<tr>
<td>Schematic</td>
<td>Experimental Setup</td>
<td>Represents logical relationships between components of experiment.</td>
<td>Relational; analytical/logical.</td>
</tr>
<tr>
<td>Color Photograph (Naturalistic)</td>
<td>Experimental Setup</td>
<td>Represents the aesthetic components of experiment.</td>
<td>Iconic; relational; shows action; shows aesthetic.</td>
</tr>
<tr>
<td>Animation</td>
<td>Alignment</td>
<td>Represents the causal relationship between components in experiment.</td>
<td>Shows action and result of action; shows causation.</td>
</tr>
<tr>
<td>Mathematical Formulae and/or Notation</td>
<td>All but Motivation, Experimental Setup, Conclusions slides</td>
<td>Represents theoretical basis of experimental work (and method).</td>
<td>Contextualizes, re-contextualizes, analyzes.</td>
</tr>
<tr>
<td>Graphic Displays</td>
<td>Alignment, Measurements, Example, Absorbance, Phase Shift</td>
<td>Represents measurements, analysis, and findings.</td>
<td>Displays findings in clear, cognitively efficient way.</td>
</tr>
<tr>
<td>Table</td>
<td>Results</td>
<td>Represents findings</td>
<td>Displays findings in clear, cognitively efficient way.</td>
</tr>
<tr>
<td>Color Photograph</td>
<td>Conclusions</td>
<td>Depicts light/matter interface and converges</td>
<td>Secures findings through convergence</td>
</tr>
</tbody>
</table>

41 I do not include the visuals from John’s presentation due to issues of intellectual property. I hope, however, that my descriptions, and the visual I have included up to this point will suffice to make my argument clear.
Each visual mode affords in its own unique ways for John. For instance, having explained his motivation through linguistic text, he visually depicts the experiment itself in the form of a schematic (see Appendix C, Figure C.10). This visual mode does a particular type of work: that is, it illustrates the general layout of objects used in the experiment and, thus, the way in which John orients them methodically. The schematic itself includes the major components of the experimental system—lasers, mirrors, sample, spectrometer—and John labels them as such. Thus, the visual rendering of his experiment is at once a representation of material objects and processes and a step toward warranting the method he has developed through them. Audience members can now visualize for themselves the basic components of the system and understand, based also upon his “Motivation” slide, what he is proposing in his presentation.

Once John has established the basic parameters of his experiment, he presents a color photograph of objects and instruments arranged on the optics table (see Appendix C, Figure C.11). This visual mode helps extend the work initiated with the schematic by creating an iconic link between laboratory and audience. It does this in two ways. First, the photograph shows what the experiment looks like if one were observing the experiment—something that many in the audience, as practicing scientists, have no doubt experienced. Second, because John has superimposed red lines to demarcate the laser path between the instruments shown, he brings a sense of logic to this image: that is, he

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42 See Shapin and Shaffer (1985) for a discussion of “virtual witnessing.”
creates connections between the objects that are otherwise unlabeled. Yet there is more than a functional, object-oriented relationship being depicted here. As John said in an interview, he includes this particular photograph for the sake of showcasing the aesthetic of the experiment itself (pp. 8-9):

*CW:* Why is a picture good here? [I point to the photo of the lab bench.]

*JOHN:* Ah, it’s a little bit of an ego thing. I wanted to convey that my experiment was beautiful [laughs].

*CW:* Besides you wanting to show people how nice your work is, what else does this [photo] do? Why include the experimental setup in it at all?

*JOHN:* OK…I have this drawing [refers to schematic] of the experimental setup, but as you can see, it’s just not as romantic, you know, it’s kind of boring and…

*CW:* Romantic?

*JOHN:* It’s just not as beautiful.

*CW:* What does it do then for the audience?

*JOHN:* It adds a layer of beauty; it’s not essential by any means.

*CW:* Oh, the pictures.

*JOHN:* The pictures, yeah.

*CW:* What does the diagram do [referring to the schematic]?

*JOHN:* It’s less beautiful, but the information is much more clear in the sense that you can understand what all the components do in a very simple way. Where the picture is more beautiful but it’s harder to understand exactly what’s happening.

*CW:* OK. Because?
Based on this brief interview excerpt, I would argue that John uses the photographic image and the schematic, in tandem, to accomplish a dual objective. First, he includes them to give his audience a direct image of the laboratory, the setup, and the material conditions of his work. Second, he uses them to show his audience that he has designed a beautiful experiment. Each visual mode thus offers a particular affordance: the image illustrates the beauty and the schematic the rationality of the experiment. More specifically, the photograph affords a “natural,” first-person look at the richness and materiality of the laboratory but is constrained by its inability to articulate relationships in specific terms. Conversely, the schematic affords the ability to articulate relationships in specific terms but is constrained by its inability to invoke the richness and materiality of the laboratory. The dynamic between the aesthetic and the rational here creates a distinct connection between John and his audience: the aesthetic provided by the image, and the rationality provided by the schematic, together validate John’s method by shoring up his ability to create an elegant experiment and communicate methodical findings to an expert audience.

This line of argument is further warranted when looking at the following slides. In them, John continues to integrate his experimental work with its theoretical basis; but importantly, as he suggests in an interview, he also includes an animation to provide a visual basis for explaining his method (see Appendix C, Figure C.12):

CW: What does it [the animation] show?
JOHN: So it’s, it’s showing in a particular state…what the nanorods [liquid crystal materials] look like when I apply a field…it orients them. To kind of help set up the geometry of what’s happening so people can understand it.

CW: The geometry is represented how?

JOHN: Just through this picture. So it helps by having this little animation that helps understand these graphs later.

CW: OK, so is it fair to say that these different things are working together and they all….

JOHN: Yeah, absolutely.

CW: How is that?

JOHN: I mean….

CW: What comes first?

JOHN: This comes first [points to the animation].

CW: The animation?

JOHN: The animation to set up my geometry, what happens when I do a certain event. And then how do I characterize that event through mathematical relationships…and then plotting these mathematical relationships gives this picture [points to graphic display], and then it’s very easy to tell how this picture relates back to the original animation.

With the schematic, John has provided the basic means for his audience to connect with the experimental enactment of his new method. Yet the animation—a before/after visual that shows how particles are aligned given the application of an electric field—provides John with an additional dimension that visualizes the relationship
between the objects, processes, and findings that he is presenting. In other words, the animation, while not iconic in the sense that the naturalistic image is iconic, graphically depicts a process; this visual thus moves the audience away from the world of objects and toward the world of actions and interactions. The interaction, here, is between various components of John’s experiment, and the result of that interaction, when an electric field is applied, is an alignment of nanorods in the material sample. John is thus able to capture the dynamic of the experiment, the relationship between his objects, and the “happening” that he is attempting to measure. This in turn provides his audience with a visual depiction of a microscopic process and, from there, an arrangement—i.e., the objects depicted in the schematic—that constitutes a vital part of John’s method.

Yet this is not the end. After examining his findings mathematically and displaying them graphically, John concludes his talk through a convergence of visual modality and symbolic notation. As demonstrated in the final slide of his presentation, he specifically provides a photographic image of the interface between light and matter that he has explained throughout his presentation, that he perceives directly in the lab, and that generates the Fringe image discussed throughout this chapter (see Appendix C, Figure 4.13). This photograph, however, does not stand on its own; indeed, it is overlaid with symbolic notation. The convergence of the photographic and the symbolic, here, is at once a return to the laboratory—its beauty, elegance, and materiality—and a movement away from the laboratory—toward the more formal presentation and confirmation of findings. Both the photograph and the symbols perform individual
functions— to depict, to measure— yet together, these modalities enable John to warrant his findings and the experimental conditions through which they were produced.

VIII. Discussion

In this chapter, I have discussed the relationship between visualization and text production in an experimental physics research setting. Starting in the laboratory, I attended to the ways in which visuals function in the conduct of everyday scientific work; continuing with John’s presentation, I likewise attended to the ways in which that work is communicated visually in a multimedia presentation. My explorations have thus yielded information about the functioning of visuals in across two related spaces: a laboratory and a text. As I have shown, the Fringe is a product (in part) of technical work and an “unknown” that must be interpreted; yet this image enables interpretation insofar as it constitutes a “social object” that has a definable origin—the experimental system—and a definable purpose—to provide a “stable” unit of analysis that can be captured, measured, analyzed, and rendered into any number of graphic inscriptions that John can study and use to warrant the system he created.

Yet more than providing scientists with a functional inscription, the Fringe also enabled me to gain access, however limited, to John and Morgan’s experimental practice and to tease apart the complex assemblage of materials, instruments, and semiotic resources involved in their work. What I found is that processes of visualization, and visuals themselves, help to set up the conditions for producing texts and disseminating knowledge. Figure 4.5 helps to illustrate this relationship, one in which the laboratory is
characterized as a site of visual production and the text as a site of visual integration. The “Image” in this figure represents how the Fringe inhabits both worlds: it is a product of John and Morgan’s experimental work, an object of analysis, and a resource for generating inscriptions that end up in the final presentation. In this way it occupies an interstitial space through which the materiality of the laboratory gets transformed into visual displays and, ultimately, a persuasive argument.

Figure 4.5. Conceptual Relationship between Visual Production and Integration

Yet just as laboratory work provides the conditions for text production, so do completed texts, in the case presented here, warrant John and Morgan’s experiment system and the method it is designed to enact. As I have shown, the visuals John deploys in his presentation each represent the experiment in some way: the schematic conveys a logical arrangement of instruments; the photograph of the optics table invokes its material aesthetic and the elegance of its design; the animations reveal a movement from the world of objects to the world of interactions; and finally, the interface photograph signifies a convergence of the material conditions of laboratory practice with a precise
symbolic explanation. Together, these visuals demonstrate the power of inscription to represent, transform, and render meaningful a complex experimental process that is not a movement away from materiality but rather an embracing of it. *Writing* in this way can be understood via experimental practice—the building, the tinkering, the visual and textual transformations—and the ways in which that practice is enabled and represented by the very inscriptions it manufactures.

Examining text production across experimental physics research and communication further suggests that meaning potential is not only a function of inscriptions in themselves but also of the constructive relationships they call forth in the laboratory and for specific audiences. Investigating the relationship between technical work and textual (re)production specifically points toward a concept of *affordance* that is both semiotic and rhetorical: semiotic in the sense that *in situ* visual production involves an active process of meaning making as semiosis; and rhetorical in the sense that visual integration involves the persuasive assembly of meaning based upon potentials deriving from visuals themselves and the technical apparatuses through which they were produced and confirmed as knowledge. The concept of rhetoric, here, is not based on verbal discourse alone but also on the object-oriented, technical work that helps set up the conditions of visual and text production. Rhetoric in this way can be considered a productive art that does not begin with the discursive composition or interpretation of a text but, rather, with the production of the means of production: that is, of the experiment as an object of study, a means of producing inscriptions, and as an object that can be documented visually for the purpose of disciplinary communication.
Examining scientists’ technical work offers additional insight into the study of scientific and technical communication. Writing and rhetoric scholars, for instance, often analyze texts as objects of analysis in order to investigate how scientists communicate their work to various audiences. This work has been valuable in many ways, not least for the emphasis it has placed on public understanding of science as a social, institutional, and rhetorical practice. Yet it may not enough to account for the nuances of scientific communication by looking to texts alone. Indeed, it is also important to account for the instruments and techniques through which inscriptions are produced and the choices that scientists and technical experts make when communicating their work textually.

Examining texts from this perspective offers much-needed corollary to existing studies of scientific writing and rhetoric that tend to understand science from the purview of discourse. Looking to contexts of production, as I have done in this chapter, specifically helps to reveal what scientists value about their work and their communication practices: whether logical precision or visual aesthetic of a well-designed experiment or multimedia presentation.

It is not only scientists, however, who deal with diverse tools of production in their work and their writing. Students and professionals from many disciplines and workplaces find themselves dealing more and more with a great variety of media and technologies in their work and communication: from the stylus and PDA duo to the I-Phone that converges multiple media into a single, mobile technological device. Examining how different groups—from students to professionals—use such technologies in their writing and text production would help to extend findings from the study
presented here. More specifically, additional research could investigate how various media, technologies, and semiotic systems mediate goal-oriented human activity across a variety of contexts: whether in the technical workplace, the multimedia classroom, or the civic forum. Many such studies have, of course, been undertaken—with many more currently in progress—but research is always needed that can contextualize writing and multimodal text production in light of real-world problems—and how those problems are met through localized strategies that people employ to achieve their work, research, and communicative objectives.
Chapter 5

Writing Theoretical Physics

I. Introduction

Physicist David Mermin, in a 1999 lecture at Cornell University, offers a somewhat provocative description of what it means to “write physics.” As he says, “Writing physics is different from both writing up physics, and the editorial refinement of written-up physics. While there has to be something there before the writing begins, that something only acquires its character and shape through writing” (p. 27).\footnote{This lecture, delivered as part of a writing in the disciplines series at Cornell, has since then been included in Jonathan Monroe’s collection \textit{Writing and revising the disciplines}. As an additional tidbit related to Mermin’s interest in writing physics, he claims to have coined the term “boojum” as a way to “loosen up” the use of jargon in scientific publication practices. This term, he notes, has been absorbed into the scientific lexicon with no trace of its origin as a “silly word” (p. 24).} In this brief passage, Mermin makes what I consider to be two key points for the study and teaching of writing in scientific disciplines: first, that the concept of \textit{writing} can be understood in multiple ways, and second, that writing, however understood, is a constructive activity through which scientists make and communicate meaning related to the physical world. I would like to extend this thinking by asking and investigating my own related question: how is writing understood and enacted in the context of theoretical physics research and communication?
Exploring questions related to writing in physics is as relevant today as it was when Mermin gave his lecture ten years ago. Perhaps even more so. Yet the questions I have about writing in physics differ somewhat than those Mermin raises. As a scientist, he is interested in exploring how scientific concepts like relativity or quantum mechanics can be communicated through writing-as-ordinary-language; this, he suggests, is the essence of what it means to “write physics.” As a writing researcher and teacher, I am interested in exploring how writing is enacted in the context of scientific work; this, I would suggest, is a useful way to approach writing as a multimodal literacy practice. My aim in this chapter, more specifically, is to approach writing—as a mode of communication, as a situated rhetorical activity—as co-extensive with the practical work involved in theoretical physics research and communication. This approach complements studies that have examined multimodality in physics texts (see Lemke 1998) and the changing dimensions of scientific communication in an age of digitization (see Mackenzie 2007).

This chapter consists of three parts. First, I explore the in situ representational practices of one physicist, Jordan, as he models and simulates liquid crystal materials. Observing this scientist at work has enabled me to explore what constitutes writing in light of the semiotic resources—e.g., programming language, mathematic equations, graphic displays—he produces and deploys in his research. Second, I examine an in-process theoretical manuscript that he composed and analyze the ways in which he represents findings related to his modeling and simulation work. Finally, I present an in-

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44 Indeed, the very concept of writing has undergone considerable change over the past two decades as new media technologies continue to shape literate activity across everyday, academic, and workplace contexts.
depth interview with Jordan and discuss how he talks about the role of writing, representation, and communication in his research. Based on analysis of observational, textual, and interview data, I ultimately argue that writing in theoretical physics is a complex semiotic practice that involves not only the description or representation of existing physical reality but also the creation of new conceptual realities that exist virtually if not always materially.

The structure of this chapter is as follows. First, I discuss research that has examined theoretical physics as representation and as practice. Second, I examine the setting and participant in this study: a theoretical physicist working in a liquid crystal physics and materials science research institute. Third, I discuss the methodological and analytical processes that informed this study and my eventual (and ongoing) understanding of what it means to undertake theoretical and computational work in a physics research setting. Finally, I present an interview with Jordan and examine how he perceives and talks about his work and the role of writing in it. The conclusion to this chapter discusses the potential value of studies that explore the media, technologies, and semiotic systems with which scientists and others increasingly engage as part of 21st century literacy practices.

II. Theoretical Physics as Representation and Practice

Physics research, while diverse in scope, tends to involve a combination of theoretical and experimental inquiry. Philosopher of science Ian Hacking offers a useful way to differentiate between these practices. Specifically, he argues that they can be
understood, respectively, as “representing” and “intervening”: “Science is said to have two aims: theory and experiment. Theories try to say how the world is. Experiment and subsequent technology change the world. We represent and we intervene. We represent in order to intervene, and we intervene in light of representations” (1983, p. 31). Hacking examines the relationship between theory and experiment, in part, because he believes that philosophers of science have paid undue attention to theoretical issues of “representation and reality” while largely ignoring important experimental and technological innovations that have shaped human culture and consciousness. While I do not attempt a “philosophy of science” in this chapter, I believe Hacking’s separation of theory and experiment is useful—descriptively, analytically—for exploring how theoretical physicists represent the world—and how their representational practices can be understood as a complex form of writing and literacy.

Karin Knorr Cetina has also investigated the related practices of theory and experimentation in physics research. Her approach, however, involves studying physicists at work. Indeed, Knorr Cetina’s ethnographic investigations are as expansive as they are impressive: over two decades of research in the field has taken her from a study of particle physicists at CERN (the European Organization for Nuclear Research) in Geneva, Switzerland, to a study of molecular biologists at the Max Planck Institute for Bio-Physical Chemistry in Göttingen, Germany. Spanning these diverse sites of scientific inquiry, her work examines “knowledge as practiced—within structures, processes, and environments that make up specific epistemic settings” and, more broadly, “epistemic cultures” (1999, p. 8). Emphasizing “knowledge as practiced,” Knorr-Cetina
has looked to processes through which scientists construct their laboratories, their
theories, and their knowledge of the physical world. I take a similar, practice-based
approach in this chapter in order to gain access—however limited—to the complex
representational work involved in theoretical physics.

Knorr Cetina’s studies provide more than interesting insight into scientific
practice and culture (see Pickering 1994). She has also reflexively examined the
methodologies—and their attendant epistemologies—that attend the sociological study of
science. Knorr Cetina and Merz (1997), for example, in “Floundering or frolicking—
How does ethnography fare in theoretical physics?” respond to a critique issued by
George Gale and Cassandra Pinnick (1997) that ethnographic methods are limited when it
comes to investigating theoretical sciences.\footnote{Gale and Pinnick are responding to an article by Merz and Knorr Cetina titled “Deconstruction in a
‘thinking’ science: Theoretical physicists at work.”} Knorr Cetina and Merz tend to agree that
ethnography of a “thinking science” like theoretical physics “poses challenges of
observability, comprehensibility and relevance to social studies of science” (1997, p.
124). Yet they do not concede that ethnographic methods are useless for coming to grips
with complex scientific practices; they argue, rather, that such methods must be used
carefully and in tandem with a deep commitment to understanding scientific concepts (p.
126). This thinking provides insight into a challenge I have encountered in my own
research: namely, coming to grips with theoretical physics as an expert literacy practice.
While I will always have much to learn about the conceptual foundations of theoretical
physics, my study of physics as practical work nonetheless stands to contribute important
insights into what is currently known about writing as a mode of communication and a semiotic practice.

Elinor Ochs (1994) has also studied physicists at work. In one well-known study, for instance, she and her colleagues investigated the language physicists use to talk about their research in group meetings. Analyzing transcripts from these meetings, Ochs and her co-authors argue that the language and gestures scientists deploy in tandem with white board representations take them on an “interpretive journey” through graphic space—a journey that enables them to work through problems related to physical objects and processes. As she suggests, “It is through this multimodal, distributed discursive activity that these physicists narrate their scientific stories and journey through graphic space and other constructed worlds” (pp. 152-53). Looking to the relationship between scientific talk, gesture, and visual representation enables Ochs to gain some access to the ways in which scientists interpret their work and render it meaningful; looking to processes of writing and representation has likewise enabled me to gain some access to the ways in which physicists conduct and communicate their research. An added point of interest for this chapter is that J. Schrodinger, one of my research participants, was part of Och’s study in the early 1990’s. I thus see a direct continuation between her work and my own (i.e., a scientist) but also a similar trajectory in examining how scientists create and talk about the visual representations that constitute an essential part of their inquiry.
III. The Case of Theoretical Physics

Laboratory work, as I have attempted to show in previous chapters, is often a material, object-oriented process. Indeed, scientists working in the optics or chemical laboratories must often grapple with any number of chemicals and instruments involved in their practice of normal science (see Kuhn 1962/1996). Theoretical physics, on the other hand, involves a somewhat different approach. While this practice is also object-oriented—e.g., scientists are constantly deploying equations, programming languages, and software programs to construct models and run simulations—the objective of their work is often more conceptual than it is material. In other words, theoretical physicists in the Institute often attempt to model and simulate objects that can be examined against experimental findings or used to produce materials that may not (yet) exist either in the laboratory or in nature. Using Hacking’s terms, the theorists that I observed tend to represent—i.e., describe and explain the world mathematically and computationally—while experimentalists tend to intervene—i.e., examine whether such descriptions holds up under observation and controlled physical conditions. Chapters 3 and 4 of this dissertation have examined the role of inscriptions and texts in the context of laboratory interventions. I would like to shift focus in this chapter and examine the writing and representational practices involved in theoretical physics.

Jordan is an advanced graduate student and a member of Dr. Maxwell’s research group. His work is diverse in scope—e.g., I observed him synthesizing materials and constructing experiments—but tends to focus on the modeling and simulation of material
systems. He is thus familiar with the material and experimental counterparts to his theoretical work but spends a majority of his time grappling with software, solving equations, writing code, and creating simulations that add to the group’s overall research output related to liquid crystal materials. This practice tends to involve two main foci. First, Jordan must construct and negotiate the various components of his “computational system,” a term I use to describe, generally, the mediational means—e.g., mathematical expressions, programming code, various media and technologies—through which he creates and enacts simulations as an object of knowledge. Second, Jordan runs his simulations, generates data, and renders the output of his work into graphic displays and, eventually, texts that ostensibly will become chapters in his dissertation or manuscripts that he submits for publication.

In addition to observing Jordan in his office, I also attended several group meetings of Drs. J. and R. Schrodinger. The Schrodinger’s are married, and their work tends to focus, respectively, on theoretical and computational physics. J. and R. each has his or her own research group and graduate students but often work together and conduct group meetings in tandem. I attended group meetings semi-weekly for approximately six months both to learn about the “theoretical side” of physics and to provide a check against the observations I was making of scientists in Dr. Maxwell’s

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46 I use the term “material system” to denote the object of study that Jordan creates theoretically and enacts computationally (e.g., a nanoparticle).

47 In this chapter, I discuss simulations as objects that can be “created” in the sense that they consist of multiple parts (e.g., code, equations, software). Yet I also recognize that to “simulate” is also to enact and that simulations, thus, are also usefully described as “happenings” as much as objects.

48 I differentiate between theoretical and computational here in the sense that the first tends to involve the “pencil and paper” work of analysis and modeling while the second deals more with computing and enacting models under specified conditions. For the sake of simplicity and clarity, I will use the term “theory” and “theoretical” to encapsulate “computational” where possible. I will in turn use “computational” when referring to activity that directly involves computing.
group. The Schrodinger group meetings tend to take one of three foci: students from either group present work in progress; R. or J. present their own work; or someone from outside the groups—e.g., a professor from the physics department—comes in and lectures on a subject related to research on liquid crystals. While I do not focus explicitly on group meetings in my analysis, these meetings offered much-needed insight into the diversity of expertise involved in the study and communication of theoretical physics.

IV. Methodology

Any *in situ* study of writing in science must contend with a host of challenges. The first, and most basic, in my research was that I needed to understand theoretical physics as work—e.g., motivations, objectives—in order to understand what constitutes writing in that work. I address this challenge in three ways: first, I provide a descriptive account of physics in action; second, I analyze a discursive text that Jordan produced to communicate his findings; and third, I supplement my observations and textual analysis with an interview of Jordan talking about his research and communication practices. Another challenge is that, unlike physics experimentation, modeling and simulation do not always give way to rich observational data. Even so, a great deal of this work is observable: from grappling with software to writing code to running simulations. Making observations, collecting visual inscriptions, and interviewing scientists ultimately enabled me to flesh out writing as mode of communication and semiotic practice in the context of theoretical physics research (see Table 5.1). Table 5.1 outlines the methods I
deployed to collect and analyze data during approximately one year spent researching scientific practice in a liquid crystal physics and materials science research institute.

Table 5.1
Method, Aims, Output, and Analysis

<table>
<thead>
<tr>
<th>Method</th>
<th>Aims</th>
<th>Output</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>Observe scientists at work; document their practices; gain insight into the way in which visual inscriptions function as part of their theoretical and computational work and text (re)production.</td>
<td>Field Notes. ~50 single spaced, typed pages, in addition to ~100 handwritten pages, across three stages of inquiry: 6, 4, and 2 months.</td>
<td>Comparative analysis; open, axial, and selective coding across stages of inquiry. Theoretical memo writing.</td>
</tr>
<tr>
<td>Visual Inscriptions</td>
<td>Collect inscriptions and texts that one scientist produced and deployed in his theoretical and computational work and text (re)production.</td>
<td>My own graphic renderings; several of Jordan’s screen captures and visual inscriptions.</td>
<td>Situate visuals in relation to field notes on theoretical and computational work and textual output of that work.</td>
</tr>
<tr>
<td>Interviews</td>
<td>Collect scientists’ self-perceptions about their work and their writing; collect language that (dis)confirms and checks my own analysis and hypotheses.</td>
<td>One interview for a total of approximately 56 minutes of talk.</td>
<td>Open, axial, and selective coding based on multiple passes through transcribed text.</td>
</tr>
</tbody>
</table>

Observations

During the initial stage of my research, which lasted approximately six months, I spent an average of 30 hours per week observing scientists at work in the chemical and optics laboratories. Some of this work involves computation—e.g., John and Morgan, both experimental physicists, relied upon computers and software programs to collect, record, and analyze data—but is typically oriented toward experimental ends. Jordan’s
work differs in the sense that he is virtually constructing his research object (material system) and means through which that object is examined (simulation). My observations mainly took place in Jordan’s office where I could observe him working on software, solving equations, coding, simulating, and generating data that he displayed visually. I also observed him discussing and presenting his research in various settings: from Dr. Maxwell’s group meetings to revision sessions where he vetted findings before presenting them at a national physics conference. I have thus seen the way in which the visual output of Jordan’s work—e.g., simulations, displays—become “social objects” (see Pauwels 2006) that travel between laboratory spaces and serve as sites for discussion and deliberation.

Inscription Collection and Visual Documentation

If observations proved challenging for studying theoretical work, collecting visual inscriptions helped me meet this challenge. Indeed, identifying the writing and representations that Jordan produced helped me to hypothesize about and investigate his research objectives. During the first week of my research, for example, I observed Jordan writing code and running a simulation. The code itself was recognizable to me as a form of writing that could enact, algorithmically, some command that he programmed into it. Looking to the relationship between code and simulation in turn led me to articulate the relationships between code-as-writing and simulation-as-enactment. In other words, each inscription told me something in itself—e.g., code does this; simulation does this—and also about the ways in which these and other components of Jordan’s
computational system relate to one another. The same might be said of the theoretical article that Jordan wrote: looking to this document helped me understand the distributed processes through which he produced simulations, generated findings, and integrated the visual outputs of his work into an in-progress manuscript.

Interviews

Interviews were crucial for helping me gain insight into the practice of theoretical physics that I observed in Jordan’s office and in Schrodinger group meetings. I specifically designed interviews around descriptive and structural questions (see Spradley 1979) that would, first, help me understand the nature of theoretical and computational work and, second, the way in which that work could shed light on scientists’ writing and representational practices. I conducted interviews with Jordan and Drs. J. and R. Schrodinger and analyzed their interview transcripts, looking for similarities, differences, and patterns between the way in which different theoretical physicists talked about their research and their writing. In this chapter, however, I focus on my interview with Jordan as a way to further explicate my observations and text analysis. In analyzing the interview, I do not necessarily attempt to examine specific linguistic patterns but, rather, to supplement other data sources and analysis involved in my observational and inscription collection procedures.
V. Analysis and Results

This section examines the concept of writing as it is enacted in the practical work of theoretical physics. I have two aims in taking this approach. First, I describe the various mediational means involved in Jordan’s work with simulations; second, I examine the way in which he represents his findings in a manuscript that will either become part of his dissertation or get sent out for publication (or both). Examining the relationship between the representational practices involved in simulation and text production ultimately sets up a useful dichotomy for exploring the concept of *writing*—as semiotic modality, *in situ* representational practice, and method of integration—in theoretical and computational work.

*Observing a Theoretical Physicist at Work*

The majority of research activity I observed throughout my study took place in the chemical and optics laboratories (see Chapters 3 and 4). Jordan could often be found participating in the activities that occur in these spaces; yet he, more than other members of Dr. Maxwell’s group, spends most of the day working at a computer in his office (see Figure 5.1). Observing him (JN) in this workspace was relatively straightforward—e.g., I had little trouble finding objects and actions (both physical and virtual) to document—but far from simple—e.g., I had some trouble determining the function of objects and actions (both physical and virtual) in light of their role in achieving specific research objectives.
Data collection procedures began with me documenting the inscriptions, texts, and instruments that I could observe Jordan using in his office (see Table 5.2). Table 5.2 lists some of these objects and describes the ways I saw them being deployed in day-to-day research activity (see Appendix D, Figure D.1). Figure D.1, for instance, an excerpt from my field notes, describes part of a relatively typical day for Jordan, one that involves figuring out the syntax in a piece of programming code, working with software, creating a graphic display, and talking to other scientists in the Institute. The focus of this work is not writing in the traditional sense of linguistic script or the practice of producing a discursive text. Yet writing is nonetheless an essential component of the work that Jordan performs: whether writing code or writing out equations in order to “do more math.”
Table 5.2
*Observable Objects, Example, and Description*

<table>
<thead>
<tr>
<th>Objects</th>
<th>Example</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td>Desktop machine in Jordan’s office.</td>
<td>Jordan works with this and often multiple computers every day. His objectives and tasks seem to vary, but the computer is a key instrument in his research.</td>
</tr>
<tr>
<td>Mathematical Formulae</td>
<td>Equations</td>
<td>Jordan writes out equations on a piece of paper while working at his computer.</td>
</tr>
<tr>
<td>Theoretical Model</td>
<td>Nanoparticle</td>
<td>Jordan models (creates theoretical expressions for) liquid crystal materials that may not exist in nature or the laboratory. This relates to the work he does with equations.</td>
</tr>
<tr>
<td>Simulation Software</td>
<td>Microwave Studio</td>
<td>Jordan uses different software programs in various aspects of his research. He talks about problems related to simulation software during morning meetings.</td>
</tr>
<tr>
<td>Programming Language</td>
<td>Fortran</td>
<td>Jordan writes code and uses existing code in his research. Code is deployed toward different ends.</td>
</tr>
<tr>
<td>Simulation</td>
<td>Nanoparticle</td>
<td>Jordan creates a simulation based upon a theoretical model. The simulation is one objective of his work but also is used to generate data related to the model.</td>
</tr>
<tr>
<td>Storage and Display software</td>
<td>Microsoft Excel</td>
<td>Jordan uses this type of software to save, store, analyze, and render data into graphic displays.</td>
</tr>
<tr>
<td>General Reference Texts</td>
<td>Fortran Manual</td>
<td>Jordan uses manuals to while working on different components of his “computational system” (e.g., writing code, working with software, etc.).</td>
</tr>
<tr>
<td>Individual Reference Texts</td>
<td>Gold and silver nanoparticle sheet</td>
<td>Jordan created this sheet and taped it to the wall so that he would have an easy reference for plugging in numbers related to properties of gold and silver nanoparticles.</td>
</tr>
<tr>
<td>Research Texts</td>
<td>Theoretical and experimental research articles</td>
<td>Jordan uses research articles while solving equations and creating simulations. He does so for different reasons (e.g., to learn about software, to replicate a method, etc.).</td>
</tr>
<tr>
<td>Calculation Instruments</td>
<td>Calculator</td>
<td>Jordan uses instruments for the purpose of calculation. Much of his work involves calculating, some of which he does without the use of instruments.</td>
</tr>
</tbody>
</table>
Part of the work Jordan does involves producing models and simulating them. He creates texts as part of his documentation (e.g., notebook) and communication (e.g., Power Point, article draft). Interestingly, writing is often a problem-solving activity in Jordan’s work as well.

Consider for instance the exchange between he and Cole described in Part II of Figure D.1. On this particular day, I was observing Jordan working in his office when Cole came in and, with no other words exchanged, began talking with him about a graph that was depicted on the computer screen. This graph provided these scientists with a “social object” (see Pauwels 2006) through which they could carry on a discussion about Jordan’s work. It also provided me with further insight into the concept of writing in this setting. Indeed, as shown in the field note excerpt, Cole “writes” code and in doing so produces a graph to compare with the one Jordan had created. While not the only writing I observed, the exchange between these two scientists illustrates the various ways in which writing can be characterized in light of computational work: in this case, as a means to produce a visual object (graph) in order to work through a problem (the phenomenon that the graph is designed to represent).

Describing objects and actions, while useful starting point for gaining some insight into Jordan’s research, was not so straightforward at task as it initially might seem. Indeed, the tools of computational physics—e.g., equations, programming

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49 Cole was a member of Dr. Jensen’s group and worked in a laboratory directly adjacent to Dr. Maxwell’s. I got to know the members of this group well and often spent time with them in their offices and their laboratory.
languages, computers, simulations—are complex objects of study in their own right and must be thoroughly understood in order to be used efficiently and well. This created some problems of interpretation for me as a researcher. As one example, I was able to observe Jordan writing and working with code on different occasions (see Appendix D, Figure D.2), yet it was unclear to me, at least initially, how this task figured into the broader practice of simulation as one central objective of his work. I faced other, similar challenges throughout my research: as a non-specialist, I did not (and do not) have the expertise required to truly engage with the “problems” of theoretical and computational physics and, thus, the ends to which writing and other mediational means are deployed to address and communicate findings related to those problems. I was nonetheless able to learn more about objects and actions by examining more explicitly how they mediated the production and enactment of computational simulations (see Table 5.3).

| Mediational Means       | Function                                                                   | Outcomes                                                                 |
|-------------------------|                                                                            |                                                                          |
| Maxwell’s Equations     | One basis for Jordan’s theoretical model.                                 | Eventual theoretical model that can be simulated and used to generate data. |
| Model of Nanoparticle   | Describes system mathematically; serves as one basis for simulations.     | Jordan has a model that he can simulate under specific conditions.         |
| Computer                | Tool for computing (e.g., creating simulations and analyzing data)        | Jordan can conduct his work through different software and programming languages. |
| Microwave Studio        | Virtual environments, tools, and methods for computing and producing simulations. | Simulation that enacts theoretical model in some way.                     |
| Fortran                 | Programming language used to enact a simulation; code also                | Program that provides a means to run a simulation; form of                |
Table 5.3 helps to illustrate the move I made from describing objects and actions to situating them more explicitly in relation to simulations as an object of study (see Appendix D, Figure D.3). I use the term *mediational means* in the left column of this table to examine how *objects* become instrumental and semiotic *tools* that Jordan deploys to complete specific tasks (see Bracewell and Witte 2003; Witte 2005). With programming, for instance, I could observe Jordan at his computer writing code. This constitutes a task in the sense that he must address specific problems: for example, working out the correct syntax or modifying it in such a way that it achieves the end that it is designed to serve. Yet writing code is not an isolated task. Indeed, the code is not an end in itself but, rather, a (mediational) means: one component in a larger “computational

50 The terms “instrumental” and “semiotic” overlap in interesting ways given that a semiotic tool like computer code is also instrumental in the sense that it can be used to enact a simulation or analyze data. Yet these terms provide useful placeholders for differentiating between the types of resources that Jordan draws upon to achieve his research objectives.
system” that Jordan creates to produce, enact, and analyze the data generated by his simulations. The concept of task situation (see Table 5.4) thus emerged as a way to link together various tasks and to examine their significance in light of broader research objectives related to the work of modeling and simulation.

Table 5.4
Task Situation, Purpose, Mediating Inscriptions, Outcomes

<table>
<thead>
<tr>
<th>Task Situation</th>
<th>Purpose</th>
<th>Mediation Means</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling</td>
<td>Solve set of equations that provide basis for modeling a material system.</td>
<td>Maxwell’s equations; calculator; various media for representing analytical work.</td>
<td>Theoretical model that can be programmed and simulated under particular conditions.</td>
</tr>
<tr>
<td>Programming</td>
<td>Generating usable code using some programming language.</td>
<td>Fortran code; Fortran code book.</td>
<td>Means to enact the model as a simulation.</td>
</tr>
<tr>
<td>Simulating</td>
<td>Enact mathematical model under specified conditions.</td>
<td>Microwave Studio software.</td>
<td>Simulation that enacts mathematical model under set of conditions.</td>
</tr>
<tr>
<td>Analysis</td>
<td>Examine of data generated by simulation.</td>
<td>Fortran code written for purpose of analysis.</td>
<td>Numbers, visual/quantitative displays.</td>
</tr>
<tr>
<td>Information Display</td>
<td>Create a visual display that makes findings easier to perceive and distribute.</td>
<td>Excel, other programs for converting numbers into displays.</td>
<td>Graphs that can be brought to group meetings and other venues and discussed.</td>
</tr>
<tr>
<td>Textual Integration</td>
<td>Bring together findings and situate them in a way that contributes to new knowledge in the field.</td>
<td>Article/Chapter.</td>
<td>Integrates findings and makes available for audience and dissertation completion, etc.</td>
</tr>
</tbody>
</table>
Table 5.4 examines how different mediational means and tasks can be situated within the broader practice of theoretical and computational physics. More specifically, task situations are particular enough to be traced to specific tasks—e.g., making sure the syntax in a piece of code is correct—yet are broad enough to begin constructing a more nuanced understanding of the relationship between tasks and Jordan’s research objectives that include, but do not end with, the production of computational simulations. Tasks situations, however, are not static. Indeed, these categories are dynamic in the sense that I continued to learn then—and continue to learn now—about the theoretical objectives they are designed to serve. Said another way, tasks and task situations involved in theoretical and computational work are not simply observable workplace actions but rather complex building blocks of scientific activity whose full significance can only be understood by acquiring a deep body of knowledge gained through years of study and practice as a working scientist.

Tasks involved in theoretical and computational physics involve a range of mediational means (both instrumental and semiotic). These tasks also involve different forms of writing: whether equations Jordan must solve in order to create a theoretical model or code he must write in order to enact that model given a particular set of programmable conditions.\(^{51}\) Some of this writing describes—e.g., a nanoparticle system—and some of this writing enacts—e.g., executes a command to enact a system in order to generate a specific type of data. Such categories are useful for exploring the various dimensions of writing—as a mode, as a practice—in theoretical physics. Yet

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\(^{51}\) For instance, Jordan might direct a light source into his nanoparticle (model) at a particular angle and frequency.
theoretical physics involves another type of writing as well: that which communicates findings. Here, then, I move from the practical work involved in creating and running simulations to the way in which that work gets represented in a discursive text. Taking this approach enables me to compare the concept of writing involved in \textit{in situ} theoretical and computational work with the concept of writing involved in the integration of findings into a genre-specific text.

\textit{Theoretical Manuscript}

In this section, I examine a manuscript that Jordan drafted based upon his theoretical and computational work.\textsuperscript{52} This text is not so different than what one might find in a journal like \textit{Physics Review} in that it follows the basic structure of a typical research article. It is specifically divided into six sections: Introduction, Theory, Numerical Method, Simulation Details, Results and Discussion, and Conclusion. Each section does what one would expect it to do based upon these headings. The Introduction, for instance, explains the purpose, scope, and potential contribution of Jordan’s work given an existing body of scholarship. The Results and Discussion likewise speaks to the ways in which his findings have been shown to extend existing research. Each section also relies to a greater or lesser degree on different semiotic modalities to communicate findings. Analyzing these modalities—e.g., linguistic script, mathematical expression, visuals, graphic displays—in and across specific sections helps

\textsuperscript{52} I do not include specific text or visuals from this manuscript due to issues of copyright. I also keep to a surface-level analysis here due to the fact that, first, this is a draft and not a peer-reviewed manuscript, and second, due to the amount of expertise required to engage with the phenomena under investigation.
to illustrate the affordances that they obtain for Jordan in this particular communicative situation (see Table 5.5).

Table 5.5
*Semiotic Modalities, Structural Location, Affordances, Constraints*

<table>
<thead>
<tr>
<th>Modalities</th>
<th>Location</th>
<th>Affordances</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linguistic Script</td>
<td>All sections.</td>
<td>Provides context; converges with mathematical propositional content.</td>
<td>Inefficient means to display large amounts of data in a cognitively accessible way.</td>
</tr>
<tr>
<td>Mathematical Expression</td>
<td>Theory, Numerical Method, Simulation Details</td>
<td>Provides theoretical and methodical basis for warranting simulation work.</td>
<td>Does not provide its own context for the work it does in this particular study.</td>
</tr>
<tr>
<td>Graphic Displays</td>
<td>Simulation Details, Results and Discussion.</td>
<td>Enables display of large amounts of data in a cognitively accessible way.</td>
<td>Does not provide its own context (or durability) in light of the study/findings presented.</td>
</tr>
<tr>
<td>Simulation (Static Visual)</td>
<td>Simulation Details.</td>
<td>Visualizes model as simulated object; provides some of its geometry.</td>
<td>For print medium, does not show simulation enacted in time/space.</td>
</tr>
</tbody>
</table>

Linguistic script is the dominant mode of communication in this manuscript. Indeed, it appears in each section but specifically plays a more pronounced role in the Introduction, Results and Discussion, and Conclusion. This makes sense, perhaps, given the purpose of each of these sections: Jordan uses verbal language to contextualize his research in the Introduction and explain the significance of his findings in the Results and Discussion and Conclusion. While he presents his findings through other modalities as well, linguistic script provides its own particular affordances. Specifically, it helps to describe the problems that motivate his research and how he has responded to those
problems through theoretical modeling and computational simulation. The concept of writing, here, is a relatively straightforward means through which Jordan can describe his research objectives, how he has achieved them theoretically, methodically, and computationally, and how his findings add to existing knowledge (in this case, of the optical properties of nanoparticles).

Yet scientific texts rarely communicate through language alone. This manuscript is no exception. Mathematical expressions, for instance, are included in the Theory, Numerical Method, and Simulation Details sections and provide a precise description of the theory that underlies Jordan’s work. As he said in an interview, “Math is really specific. What goes in the equation is what is there. With verbal language there’s a lot of ambiguity, a lot of meaning to be read into things. An equation is an equation….It is what it is” (Transcript, p. 9). One affordance of mathematical expression, for Jordan, is that it reduces the ambiguity involved in verbal communication. Yet the mathematics he includes do not alone suffice to communicate his aims. This is one reason, perhaps, his expressions are often integrated syntactically with linguistic script. The combination of mathematic with linguistic enables Jordan not only to solidify the theoretical basis of his work in a precise and unambiguous way; it also enables him to explain the steps taken in order to do so. In other words, the mathematical expression provides formal grounds upon which a more discursive “story” can be built.

The theoretical grounding of Jordan’s work, however, is only part of the larger equation (so to speak) in this manuscript. Indeed, in the following section, Numerical Theory, he discusses the simulations he carried out (using Microwave Studio software) in
order to examine further the nanoparticles he modeled theoretically. Similar to other sections, Jordan uses linguistic script to discuss his work, for instance, to describe the software and equations used to carry out simulations. Yet he also includes a visual rendering of his simulation in addition to his linguistic and mathematical description. This visual is somewhat limited by the medium of print in the sense that he cannot include a three-dimensional object that simulates action in time and space. Although two-dimensional, Jordan can nonetheless use it to express the geometry of his simulation and thus explain to his audience what it is designed to do and how it has helped to extend existing theory. This is a visual affordance that complements the mathematical and linguistic descriptions he has provided up to this point. More specifically, the visual rendering of the simulation offers readers a more direct view of the object he has simulated and how, thus, it can extend the theoretical model he has constructed.

The final modalities Jordan includes in his manuscript are graphic displays. These displays appear in the Simulation Details and Results and Discussion sections of the manuscript. While I cannot speak to the specific reasons that Jordan includes them in these sections, it is possible to conjecture about the general affordance of graphic displays for presenting information. Simply put, they make vast amounts of data easier to read and understand given specific coordinates and variables (see Tufte 1983). These graphs thus afford in the sense that they make findings easier to “read” and interpret in light of the theory and simulations that Jordan describes in earlier sections through linguistic, mathematical, and visual modalities. The information included in the graphs could ostensibly be communicated through linguistic script, but this would be less efficient
given the amount of text that would take and the relative difficulty of doing so.

Linguistic script does, however, serve a purpose in the Results and Discussion section: namely, to re-contextualize Jordan’s findings and explain how they extend existing research.

*Writing and Text Production in Theoretical Physics*

This chapter has described the general process that goes into creating and running computational simulations and integrating findings into a discursive text. Taken as a whole, this process involves many individual tasks that must be completed in order to journey from Jordan’s office to the rhetorical display of his findings: from creating a theoretical model to simulating a model and generating data to analyzing and visually displaying data to integrating findings in manuscript form. Figure 5.2 provides a simple model that helps to illustrate the various dimensions of this practice. More specifically, this model demarcates different stages—one’s that correspond roughly with the “task situations” discussed above—involved in generating and communicating findings related to simulations. For example, a theoretical model is necessary for describing the material system under investigation; creating a simulation is necessary to enact that model and generate data; creating a display is necessary to present quantitative relationships; and creating a text is necessary to integrate the sum total of this work into the same graphic space where it can be used in Jordan’s dissertation or sent out for publication and circulated among the broader scientific community. The arrows depicted in this model signify the recursive nature of this process: that is, modeling and computational work
provides materials for the text, and the text in turn gives context to both to the model and simulations and the methods through which they were produced. While this model oversimplifies a complex process, it does speak to the general ways in which text production is distributed across the day-to-day work involved in theoretical and computational physics.

![Diagram showing the model of text production in computational physics](image)

**Figure 5.2. Model of Text Production in Computational Physics**

Individual task situations in Jordan’s computational work also tend to involve individualized forms of writing. For instance, modeling requires mathematical expressions and equations that can be used to describe and analyze physical/conceptual objects and processes; the simulation requires code that must be written and deployed so that it can enact a model; data generated by the simulation requires code to analyze it; and assembling a text involves integrating, through the practice of writing, various semiotic
modalities—linguistic, mathematic, visual, graphic—into a persuasive document. The many forms that writing takes in theoretical and computational physics speak both to the complexity of this work and the complex representational systems required to undertake and communicate it.

*Interview with Jordan*

So far in this chapter, I have described some of the objects and processes involved in Jordan’s theoretical and computational work. I understand, however, that these descriptions remain at a relatively superficial level given the limitations of observational data for explaining complex theoretical concepts. I thus turn to an interview with Jordan in order to explicate and expand upon the observations I have made. Doing so helps me not only to explain his work according to his own perspective; it also helps me to explain better what constitutes writing in theoretical physics and what role it might be said to play in scientific research and communication more broadly.

The interviews I conducted throughout my research were based on the “ethnographic interview” method described by Spradley (1979). Simply, this method aims not to obtain answers to a set list of questions but rather to collect “naturalistic” language used by the participants themselves. This is not to say that the method itself is random; rather, it advocates that the interviewer ask different types of questions—e.g., descriptive, structural, contrast—so that the interviewee is guided yet able to speak openly and conversationally. Within the context of this chapter, interviews helped me comprehend theoretical physics on an intuitive if not expert level; this was made possible
by asking physicists to describe their research and their writing to me in a simple but
detailed way.\footnote{In addition to interviewing Jordan, I also interviewed Drs. J. and R. Schrodinger and thus obtained a rich
view of the way in which theoretical physicists talk about their work and their writing. While analyzing
each of these interviews is beyond the scope of this chapter, additional work can be done to carry out such
analyses.} It is important to note that I have not treated my interview with Jordan as
stand-alone data source but rather as a resource that was used to supplement what I had
already observed and begun to understand about writing in theoretical and computational
work.

Interview questions were not prescribed per se, but they did generally fall within
two categories: descriptive and structural. The first obtains information about a
participant’s use of language when describing some phenomenon; the second obtains
information about the way a participant tends to organize his or her knowledge related to
that phenomenon (Spradley 1979, p.60). Jordan’s response to descriptive questions
specifically enabled me to examine the language he uses to talk about his work and his
writing; his response to structural questions likewise enabled me to examine how he
perceives his work in relation to other research (e.g., group, Institute, field) and his
writing in relation to the representational forms (e.g., equations, programming language)
that he may or may not consider \textit{writing} per se (see Appendix D, Table D.1). Starting
from the left column, Table D.1 outlines the types of questions asked and the ways in
which they were directed toward Jordan, his work, and his writing. The far right column
describes some of the outcomes of these questions and how Jordan helped me understand
better the role (and the concept) of writing in theoretical physics.
Obtaining interview data of scientists talking about the basics of their research provided me with an invaluable resource for learning about the tasks and practices that I observed across laboratories, offices, meeting rooms, and conference halls. And, the more I learned about scientific inquiry—e.g., concepts, motivations, methods, outcomes—the more I could learn about the role of writing in that inquiry. Asking scientists specific questions about writing also provided important insight into “what writing is” to them and, accordingly, how they perceive the role of writing in what they do. Because my interview with Jordan was designed to supplement other data sources (e.g., observational field notes), I was less interested in detailed analysis of linguistic patterns than I was in examining the specific language he used to talk about his work and his writing.

Still, I did conduct preliminary analyses that led to interesting and unexpected categorical insights (see Table 5.6). Table 5.6 lists some of the analytical categories that relate both to the types of questions I wanted to ask Jordan at the outset—e.g., how he would describe his work—and to other topics—e.g., theory/experiment relationship—that I did not set out to inquire into but that formed a useful and interesting component of the data I collected. I would emphasize that these categories are preliminary in the sense that more robust analysis is needed to tease out specific codes and categories related to language use; even so, the excerpts I discuss below help to contextualize these categories as well as the observations I have made related to Jordan’s in situ and textual representational practices.
Table 5.6

*Interview Category, Aim, and Outcome*

<table>
<thead>
<tr>
<th>Category</th>
<th>Description of Data</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description of Work</td>
<td>Language that Jordan uses to talk about theoretical physics as a practice</td>
<td>Clearer sense of what Jordan does as a theoretical physicist</td>
</tr>
<tr>
<td>Research Aims and Output</td>
<td>Language that Jordan uses to describe the research objectives of theoretical physics and the various outcomes of his work</td>
<td>Clearer sense of Jordan’s aims as a theoretical physicist and how writing helps achieve them (and results from them)</td>
</tr>
<tr>
<td>Theory/Experiment Relationship</td>
<td>Language that Jordan’s uses to describe the relationship between his work and other types of physics research</td>
<td>Clearer sense of how Jordan’s work relates to other physicists and (thus) how his writing practices differ from theirs</td>
</tr>
<tr>
<td>Writing as Mode</td>
<td>Language that Jordan uses to describe writing as a mode of communication</td>
<td>Clearer sense of “what writing is” to a theoretical physicist like Jordan</td>
</tr>
<tr>
<td>Rhetorical Sensitivity</td>
<td>Language Jordan uses to talk about writing as part of broader communication practice</td>
<td>Clearer sense of how Jordan is attuned to nuances of persuasion in his writing and communication</td>
</tr>
<tr>
<td>Modal Affordance</td>
<td>Language Jordan uses to talk about choices in representation for work and communication</td>
<td>Clearer sense of the choices Jordan makes given particular research and communicative situations</td>
</tr>
<tr>
<td>Concept of Text</td>
<td>Language that Jordan uses to talk about text as object and text production as practice</td>
<td>Clearer sense of how Jordan perceives the role of text in his work and the way he produces texts to communicate findings from his work</td>
</tr>
</tbody>
</table>

*Description of Work*

One aim of my interview with Jordan was to obtain a descriptive account of the language he uses to talk about his work as a theoretical physicist. This was crucial for me for at least two reasons: first, due to the complexity of theoretical physics as an area of expertise, and second, due to the relative difficulty of gathering data through
observational methods. Jordan’s initial response to my query about “what he does” as a physicist was to begin describing the types of work he performs: “I basically do simulations of nanoparticle systems and…work on liquid crystal elastomer and rubber stretching…and elastomer properties and synthesis of materials” (p. 1).\textsuperscript{54} Based on this statement, it is clear that Jordan’s expertise is not limited only to working with theoretical models and computational simulations. Indeed, he often works in the laboratory with liquid crystal materials in both a productive and an experimental capacity. Yet much of the work he performs involves theory and simulation—a practice that relates to material production and experimentation in important ways. As he says, “We’re not actually designing materials that we can build, although that’s part of it, but…we’re trying to understand better the equations that govern the response of the system” (p. 2). The breadth of Jordan’s experience thus involves the production of and experimentation with liquid crystal materials; yet his specific expertise in creating models and running simulations adds an important dimension to this work: whether providing insight into the production of new materials or providing models that can be used to complement experimental research in the laboratory.

\textit{Research Aims and Output}

Through observation, I discovered that Jordan’s research involves constructing theoretical models and running computational simulations, and I was specifically able to identify various mediational means and tasks involved in this practice. I was also

\textsuperscript{54} Page references in this section refer to the interview transcript.
interested, however, in hearing about this work from Jordan himself. According to him, one of the group’s aims is to “simulate the properties of materials without having to build them” (p. 1). This, he suggests, is a cost-effective way to generate new and important insights into the production, experimental characterization, and technological application of liquid crystal materials in general. Jordan explained further how simulations actually contribute to his process:

The idea behind the simulation is that you are trying to get a computer to tell you something about the system that you are studying that approximates what would happen in real life. So you have to come up with some way to represent your system inside of a computer that a computer can understand, and usually, for us, we start with small particles, and we take the particles and turn them into a series of points and then apply a set of equations that describe the response of the individual points. Once we find a solution to these equations, that becomes the result of the simulation. (p. 1)

Interesting here is the dual nature of simulation work. First, a simulation is something: an object that is constructed of many parts—e.g., equations, programming language, software—that Jordan must orchestrate in order to obtain his desired results. Second, a simulation does something: a process that enacts those parts and generates data related to some theoretical model. More specifically, what a simulation does, in part, is help Jordan to approximate something that would happen in “real life.” This raises important questions about his work in relation to the group’s research activity (e.g., production and experimentation); it also raises potentially interesting questions about the way in which
writing—e.g., equations, programming code—mediates the relationship between “representation” and “reality” as it is enacted in physics research.

**Theory/Experiment Relation**

The relationship between theory and experimentation became clearer to me as a non-scientist after spending several months in the laboratory. The first, I discovered, tends to involve minimal physical instruments (besides a computer) and generates data related to conceptual objects and processes. The second, I found, tends to involve many physical instruments and generates data related to material objects and processes. While this view oversimplifies the relationship between theory and experiment—indeed, experimentalists use theory, and theorists sometimes experiment or use experimental data in their work—there is a useful distinction to be drawn between scientists who spend more time involved in one or the other practice. This distinction came up in my interview with Jordan:

[T]here’s two sides of you know working in a lab. One’s theory, and the other is experiment. You know the mass on a spring…you have to take into account the spring content and gravity…and all that kind of stuff. And so you build a theory to describe the position of the mass on the spring as a function of time….And then on the other side [are] experiments, where you actually measure the position of the mass on the spring as a function of time. And then hopefully if you’ve put in everything you need to, the theory will be able to describe the experimental results. (p. 2)
For Jordan, theory is “built” in order to describe some phenomena; experiments on the other hand are built to test phenomena under physical and measurable conditions. I emphasize this distinction, in part, for what it suggests about writing in theoretical physics: insofar as equations are written, and insofar as theory can be built through equations, writing in theoretical physics is part of constructive activity through which scientists describe physical reality. This is not to say that writing literally constructs reality; it is to suggest, however, that writing to physicists is a more complex activity than using linguistic script to produce a discursive text.

**Writing as Mode**

One of my primary research objectives in studying writing in the Institute was to discover what writing actually means to physicists—and how it is enacted in the context of their research and communication. I have thus attempted to tease apart, through observation, the different forms of writing deployed in theoretical and computational work. Yet Jordan offers his own insight into the concept of writing as he talks about the relationship between theory and experiment:

[I]t’s a great thing when you can get the theory that you have for your system to match the experimental results that you get in the lab. And a lot of times, you know, when you’re writing the theory, and you go in the lab and see something different, it makes you realize that you need something else in your theory that’s missing. And so, the combination of the two rather than just one alone is definitely a benefit. (p. 4)
Writing in this case involves “writing theory” which in turn involves a description (or prediction) that can be compared with or examined against experimental work in the laboratory. This type of “writing,” of course, is not the same as writing-to-describe in a linguistic sense. Still, the way Jordan talks about “writing theory” offers insight into the concept of writing more generally: namely, that it is a mode as well as a practice that describes physical reality but also generates conceptual knowledge of a reality that may not yet exist.

Rhetorical Sensitivity

Listening to Jordan talk about writing as part of his work also led me ask about specific contexts for communicating that work—whether in a presentation, an article, or for members of the community. In listening to him talk about communication, it in turn became clear that he—like many other scientists I have spoken with—has a nuanced understanding of audience. As one instance of this “rhetorical sensitivity (my term), Jordan described his experience talking to different groups of people:

[W]hen you talk to a member of the community who doesn’t have much of a math background, you can’t just show him the equations; so you have to show make it something that’s understandable on a more basic level….You don’t give them equations to say why, but you just say “the light follows the molecules,” and based on this, you can understand why the display works. You really do have to distill it down to the level of the audience.
Communication for Jordan involves more than just the presentation of information. Indeed, it involves articulating specific concepts in a way that his audience, specialist and non-specialist alike, can understand. David Mermin talks about this in his lecture when he says that writing (as ordinary language) is essential to communicating complex scientific ideas. Writing can also make those ideas more complex, however, if it includes theoretical and mathematical forms of inscription. Writing in this case can be understood in at least two ways: 1) language-based writing for non-specialists; and 2) mathematical and language-based writing for specialists. How one approaches the concept of writing in science is thus shaped by what ends—and what audiences—that writing is designed to serve.

Modal Affordance

Jordan’s ability to accommodate complex scientific ideas to different audiences is also shaped by the way he views different modes of communication. On the one hand, examining the draft of his manuscript reveals how semiotic modes afford for the communicating his work textually. On the other hand, Jordan has his own views about the way in which different semiotic modes ought to be deployed in oral presentations:

The saying goes that you lose one person in your audience for every equation that you put up….You know, mathematics are abstract…. [Y]ou can’t read a page of math like you can a page of text. A page of text you just read; a page of math you have to sit there and analyze every single line of it…and try and generate meaning from the equations. Sometimes it’s not so obvious, but if you sit there and look at
the equations long enough, you realize the effect of one term in it or something like that.

Jordan’s concept of modal affordance here relates to the relationship between mathematics and text-as-linguistic. Specifically, he realizes that to read an equation takes a great deal of time compared to reading words on a page. That time, Jordan suggests, especially in the context of a presentation, is better spent connecting with his audience directly through oral language. It is worth noting as well that the concept of “reading,” here, reveals an important dimension to Jordan’s concept of writing. Namely, one can read and write theory—and that theoretical physics might thus be considered (complex) type of literate practice.

**Concept of Text**

While Jordan tends to associate the concept of text with linguistic script, I also was interested in the language he uses when talking directly about writing. During one part of the interview, for instance, I asked him to pull up a Power Point presentation that he delivered at a national physics conference. We then proceeded to go through the presentation and talk about it—me asking questions, him explaining concepts. Near the end of this process, I asked what were perhaps the inevitable questions: “So what do you call the activity of putting together a PPT? Would you call that writing?” His response was as revealing as it was thoughtful:

I don’t know if I would call it writing. It’s more like synthesis process, you know, because it’s not a lot of writing. In my presentations, there’s not a lot of
words generally. The whole presentation might have 120 words in the whole thing, if that, so, but, a lot of it is pulling together the different things that you have. So I have to pull together the pictures, and the equations, and the data, and then come up with just enough text to explain what I need to without having too much in there, because I don’t like to have too much text in my presentations. (p. 11)

Like other scientists I spoke with during my study, Jordan tends to talk about writing as a linguistic or language-based modality (“words”) and as a practice (“pulling together”). Writing is thus an object and a process. More specifically, text production for Jordan is a “synthesis process” where he has to “pull together the pictures, and the equations, and the data.” This view is in keeping with the general picture that has emerged throughout my research: namely, that text production in scientific practice involves an assembly of inscriptions that are generated in the context of scientific work and used to report on that work—and make it persuasive—for various audiences and exigencies.

VI. Discussion and Conclusions

This chapter has explored the processes through which one physicist undertakes, communicates, and talks about his work and writing related to theoretical physics. Through observations of Jordan at work, I identified and described some of the tasks he performs to create and enact simulations; through analysis of a text he produced, I

55 For a related discussion, see Bruno Latour’s (1990) essay “Drawing things together” included in Lynch and Woolgar’s collection Representation in scientific practice.
examined how he reports on research findings; and through discussion of interview data, I examined how he talks about his work and the role that writing plays in it.

Throughout this discussion, I have begun to characterize the concept of writing in two main ways: 1) as an *in situ* representational practice involving equations, programming languages, and other mediational means; and 2) as an integrational practice through which Jordan draws together, or assembles, multiple semiotic modalities into the same graphic space. More specifically, writing can be understood as a semiotic mode: whether equation, code, or notes on a piece of scrap paper. Writing can also be understood as a practice: whether to describe (e.g., a nanoparticle), to enact (e.g., simulating a nanoparticle), or to solve a problem (e.g., to write out mathematical expressions on a scrap of paper). In each case, writing is bound up in the practical work of theory and computation and is a key means—instrumental, semiotic, rhetorical—of visualizing and constructing knowledge related to liquid crystal materials.

Writing in theoretical physics is also what scientists do when they want to communicate their work to others. Indeed, writing is not just a semiotic mode or *in situ* representational practice; it is also an integrational practice through which scientists like Jordan draw together, or assemble, the diverse components of their research into a genre-specific text that communicates findings in genre-specific ways. Looking to the theoretical manuscript that he drafted, I discussed the semiotic modalities through which he represented and communicated his work: linguistic script, mathematical expression, visual image, and graphic display. I showed, further, what each of these modalities affords in its own unique ways. Verbal language, for instance, enabled Jordan to situate
and give context to his findings; mathematical expression enabled him to ground his findings in theory; a visual image helped him confirm the geometry of his model and simulation; and graphic displays helped him to present findings in a readable way. Individually, each modality does important work for helping Jordan present his work; yet together, these modalities offer an integrated picture of the practice that went into producing and confirming those findings as knowledge.

My interview with Jordan also helped me extend, and in some ways confirm, what I had learned through my observations of Jordan at work and my analysis of his manuscript. It confirmed, for instance, that writing in theoretical physics involves not only the act of “inscribing”—e.g., writing equations, creating code—but also the practice through which multiple semiotic systems can be integrated into the same graphic space. Writing in this way might be said to include multiple semiotic systems and, thus, and the conceptual realities that they are designed to represent. Yet I would hesitate simply to equate different forms of writing in theoretical physics—e.g., writing-as-mathematic, writing-as-code, and writing-as-linguistic—with one another. To do so would be to overlook how each affords to the situation at hand and the ways in which each draws upon a different ways of constructing and communicating meaning related to the physical world.

Investigating and teasing apart the concept of writing in theoretical physics reveals the complex resources that scientists deploy in their research and communication. Yet studies such as the one presented here also have implications for how the field of writing studies conceptualizes writing as a literacy practice and a teaching subject. Over
the past two decades, for instance, writing and literacy scholars have increasingly begun to explore how new media technologies shape writing research and pedagogy. The field’s general consensus is that conventional approaches to the concepts of “reading” and “writing” no longer suffice to describe the complex media, technologies, and semiotic resources that students and others draw upon to make and communicate meaning. Yet a great deal of scholarship in writing studies continues to focus on the classroom as a site of investigation. Scholars have examined, for instance, how students can use multiple media and semiotic modes to construct texts that express meaning in different ways: whether through oral essays or video documentaries. Taking this approach might be useful pedagogically—e.g., in teaching students about audience—but it does not necessarily help them to engage with the types of problems they will encounter in their writing outside the writing classroom: whether in their disciplines, their workplaces, or their communities.

Looking to the role of new media in scientific practice helps move the study of writing into contexts where people—in this case, a theoretical physicist—are using technological and semiotic resources not just to express meanings textually but rather to solve specific problems. Indeed, with Jordan in particular, using multiple media, technologies, and semiotic modalities is not an end in itself but rather a means to an end that involves the construction of new conceptual realities. It is possible to envision a writing classroom—and writing curricula—that draws upon this thinking to situate instruction in real problems and exigencies with which students can engage—not only as students but also as citizens and members of an increasingly networked and globalized
society. Many scholars have taken this approach in their teaching and continue to elaborate upon and push at the boundaries of writing, text, and literacy. Additional research can be done, however, to elaborate upon theories of multimedia and multimodality by investigating the ways in which multimedia and multimodal texts respond to specific social, cultural, technological, and political issues. Starting with the socio-cultural activities within which texts are embedded outside the classroom, I would argue, offers one powerful way to improve pedagogy that would aim to equip students with the tools they need to function as literate individuals and persuasive communicators in the 21st century.
Chapter 6

Conclusions, Directions, and the Study of Writing in Science

I. Introduction

This dissertation has explored some of the material, technical, and symbolic dimensions of writing and multimodal text production in a liquid crystal physics and materials science research institute. In undertaking and following through on this study, I have made progress toward answering my original research question: how is writing understood and enacted in the context of scientific research and communication? This inquiry, however, has also raised some additional questions that are worth discussing. For this concluding chapter, I thus retrace some of the steps I have taken, reflect on the ways in which my research might be elaborated upon through further inquiry, and discuss the value of my dissertation for the study and teaching of writing.

I begin by recounting some of the challenges I faced in this project, how I addressed them, and what this process has taught me about the study of writing in expert settings. Second, I explain how my case studies have contributed a holistic understanding of writing as a mode of communication and a multimodal literacy practice; I also examine how these studies might be made more robust through further investigation. Third, I respond to the question that has motivated my study and, in doing so, begin to articulate the substantive theory of writing that has emerged over the course
of my inquiry. Fourth, I discuss the general ways in which findings from this project can be improved upon through additional research and analysis. And finally, I conclude this chapter by making some suggestions about what my dissertation offers for the field of writing and rhetoric studies.

Methodological Challenges

Becoming immersed in a complex scientific workplace and culture was perhaps the most difficult challenge I faced throughout my investigation. Indeed, undertaking a study of writing in a scientific research institute, for this English graduate student, was not unlike visiting a foreign country: I had to learn some of the language and customs if I wanted to draw any sort of meaningful conclusions about writing as it is enacted in the context of scientific practice. Suffice it to say that this did not occur only through observations, interviews, and other qualitative methods of data collection and analysis. Learning about science as a practice—and writing as part of that practice—also involved countless interactions and conversations with scientists themselves. For those most closely involved with my study, I suspect that my presence in the laboratory—observing, taking notes, asking questions—was as novel to them as their work was to me. I thankfully found them to be as patient with my inquiries as they were generous with their time in talking to me about their work and their passion for science.

Interacting with scientists provided many insights into scientific writing that I might not have discovered otherwise. Just as important, these interactions also taught me a great deal about the nature of my own inquiry. There is a temptation in qualitative
research, I think, simply to narrate one’s story and expect readers to find it believable—at least, if it is told well. I will admit to having done some of my own “storytelling” in this dissertation as a way to explain the complexities that attend the study of writing in an expert scientific setting. Yet I have also attempted to ground my narrative through detailed examination of the media, technologies, and semiotic systems that scientists deploy to make their work analyzable and communicable both in and outside the laboratory. Keeping this in mind, I have approached my inquiry—and my reporting of it—not with the intent to unveil some indisputable truth about writing or science. Rather, my aim has been to offer an honest, accurate, systematic, and, I hope, engaging account of writing as it understood and enacted by working scientists.

Constructing such an account has involved a substantial personal and intellectual commitment not only to describe social action—e.g., how scientists spend their time—but also to understand its broader significance within the group, the Institute, the liquid crystal community, the scientific community, and so on. Coming to grips with the symbolic dimensions of scientific practice involved a similar undertaking: accounting for writing is more complicated than looking to the semiotic resources deployed in the laboratory or to the texts that scientists produce to disseminate their findings to various audiences. Indeed, each inscription, each text, and each practice I observed has a life and a history of its own that signifies meaning beyond what my time spent conducting research could possibly reveal. Gaining access to that meaning has nonetheless been part of my aim as a researcher. I would like here to recap some of this experience, explain its
relevance to research and teaching, and point toward some directions that this work can be developed and improved upon through further investigation.

II. Case Studies of Writing in Scientific Practice

The three case studies that form the core of this dissertation each contribute a unique perspective to my account of writing, text production, and media reproduction in scientific practice. In this section, I discuss each study individually, examine what it suggests about the material, visual, and computational dimensions of scientific writing, and suggest how findings can be extended through additional research and analysis. I then examine these studies together and argue for an integrated view of writing and literacy as enacted in the context of scientific research and communication. More specifically, looking to each of these studies reveals the complex material, technical, and semiotic practices with which scientists engage; looking at them together likewise reveals the complex ways in which materials, technologies, and semiotic systems shape what it means to theorize writing as a mode of communication and a complex literacy practice.

Materiality and Modality

Chapter 3 examined the laboratory notebook as a site of technical and textual integration through which one chemist, Dave, represents and comes to grips with the materiality of his practice. This process involves more than simply recording procedures and outcomes on a printed page; indeed, it involves creating and deploying any number of inscriptions—photographs, visual spectra, TLC plates—that are a fundamental part of
his technical work. The relationship between technical work and textual (re)production in this case involves a dynamic relationship between Dave, his instrumental and semiotic tools, and the object of his research: material samples that constitute a form of knowledge in their own right. Yet these materials do no start out as “epistemic objects.” Indeed, they must be confirmed as such through procedures like thin layer chromatography—and their output, TLC plates.

The TLC plate is an instrumental object and a semiotic resource that Dave uses to check and confirm the content of his material sample; it also becomes a textual object that gets deployed alongside other inscriptions—e.g., chemical structures, photographs, visual spectra—in order to render the production process into a durable form of procedural knowledge. The concept of literacy here involves a tangible, material dimension that has yet to be fully theorized in writing and literacy scholarship. More specifically, the TLC plate, as a three-dimensional object, signifies not only as a visual and tactile semiotic modality—something that existing scholarship can help to explain—but also in relation to the material process through which it was enacted and created. Thus, approaching this object as not only as a textual representation but as evidence of a complex literacy practice is crucial for understanding the way in which it signifies and affords for Dave’s research and communication.

Analyzing the material and semiotic dimensions of Dave’s notebook, however, is not an end in itself. Indeed, a more comprehensive analysis might examine in greater detail the specific scientific procedures that he undertakes and represents textually. For instance, when I discuss the relationship between TLC as a process and the TLC plate as
an instrumental-cum-textual inscription, I remain at a relatively descriptive, object-oriented level. Simply put, I do not delve into the science behind Dave’s syntheses and how his practice relates to the production and characterization of liquid crystal materials as an object of study. This has been a necessary strategy given the extent of my own (in)expertise. Even so, additional research could investigate this science more closely and thus understand better the choices Dave makes when representing his work as knowledge. More specifically, such an investigation might reveal whether and how his choices of representation relate to a history of symbolic and representational activity in the field of chemistry—and thus how his work takes part in that history and even extends it through his own localized representational practices.

Visualization and Text Production

Chapter 4 examined the relationship between *in situ* visualization and text production as a way to explore the semiotic and rhetorical dimensions of visual inscription in experimental physics. More specifically, I investigated how John and Morgan’s visual production practices in the laboratory—and specifically those that resulted in the Fringe image—provide material and symbolic grounds for generating additional inscriptions and producing a multimedia presentation. Experimental knowledge, in this case, results from the relationship between technical work performed in the laboratory—e.g., the production and orchestration of an experimental system—and the textual work performed in a multimedia presentation—e.g., the way in which technical work is represented visually and multimodally. Both are rhetorical in some
manner of speaking: the experiment in its design, creation, and execution qua method, and the presentation in its design, creation, and execution qua means of delivering and presenting findings related to the experiment and the method it is designed to enact.

Writing for John is specifically an integrative practice through which he “assembles” various components of his work into a multimodal text. He does this, in part, through visual inscriptions that he creates in the laboratory or uses to document his laboratory work. Those that he uses in his presentation—e.g., schematic, photographs, animation—each afford in specific ways based upon the way in which they represent in John and Morgan’s experimental work. The schematic, for example, helps convey the logic of the experiment; the photographs help convey the richness and aesthetic of the setup; and the animation helps convey the action involved in aligning particles through the application of an electric field. The concept of literacy in this practice involves not only the in situ production and interpretation of visuals; it also involves the way in which the experimental process itself gets represented visually and persuasively in a multimedia presentation.

Similar to my experience in the chemical laboratory, however, I experienced difficulty in coming to grips with physics experimentation—a practice that requires deep knowledge of instruments, software programs, and mathematical theory (to name just a few). Further research would accordingly examine John and Morgan’s work more deeply from the perspectives of instrumental and theoretical problems they are attempting to work through in producing a new method. I could, for example, become better versed in the method John is developing (what it is, what it does, how it is enacted) so that I could
better understand how the Fringe, as a visual datum, helps to analyze and represent it. Likewise with the materials and instruments involved in this experiment: understanding the sample and the way in which John is attempting to work with and characterize it would offer useful insight both into his method (as object) and, more broadly, into his and the group’s broader research objectives for studying and technologically developing liquid crystal materials.

Writing Theoretical Physics

Chapter 5 examined the practice of theoretical physics as a way to explore what constitutes writing in the context of scientific research and communication. This case study focused on one physicist, Jordan, and the work he performs to model and simulate material systems. Taking this approach specifically enabled me to gain insight into the different forms that writing takes in theoretical and computational work and, additionally, the way in which that works gets represented—i.e., “pulled together”—into manuscript form. Writing in this case can be understood in at least two ways: 1) as a semiotic modality through which Jordan theoretically describes and computationally enacts objects and processes; and 2) as an integrative practice through which Jordan assembles the diverse components of his theoretical and computational research into an in-progress scientific text.

Writing in theoretical physics takes many forms, but for this case study I found two in particular worth examining in some depth: writing that describes (e.g., mathematical expression) and writing that enacts (e.g., programming code). Together,
these forms of writing enable Jordan to model liquid crystal materials and enact those models based on a set of computational constraints. In doing so, he can probe the conceptual dimensions of materials that the group might ultimately produce in the chemical laboratory or experiment with in the optics laboratory. Writing is instrumental to this process in more ways than one. Significantly, it provides a basis for constructing and characterizing theoretical models; yet it also provides a way to integrate findings from that research into a genre-specific text that can communicate findings—and possibly, for Jordan, contribute to a dissertation project. Both types of writing—writing-as-mode and writing-as-integration—are essential to the theoretical and computational work that he performs on a day-to-day basis.

Similar to my other case studies, I faced challenges in studying a theoretical physicist at work. Indeed, while each practice I investigated was complex, theoretical physics was particularly thorny in the sense that it involves a great deal of analytical work that is beyond my expertise to understand—and beyond my ability to observe and document in explicit ways. This expertise might include an equation Jordan solves to construct a theoretical model or a piece of code he writes in order to enact that model in a particular way. The concept of “writing” here is intuitive in some sense—e.g., it fulfills some instrumental or communicative function—but I am still left to question, and to wonder, what and how these forms of writing relate to the complex conceptual objects that Jordan models and simulates. Additional study would investigate these relationships and examine more closely how different types of writing inform the relationship between this theoretical and computational work. There is also reason, I believe, to continue
examining the concept of visualization from a computational perspective—this is a growing field that will continue to generate new and important insights into the relationship between writing and knowledge production in the sciences as well as other socio-cultural domains.

Each case study brought with it a unique set of insights related to writing and literacy. Each one also brought a unique set of challenges for me as a researcher. With all three, for instance, I experienced the same general difficulty: namely, interpretation was always a factor due in part to my lack of scientific training and due in part to the interpretive nature of scientific inquiry. This is not to suggest that science is wholly interpretive. Indeed, physical reality exists, and scientists have been able to describe and predict it with remarkable accuracy. Yet the art and science of experimental and theoretical inquiry—at least, from my own perspective—involve what I would refer to as “interpretive sensitivity”—a type of embodied knowledge that enables scientists to grapple with and understand complex physical and conceptual objects and processes. For Paul in the chemical laboratory, this involves producing materials; for John and Morgan in the optics laboratory, this involves characterizing materials and creating new methods for doing so; and for Jordan working in his office, this involves modeling and simulating conceptual realities that can complement and extend material production and physics experimentation in new and interesting ways.
III. Steps Toward a Substantive Theory of Writing

Based on my case studies, a theory of writing would need to account for a range of material, technical, and representational practices. Yet writing is no more and no less to these scientists than what they need it to be given the work in which they are involved: whether producing materials, experimenting with them, or modeling and simulating them. This is one reason why the theory that I would propose, while still in an early stage, would not start with the analysis of texts or even the various inscriptions through which they are assembled. These are both relevant objects of analysis, and much important scholarship has explored them in great detail. The theory I propose here instead focuses on practice as a way to understand writing and representation—both in science and more broadly.

I have argued throughout this dissertation that writing in scientific research and communication involves a complex negotiation of material, technical, and symbolic resources. While I would not claim that I have exhausted or accounted for the entire spectrum of writing or representation in the Institute—let alone the physical sciences—I have, I believe, been able to capture some important features about “what writing is” and “what writing does” for the scientists involved in my study. Based on my explorations, I would posit the following three categories in response to my original research question: how is writing understood and enacted in the context of scientific research and communication? Together, these categories help form a basis for answering this question and articulating my own substantive theory of writing.
1. Writing is a material form of inscription. When I talk about writing as inscription, I do not mean to characterize all forms of inscription as writing per se. Rather, I would look to inscriptions as semiotic resources—e.g., linguistic script, mathematic expression, graphic display—in order to examine how they afford and constrain for the specific situations—e.g., technical, communicative—in which they are deployed. Indeed, there is reason to differentiate, say, between a graphic display and stretch of linguistic script. Not only do these resources communicate in different ways; they also afford differently for particular tasks. A graph, for instance, might afford for the visual display of quantitative data; and linguistic script, for instance, might in turn afford for the contextualization and explanation of that visual display. Both might be considered “writing” in a broad sense—e.g., insofar as they are used to inscribe—but ultimately are used to perform quite different work.

Rather than proposing a theory of writing that attempts to account for all forms of inscription, or the way in which inscriptions become culturally recognizable semiotic modes, I would instead argue that writing must be “disciplined.” In other words, researchers and teachers alike should have a concept of writing that can more or less be agreed upon—whether as an object of study or a teaching subject. This could mean, for instance, that an English professor and Physicist can agree, generally, on their concept of writing yet have enough room to understand that writing in English classes involves a quite different set of practices than writing in the laboratory or writing for a scientific audience. The common ground, here, might be that writing is not beholden to one type of
inscription or semiotic modality—e.g., linguistic script—yet is not so comprehensive as to encapsulate all acts of inscribing.

II. Writing is an integrative literacy practice. The question “how is writing understood and enacted in scientific research and communication?” cannot be answered by looking only to material forms of inscription. I take a step closer to answering this question, however, by looking to writing as both an inscriptive and integrative literacy practice. More specifically, writing in science involves the “assembly” of different semiotic resources (modalities, inscriptions) that scientists use and produce to transform the material and technical dimensions of their work into durable and persuasive forms of communication. Yet the process of integration involves more than the act of assembling inscriptions into the same graphic space; it also involves an integration that takes place through the verbal language that scientists use to contextualize and explain their theoretical and experimental findings.

An additional dimension of writing as an integrative literacy practice can be explored by asking the question, “What actually gets integrated or assembled into scientific texts?” This seems like a simple question on the surface of it. After all, inscriptions are what get assembled. Yet, drawing together diverse semiotic resources into the same graphic space involves more than specific inscriptions or stretches of linguistic script. I would argue that what also gets assembled in scientific texts is scientific practice itself: the material, technical, and symbolic work that scientists perform in order to probe the physical and conceptual dimensions of the known (and
unknown) universe. Conducting textual analysis alone is useful but ultimately limits the richness of interpretation that comes from examining scientific practice—and how, specifically, it gets rendered textually and multimodally for the sake of communication.

III. Writing is a constructive activity. Writing is a constructive activity in many respects, not least because it is deeply embedded in the work scientists perform in their day-to-day research—whether working through a problem on the white board or writing down information on a piece of scrap paper. As a material form of inscription, writing enables scientists to visualize their work and make it analyzable and communicable in and outside the laboratory; and as a practice, writing enables scientists to draw together their findings and present them in a rhetorically persuasive way. Writing, in these ways, constructs, first, insofar as it mediates between scientists and the objects of their study, and it constructs, second, insofar as it is used to communicate between scientists and various audiences about those very objects.

Yet writing is constructive in other ways as well. With each practice I studied, writing in some way brought new insights into the work being performed. With Dave, this involved TLC and the TLC plate: the plate is a site of interaction/interactivity that constructed for him a view of a material sample and the process through which it was synthesized. Integrating this plate into his notebook in turn constructs a more holistic view of his production process and thus the sample as an epistemic outcome of that process. With John and Morgan, this involved creating a Fringe image in order to interpret their experiment in the laboratory and to create material for analysis, further inquiry, and disciplinary communication. Integrating visuals into the multimedia
presentation in turn constructs a more holistic view of the experimental process and thus the method as an epistemic outcome of that process. With Jordan, this involved the model and simulation: the simulation is a site of interaction that constructed for him a view of the material system he was modeling. Integrating this simulation into a manuscript in turn constructs a more holistic view of the theoretical model and the computational process that went into enacting and investigating it.

Looking to writing as a mode, writing as an integrative literacy practice, and writing as a constructive activity helps to make sense of the broad spectrum of representations I observed while studying scientists at work. Ultimately, however, I would not advocate for an exclusive or exclusionary definition of writing per se. Indeed, to do so would be to limit what is actually known about writing as it is enacted in the sciences and across other, diverse cultural settings. Rather, I would focus on meaning making in the context of practical work and communication as a way to ground what we—the field of writing and rhetoric studies—know and want to know about the role of writing in human activity.

IV. Constraints and Necessary Explorations, Or, Curbing My Enthusiasm

The study of writing is fraught with challenges. Whether exploring the cognitive processes involved in composing texts or exploring settings where writing enacted in situ, researchers must contend with any number of problems and obstacles. With this dissertation project, I have encountered many challenges of my own—as a researcher, as a human being—that have taught me a great deal about writing and research but that have
nonetheless constrained to some extent what my findings can actually say about writing
in the context of scientific practice. I share some of these constraints in an attempt to be
forthright about the difficulty of undertaking research in an expert scientific setting.

Foremost, perhaps, I have discovered the extent of my own (in)expertise when it
comes to studying writing in the context of chemical physics research. I have attempted
to overcome this constraint in various ways—e.g., through long term study, by taking
part in as many scientific practices as I could—but in the end must concede that I can
offer but a useful and perhaps provocative description of writing in the context of
scientific work. I would add, however, that such constraints have also been productive
from a research standpoint: that is, had a more expert researcher, or even a scientist,
conducted a similar inquiry, he or she might focus on wholly different objects of analysis
that may have led to different findings. Those findings might be as (equally) useful as
my own—if I can make that assumption about my own work—but may not have teased
out some of the interesting insights I have gained into the material visual, and
computational dimensions of scientific writing and literacy.

Second, I have been able to discuss only part of the data I have collected over the
course of my research. Spending several months taking field notes, writing theoretical
memos, collecting inscriptions, visually documenting my work, and becoming part of a
scientific culture, I have indeed generated an abundance of resources for analysis.
Distilling that data into individual case studies and chapters was a necessity for writing
this dissertation; yet also by necessity I have been forced to discuss only a small part of
my experience and what I have learned about writing as part of scientific research and
communication. Even so, I would say that the findings I do share speak to the important issues of writing that I discovered throughout my study. Further analysis would, of course, explicate these issues in greater detail as they relate to other participants involved in my study.

Third, I need to explore more thoroughly the science behind what I have investigated and described in the way of writing and representation. While I have remained primarily at a descriptive level—at least, this has been my intent—throughout this dissertation, it would help to know some of the content behind the practices I have studied so I could more fully explore the broader aims behind the practical work that scientists perform. This would in turn enable me to understand better the choices they make when representing their work and, thus, the “rhetoric” of science as it is practiced in the laboratory and represented in more public texts (like multimedia presentations and research articles). Ultimately, I realize that I will never become as expert as the experts I have investigated. I could, however, gain enough knowledge to start and maintain interdisciplinary collaborations that lead to better and more robust understandings both of written communication and of science as a domain of human activity.

Finally, based upon the first three constraints, it is evident that I have only begun to tap into the richness and complexity of writing in the Institute let alone writing in other scientific settings, disciplines, and fields. Indeed, while I have worked hard to investigate the concept and practice of writing as understood and enacted by working scientists, I have only begun to answer the questions I have generated about writing in general and writing in science in particular. Yet while I see this is a constraint, I also believe that it
speaks to the need for research that continues to investigate writing through qualitative
inquiry in and across diverse sites of scientific practice. This, in fact, will potentially
occupy my own research agenda for the foreseeable future.

V. General Conclusions

This study has shown that writing in scientific practice involves a complex
negotiation of materials, technologies, and semiotic resources. For scientists in the
Institute, writing specifically serves key functions for the production of material samples,
development of experimental methods, and construction of theoretical models and
computational simulations. Within each of these practices, scientists bring different
tools, techniques, and domains of expertise to bear on a generally common object of
knowledge: liquid crystal materials. These materials are both a physical and conceptual
outcome of scientific work. They might also be considered a dynamic referential
outcome of this work insofar as scientists in this site are often engaged in a dialectic
inquiry between the object of their study (physical and conceptual materials) and the way
in which they represent, warrant, and circulate that object visually and textually for each
other and for broader audiences.

Writing in the context of scientific practice thus serves multiple purposes. As a
mode of communication, it enables scientists to record their work and communicate it in
various ways: whether through linguistic script, chemical structures, or TLC plates. As a
literacy practice, it enables scientists to assemble the substance of their work—e.g.,
inscriptions—into durable, persuasive texts: whether through laboratory notebooks,
multimedia presentations, or theoretical manuscripts. And as a constructive activity, writing enables scientists to visualize and represent the object of their study for themselves in the laboratory and for audiences outside the laboratory. Writing, so understood, is at once a technical, rhetorical, and a knowledge-productive activity through which scientists make and communicate meaning related to the physical world that they inhabit and that they construct through their research.

A study such as this helps to contextualize research on writing and multimodal literacy by grounding these concepts in a specific site of human activity. It accordingly helps to contextualize the teaching of writing in an age of new media. If instructors, for instance, want to improve what students understand about writing for disciplinary, technical, scientific, or, in general, professional workplace contexts, it is important to explore those contexts and interrogate what writing is for specific communities of practice. With physics in particular, it is essential that one account not just for genres like laboratory reports or published articles; indeed, one must also account for the media, technologies, and semiotic systems through which knowledge is produced and distributed through these texts. Doing so helps to inspect more closely the concept of writing, understand it as scientists do, and bring that knowledge to bear on what we—as researchers and teachers—know about writing and multimodal literacy based upon the theories that inform our teaching and research.

My investigation has taught me that it is not enough to look only at completed texts to understand scientific writing—whether as a semiotic mode, a literacy practice, or a constructive activity. To do so would be similar to learning about ship navigation by
studying pictures in a book: while those pictures might well teach us how to conceptualize life at sea, we only get our sea legs by climbing aboard. This is not to say that I can now navigate scientific practice or scientific writing as a seasoned expert. Indeed, I am still just the “English guy” who has limited knowledge of what I observe and, thus, what I can ultimately understand about writing in scientific practice. Yet by keeping my analysis grounded in data, and by committing myself to a long term research project, I have begun to show that writing and texts are not merely outputs of scientific inquiry or means of disseminating knowledge—writing and producing texts, rather, is fundamental to science as a human enterprise.
Appendix A: Chapter 2 Illustrations

Table A.1
Dissertation Trajectory by Date and Research Activity

<table>
<thead>
<tr>
<th>Date</th>
<th>Research Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 2006-</td>
<td>Wrote and submitted proposal for a study of writing in the Institute based upon problem, questions, and proposed methodology for researching multimodal text production in a scientific context.</td>
</tr>
<tr>
<td>January 2007</td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>Met with Dr. Maxwell to discuss proposal, scope of research, and issues of access and confidentiality.</td>
</tr>
<tr>
<td>February</td>
<td>Invited by Dr. Maxwell, I give a brief (3-5 minute) presentation to board of directors at the Institute. Accepted into the site.</td>
</tr>
<tr>
<td>March-May</td>
<td>Make select visits to the Institute and various seminars it sponsors to make my presence familiar in the research space.</td>
</tr>
<tr>
<td>August</td>
<td>Gain approval for research from Kent State University’s Institutional Review Board.</td>
</tr>
<tr>
<td>September-December</td>
<td>Begin regular visits to Institute anticipating an approximately 4-month research trajectory. Immersion: daily visits (5 days/week) anywhere from 5-8 hours per day (~30+ hours/week).</td>
</tr>
<tr>
<td>January-March 2008</td>
<td>Extend my research trajectory and immersion in Institute.</td>
</tr>
<tr>
<td>March</td>
<td>Present work at the American Physical Society March Meeting.</td>
</tr>
<tr>
<td>April-June</td>
<td>Selective visits (~20 hours/week).</td>
</tr>
<tr>
<td>Time Period</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>September-Present</td>
<td>Weekly visits for morning coffee, ongoing discussions, selective interviews and checking of data analysis. Begin write-up of research. Begin drafting dissertation chapters.</td>
</tr>
<tr>
<td>January-May 2009</td>
<td>Write-up of research, conceptual integration, and modeling of writing, literacy, and multimodal text production in the Institute. Dissertation chapters emerge and are revised. Articulate an emergent theory of writing and text production in a scientific workplace setting.</td>
</tr>
</tbody>
</table>

Table A.2
*Observed Actions and Explanation*

<table>
<thead>
<tr>
<th>Observed Actions</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building an apparatus in order to conduct an experiment.</td>
<td>Scientists spend time piecing together different parts in order to conduct an experiment they have envisioned.</td>
</tr>
<tr>
<td>Constructing equipment.</td>
<td>Scientists spend time assembling new devices.</td>
</tr>
<tr>
<td>Conducting experiments using equipment and apparatuses.</td>
<td>Scientists doing work using the equipment and apparatuses they have designed and constructed.</td>
</tr>
<tr>
<td>Moving equipment and arranging the laboratory space.</td>
<td>Scientists must find ways to utilize space functionally for experiments (e.g., getting computer monitor close to table without touching it) as well as pragmatically (making sure nobody trips over cords, tubes, etc.</td>
</tr>
<tr>
<td>Mixing chemicals to create material for experiments.</td>
<td>Scientists in chemical laboratory weighing, measuring, and/or mixing different materials that will be used at a later time.</td>
</tr>
<tr>
<td>Mixing chemicals to create material for a specific experiment.</td>
<td>Scientists in chemical weighing, measuring, and/or mixing different materials to be used in the near future for a specific experiment.</td>
</tr>
<tr>
<td>Making notes in lab notebook.</td>
<td>Usually occurs when scientists are making materials for experiments. This is an important feature for later replication and reference.</td>
</tr>
<tr>
<td>Labeling materials.</td>
<td>Usually occurs when scientists are making materials so they can be used for current</td>
</tr>
<tr>
<td>Activity</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Programming (making a code).</td>
<td>Scientists construct code in order to get a result, usually from data they have collected. E.G.: Date is in the form of numbers and gets translated, through the program, into a visual representation.</td>
</tr>
<tr>
<td>Debating.</td>
<td>Scientists debate something, usually in the context of problem solving. This could refer to anything from the placement of equipment to and equation.</td>
</tr>
<tr>
<td>Posing problems and then trying to solve them.</td>
<td>Scientists asking specific questions about why something is the way it is.</td>
</tr>
<tr>
<td>Asking questions.</td>
<td>Scientists’ general inquiry. E.G.: “Why does this happen”?</td>
</tr>
<tr>
<td>Using computers to interface with experiments.</td>
<td>Scientists have computers hooked up to apparatuses and equipment that are being used in experiments. The monitor thus, in effect, becomes the interface between scientists and material experiment (though the experiment itself is also a material interface).</td>
</tr>
<tr>
<td>Using computers to interface with data.</td>
<td>Scientists entering data into Excel or other programs for later use. See “Visualizing Data” below.</td>
</tr>
<tr>
<td>Using computers to interface with each other.</td>
<td>Scientists sending email, corresponding.</td>
</tr>
<tr>
<td>Visualizing data.</td>
<td>Scientists enter data into program and produce a visual display.</td>
</tr>
<tr>
<td>Transferring information.</td>
<td>Scientists move data from one computer or program to another.</td>
</tr>
<tr>
<td>Reading.</td>
<td>Scientists reading for function (e.g., vial label), procedures (e.g., manual), or directions (e.g., constructing equipment).</td>
</tr>
<tr>
<td>Taking photographs.</td>
<td>Scientists using digital camera to capture material, apparatus, experiments. These usually would go into a written text or a Website.</td>
</tr>
<tr>
<td>Making posters.</td>
<td>Scientists display data for particular audience. May include other scientists or public generally (LC Day, Scholars Day).</td>
</tr>
<tr>
<td>Making notes.</td>
<td>Scientists writing in a lab notebook or any</td>
</tr>
<tr>
<td>Activity</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Checking against text to replicate experiment or test equipment.</td>
<td>Scientists using text to do something like see why a laser is working the way it is. This often involves getting the computer “talking” to a device and then understanding what is happening.</td>
</tr>
<tr>
<td>Looking for tools and other devices.</td>
<td>Scientists, perhaps because they share much of their equipments, are often looking for where they can find a “guy”— anything from a screwdriver to a block of metal.</td>
</tr>
<tr>
<td>Using tools.</td>
<td>Scientists are constantly building apparatuses; this involves using a range of tools to do so.</td>
</tr>
<tr>
<td>Cleaning up spills.</td>
<td>Sometimes things don’t go as planned and mistakes need to be cleaned up.</td>
</tr>
<tr>
<td>Explaining work (to others, to me).</td>
<td>Scientists are often asking each other questions and explain their work to each other.</td>
</tr>
<tr>
<td>Showing experiments.</td>
<td>Scientists seem to like what they do and thus like to demonstrate what they do for visitors.</td>
</tr>
</tbody>
</table>
## Variable

<table>
<thead>
<tr>
<th>Participants</th>
<th>Task</th>
<th>Task</th>
<th>Task</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Primary</td>
<td>Dave</td>
<td>John</td>
<td>John</td>
<td>Jordan</td>
</tr>
<tr>
<td>b. Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Objective

<table>
<thead>
<tr>
<th>a. Immediate</th>
<th>b. Long Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create materials that will be used in experiments</td>
<td>Arrange instruments on the optics table.</td>
</tr>
<tr>
<td>Run an experiment.</td>
<td>Write computer code to create a simulation.</td>
</tr>
</tbody>
</table>

## Mediational Tools

<table>
<thead>
<tr>
<th>a. Material</th>
<th>b. Instrumental</th>
<th>c. Symbolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials, scale, various tools (scoop, brush), lab NB and stylus, various sign systems, ways to mix, heat, etc.</td>
<td>Lasers (argon, dye), mirrors, detector, camera, computer, software, material sample, electrodes, pipette, solution (Toluene).</td>
<td>Lasers (argon, dye), mirrors, detector, computer, software, material sample, electrodes, pipette, solution (Toluene), verbal language.</td>
</tr>
<tr>
<td>Computer(s), software, code, various texts (Fortran, journal articles, scrap paper, properties sheet).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Outcomes

<table>
<thead>
<tr>
<th>a. Material</th>
<th>b. Instrumental</th>
<th>c. Symbolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material sample, entries in lab notebook, labels, ability for other experiments to continue working.</td>
<td>Experimental setup that represents a translation or a way to test existing theory.</td>
<td>Fringe image displayed on screen—constitutes data that can be collected and analyzed.</td>
</tr>
<tr>
<td>Simulation of material (e.g., ellipsoid).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Link(s) to other tasks

| Sample can be used by scientists in the group or sent out to scientists in other laboratories. | John can run his experiment. | Fringe is analyzed as data in John’s office. | Simulation is run and results are analyzed as data. |

---

*Figure A.1. Task Heuristic*
Table A.3
Practice Context for Production, Experimentation, and Simulation

<table>
<thead>
<tr>
<th>Practice Context</th>
<th>Production</th>
<th>Experimentation</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>People</td>
<td>Dave</td>
<td>John, Morgan</td>
<td>Jordan</td>
</tr>
<tr>
<td>Primary Space</td>
<td>Chemical Lab</td>
<td>Optics Lab</td>
<td>Office</td>
</tr>
<tr>
<td>Practice Objectives</td>
<td>Synthesize and produce liquid crystal materials (LCMs). Create and document procedures.</td>
<td>Characterize LCMs; develop experimental method/technique.</td>
<td>Characterize LCMs; develop mathematical models and computer simulations.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Material</th>
<th>Instrumental</th>
<th>Symbolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Weighing, measuring, synthesizing materials. Testing validity of findings through various techniques.</td>
<td>Set up productive system for producing materials that can be used in experimentation in and outside the group/laboratory.</td>
<td>Generate inscriptions; document procedures in lab notebook using and supplementing inscriptions.</td>
</tr>
<tr>
<td>Instrumental</td>
<td>Set up experimental system for measuring and testing the susceptibility of materials to electric fields.</td>
<td>Set up computational system for modeling, simulating, and enacting the relationship between light and matter.</td>
<td>Generate visual data; analyze data and render it into inscriptions that can be deployed textually.</td>
</tr>
<tr>
<td>Symbolic</td>
<td></td>
<td></td>
<td>Create theoretical model; run simulation to generate and data. Render results of analysis into graphic display.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Material/Conceptual</th>
<th>Instrumental/Procedural</th>
<th>Symbolic/Textual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material/Conceptual</td>
<td>LCM Sample</td>
<td>Procedural knowledge of LCM production; connections to other laboratories through transport of materials and textual procedures.</td>
<td>Thin Layer Chromatography Plate; Notebook</td>
</tr>
<tr>
<td>Experimental Method</td>
<td>Procedural knowledge of LCM experimentation; new method for measuring susceptibility of LCM to electric fields.</td>
<td>Fringe Image; PowerPoint</td>
<td></td>
</tr>
<tr>
<td>Theoretical Model</td>
<td>Procedural knowledge of LCM simulation that can generate data.</td>
<td>Simulation; Research Article</td>
<td></td>
</tr>
<tr>
<td>Practice</td>
<td>Components</td>
<td>Procedural Tasks</td>
<td>Indexical Reference</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Material Production</td>
<td>Components of Material System (e.g., materials, instruments for measuring and synthesizing)</td>
<td>Material Procedures (synthesis)</td>
<td>TLC (confirms): different chemicals become “sample” through synthesis.</td>
</tr>
<tr>
<td>Experimentation</td>
<td>Components of Experimental System (e.g., instruments, programs, material for characterizing)</td>
<td>Experimental Procedures (testing, measuring, characterizing)</td>
<td>Fringe Image (enables): method becomes visual and open to analysis and confirmation.</td>
</tr>
<tr>
<td>Simulation</td>
<td>Components of Computational System (e.g., theory, program language, simulated material for characterizing)</td>
<td>Computational Procedures (modeling, programming, simulating)</td>
<td>Simulation (enacts): model enacted to generate data given programmed conditions.</td>
</tr>
</tbody>
</table>
Appendix B: Chapter 3 Illustrations

Figure B.1. Chemical Laboratory, View 1
Figure B.2. Chemical Laboratory, View 2

Figure B.3. Chemical Laboratory, View 3
Figure B.4. Dave’s Notebook
Figure B.5. Notebook in Use

Figure B.6. Notebook in Production
Supplies were now low for the cholesterol material.

To make this material, we followed the procedure developed by Dr. Fuks, L. This complete procedure is described below.

Chemical structure:

\[
\text{Chemical structure:}
\]

\[
\text{The reaction was started in at the}\]
Figure B.8. Notebook Excerpt—
Spectrum, Chemical Structure, Linguistic Script
Figure B.9. Material Sample
Figure B.10. Notebook Excerpt—Chemical Structure, Spectrum, and TLC Plate
Figure B.11. Dave Marks TLC Plate with Pen
Figure B.12. Dave Applies Chemical to TLC Plate
Figure B.13. Dave Completes TLC Procedure Using UV Light
Figure B.14. Notebook with TLC Integration
Figure C.1. Photo of Experimental Setup Taken by John
Mach-Zehnder: Measuring phase as a function of applied voltage

- Observed a fringe pattern:
- Width of field
- Spacing between maxima: 6 mm
- Shift at 70% voltage: 3 mm
- Without tolerance -> no response
- The fringe shift is continuous w/ continuous increase in voltage

Figure C.2. Schematic of Experimental Setup in John’s Notebook
Figure C.3. Whiteboard Activity in the Optics Laboratory
<table>
<thead>
<tr>
<th>Text/Inscription</th>
<th>Descriptive Form and Function</th>
<th>Perceived In Situ Affordance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scholarly Posters</td>
<td>Text that integrates many semiotic modes and displays findings from experimental work.</td>
<td>Resource for scientists to build on existing work produced in the lab and extend that work through ongoing replication and findings.</td>
</tr>
<tr>
<td></td>
<td>Provides visual, on-site information related to experiments that are being replicated and/or extended in the laboratory.</td>
<td></td>
</tr>
<tr>
<td>Journals/Articles</td>
<td>Text that integrates many semiotic modes; typically a peer-reviewed resource that takes genre-specific form.</td>
<td>Provides information on research produced in/outside the lab—e.g., theory, method—that can supports or (dis)confirms experimental findings.</td>
</tr>
<tr>
<td></td>
<td>Mediates between John, physical theory, material and technical objects, and methods through which his experiment is enacted.</td>
<td></td>
</tr>
<tr>
<td>Frequency Sheet</td>
<td>Text (table form) that provides information in a bounded space.</td>
<td>Provides a range of necessary information in a single, accessible textual space.</td>
</tr>
<tr>
<td></td>
<td>Mediates between John, argon laser, and experiment.</td>
<td></td>
</tr>
<tr>
<td>Binders</td>
<td>Reams of paper related to various equipment in the lab.</td>
<td>Provides information for constructing equipment, instruments, and materials in multiple volumes in an accessible textual space. Helps keep the lab functioning as an active research space.</td>
</tr>
<tr>
<td></td>
<td>Location is on the optics table/bench where work is conducted.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mediates between John, equipment, instruments, experiment.</td>
<td></td>
</tr>
<tr>
<td>Sheet with Phone #s</td>
<td>Text that contains contact information for group members.</td>
<td>Facilitates and perhaps encourages contact between group members.</td>
</tr>
<tr>
<td></td>
<td>Mediates between group members and each other.</td>
<td></td>
</tr>
<tr>
<td>Business Card</td>
<td>Text with contact information for equipment specialists.</td>
<td>Resource for keeping the laser working and thus keeping experiments moving forward.</td>
</tr>
<tr>
<td></td>
<td>Used to contact engineers to work on the argon laser.</td>
<td></td>
</tr>
<tr>
<td>Poster (map of the sky)</td>
<td>Text with constellations.</td>
<td>Suggests a general interest in things scientific.</td>
</tr>
<tr>
<td></td>
<td>No apparent mediational function.</td>
<td></td>
</tr>
<tr>
<td>Parts Catalogs</td>
<td>Text with information for parts, instruments, equipment.</td>
<td>Resource for ordering equipment and instruments and thus for keeping experiments moving forward.</td>
</tr>
<tr>
<td></td>
<td>Used to order parts, instruments, equipment.</td>
<td></td>
</tr>
<tr>
<td>Inspection Sheet</td>
<td>Text with verification that the lab is up to code.</td>
<td>Resource for ensuring safety of laboratory. Provides a link between group and regulating organizations in the university and beyond.</td>
</tr>
<tr>
<td></td>
<td>Mediates between group and outside/public institutions who maintain standards for (workplace) safety.</td>
<td></td>
</tr>
<tr>
<td>Safety Manuals</td>
<td>Text with information related to safety procedures.</td>
<td>Serves a regulating function for operating equipment and instruments; facilitates safety of group.</td>
</tr>
<tr>
<td></td>
<td>Mediates between scientists and the proper-safe way to handle and run equipment and instruments in the lab.</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Sign out sheet</td>
<td>Text with space to sign out equipment.</td>
<td>Resource for keeping track of various equipment and instruments that move in/out of the laboratory; enables some degree of collaboration and community between groups in terms of exchange.</td>
</tr>
<tr>
<td></td>
<td>Used to keep track of equipment and instruments that are borrowed from the lab.</td>
<td></td>
</tr>
<tr>
<td>Sticky Notes</td>
<td>Medium for recording and communicating information.</td>
<td>Provides a durable and mnemonic resource for communicating and transporting information; as a medium, can be attached to various tools and instruments as a reminder and/or instruction, etc.</td>
</tr>
<tr>
<td></td>
<td>Used in various ways between scientists and scientists and their tools, objects of study, etc.</td>
<td></td>
</tr>
<tr>
<td>Scrap Notes</td>
<td>Various inscriptions that are part of everyday lab activity.</td>
<td>Facilitates communication between scientists and between scientists and objects (of study).</td>
</tr>
<tr>
<td></td>
<td>Used by scientists to problem solve and to communicate their work to themselves and others.</td>
<td></td>
</tr>
<tr>
<td>Notebooks</td>
<td>Texts for recording/documenting experimental work.</td>
<td>Enables problems and successes to be documented and shared in and across time; provides a durable resource that can be consulted in and across time; may provide information that will be included as part of other texts (e.g., articles).</td>
</tr>
<tr>
<td></td>
<td>Used by scientists to record/document and take on experimental work. Mediates between scientists and experimental system: from the instruments to the procedures enacted.</td>
<td></td>
</tr>
<tr>
<td>Fringe Image</td>
<td>Visual output of experimental system.</td>
<td>Enables scientists to interpret the workings of the system and generate visual data that can be analyzed and transformed into a graphic display and/or other immutable mobile/inscription.</td>
</tr>
<tr>
<td></td>
<td>Mediates between scientists and experiment; mediates between scientists and analysis of data and findings.</td>
<td></td>
</tr>
<tr>
<td>Software/Graphic</td>
<td>Technology for visual inscription.</td>
<td>Provides a visual, and inter-subjectively available, resources for collecting, transmitting, analyzing, and visually displaying information.</td>
</tr>
<tr>
<td>Interfaces</td>
<td>Used by scientists to display information in situ and based upon analysis.</td>
<td></td>
</tr>
<tr>
<td>Monitors (Screens)</td>
<td>Medium for visual inscription.</td>
<td>Display technologies enable vast amounts of data to be perceived by multiple people in multiple ways.</td>
</tr>
<tr>
<td></td>
<td>Used by scientists to collect, transmit, analyze, and visually display information.</td>
<td></td>
</tr>
<tr>
<td>White Board</td>
<td>Medium for visual inscription.</td>
<td>Writing surface that integrates for many people at once; similar to monitor, but different tools and means of documenting, sending, and communicating.</td>
</tr>
<tr>
<td></td>
<td>Scientists use to record information, problem solve, and analyze relationships.</td>
<td></td>
</tr>
<tr>
<td><strong>Inscription/Text</strong></td>
<td><strong>Role in Construction and Example</strong></td>
<td><strong>Role in Enactment and Example</strong></td>
</tr>
<tr>
<td>------------------------------</td>
<td>------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Scholarly Posters</td>
<td>Resource for constructing an experiment in order to obtain replicable results; modifying an existing experiment in order to obtain different results.</td>
<td>Resources for running an experiment in order to obtain replicable results; modifying an existing experiment in order to obtain different results.</td>
</tr>
<tr>
<td></td>
<td>Morgan consults poster in ongoing replication and modification of Victor’s (visiting scientist) experiment.</td>
<td>Morgan consults poster in order to examine Victor’s findings against what she was seeing in her own work.</td>
</tr>
<tr>
<td>Journals/Articles</td>
<td>Resource for examining how other scholars had set up a particular experiment.</td>
<td>Resource for examining how other scholars had run a particular experiment.</td>
</tr>
<tr>
<td></td>
<td>John consults journal article during construction process.</td>
<td>John consults journal article during enactment process.</td>
</tr>
<tr>
<td>Frequency Sheet</td>
<td>NR *</td>
<td>Resource for running an experiment at a particular frequency.</td>
</tr>
<tr>
<td></td>
<td>NR</td>
<td>John and Morgan consult sheet</td>
</tr>
<tr>
<td>Binders</td>
<td>Resource for constructing equipment.</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>Morgan used a binder when changing out dye in the dye laser.</td>
<td>NR</td>
</tr>
<tr>
<td>Parts Catalogs</td>
<td>Used as a resource for ordering parts used in experiment(s).</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>Morgan used to order parts for various experiments. This occurs regularly but not every day.</td>
<td>NR</td>
</tr>
<tr>
<td>Sticky Notes</td>
<td>Used to record information during various tasks.</td>
<td>Used to record information for the purpose of problem-solving, recording ideas, etc.</td>
</tr>
<tr>
<td></td>
<td>Morgan uses a sticky note to reference between different binders when changing out dye.</td>
<td>John uses a stick note to jot down information while running his experiment.</td>
</tr>
<tr>
<td>Scrap Notes</td>
<td>Used to record information during various tasks.</td>
<td>Used to record information during various tasks.</td>
</tr>
<tr>
<td></td>
<td>John writes down information on sticky note during construction process.</td>
<td>Morgan writes down information for explaining some problem to Victor while working on his experiment.</td>
</tr>
<tr>
<td>Notebooks</td>
<td>Used to record information related to various tasks.</td>
<td>Used to record information related to various tasks.</td>
</tr>
<tr>
<td></td>
<td>John’s notebook. I did not observe him writing in it in the laboratory but did get a chance to study what he recorded, for instance, in his office space.</td>
<td>John’s notebook. I did not observe him writing in it in the laboratory but did get a chance to study what he recorded, for instance, in his office space.</td>
</tr>
<tr>
<td>Fringe Image</td>
<td>NR</td>
<td>Visual datum that results from experiment.</td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>NR</td>
<td></td>
<td>John and Morgan produce a “Fringe” image in the context of experimental enactment.</td>
</tr>
<tr>
<td>Computers</td>
<td>Set up as site of interface between scientists and experimental system.</td>
<td>Serves as site of interface between scientists, software, and experimental system.</td>
</tr>
<tr>
<td>John orients his computer spatially to optics table.</td>
<td>John and Morgan use computer during experiment(s) to record and transfer visual data.</td>
<td></td>
</tr>
<tr>
<td>Software/Graphic Interfaces</td>
<td>Software used to orient experimental system and/or used to capture visual data.</td>
<td>Software used in context of experiment.</td>
</tr>
<tr>
<td>Software installed on machines.</td>
<td>John uses software to capture Fringe Image that will be used and analyzed as data.</td>
<td></td>
</tr>
<tr>
<td>White Board</td>
<td>Resource/Writing Surface that enables John to work out problems based on construction.</td>
<td>Resource/Writing Surface that enables John to work out problems based on enactment.</td>
</tr>
<tr>
<td>John writes out schematic on board.</td>
<td>John writes out equations on board.</td>
<td></td>
</tr>
</tbody>
</table>

* NR denotes no observable relation either to experimental construction or enactment.
Figure C.4. John’s Notebook Renderings of Fringe and Analysis
Figure C.5. John’s Notebook with Hand Drawn Illustrations and Photographic Image
Figure C.6. Screen Capture of LabView Front Panel Used in John’s Analysis

Figure C.7. Figure of LabView Back Panel Used in John’s Analysis
Figure C.8. Screen Capture of Maple Software Used in John's Analysis
Figure C.9. Graphic Display Produced and Used by John During Analysis
Figure C.10. Schematic of Experimental Setup from John’s Presentation

Figure C.11. Photograph of Experimental Setup from John’s Presentation
Figure C.12. Particle Alignment Animation from John’s Presentation

Figure C.13. Multimodal Convergence Photograph from John’s Presentation
Part I

- Jordan: ‘Some syntax isn’t right here’
  - Referring to mistakes, etc.—correct way it should be ‘written’ (my term)
- Jordan: ‘Coding is the most logical thing you can do’
- If you do it right, the result can/should be predicted
- Jordan: ‘This is how robots think’
  - Only as smart as the person who coded them
- Jordan using Excel
  - Finding minimum—function that most people do know how to use (I would think)
- Typing stuff in, but had to stop—‘Have to do some more math’
  - Writes out on paper
  - Uses calculator
- Dialectic constant over a range of wavelengths
  - Graphs to see if he’s right

Part II

- Cole [from Jensen’s Lab] comes in—they started talking about graph
  - Graph integrates activity—problem solving in this case
- Cole starts using the mouse
- The graph doesn’t ‘look right’—becomes the basis for understanding the code, numbers, equations—should (I assume) have a particular look
- Cole: ‘Let me just write something real quick. I won’t mess it up, I promise’
  - Produced a different graph to compare to the first
  - To ‘write’ in this case is to produce code and, in doing so, a graphic representation

Figure D.1. Field Note Excerpt from Observations in Jordan’s Office
WRITE(3,*)
WRITE(3,*) 'RxPSumImX',' RxPSumImY',' RxPSumImZ'
DO a=1,FileNum
    Write(3,*) RxPSumIm(a,1),RxPSumIm(a,2),RxPSumIm(a,3)
END DO

WRITE(3,*)
WRITE(3,*) 'Magnetic Interactions II'
WRITE(3,*) 'Wavelength(nm)',' BReX',' BReY',' BReZ'
DO a=1,FileNum
    Write(3,*) Wave(a),Bre(a,1),Bre(a,2),Bre(a,3)
END DO

Figure D.2. Excerpt of Fortran Code Jordan Used in Simulation Work
Figure D.3. Screen Capture of Computational Simulation Produced by Jordan
Table D.1
*Question Type, Sample Questions, Aim (Work), Aim (Writing) Outcomes*

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Sample Questions</th>
<th>Aim (Work)</th>
<th>Aim (Writing)</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive</td>
<td>How would you describe your work as a physicist?</td>
<td>Explore how Jordan perceives and talks about what he does; learn about this work myself.</td>
<td>Situate writing in relation to the way scientists talk about their work.</td>
<td>A more nuanced perspective of (writing in) theoretical and computational physics.</td>
</tr>
<tr>
<td></td>
<td>What are the aims of your research?</td>
<td>Explore the objectives of theoretical and computational research</td>
<td>Situate writing with in specific research aims and the ways in which those aims can be achieved</td>
<td>A more precise view of scientific problems and the way in which (and means by which) they are solved.</td>
</tr>
<tr>
<td></td>
<td>What is the output of your work?</td>
<td>Explore what constitutes a knowledge object in theoretical and computational work.</td>
<td>Situate writing in relation to the production of knowledge objects.</td>
<td>Clearer understanding of the relationship between writing and knowledge production</td>
</tr>
<tr>
<td></td>
<td>So would you talk a little bit about simulations and what’s involved in that process?</td>
<td>Explore what simulations are and how they are produced.</td>
<td>Situated writing in relation to simulations; inquire into different forms of writing involved in this process.</td>
<td>Clearer understanding of the relationship between writing and the production of simulations.</td>
</tr>
<tr>
<td></td>
<td>So how do you think about writing, and what sort of role does it play in your work?</td>
<td>Explore writing as object and writing as means of accomplishing various objectives.</td>
<td>Situate writing in relationship to scientists’ perceptions about its role in their work</td>
<td>A scientific view of writing and the role it plays in research and communication.</td>
</tr>
<tr>
<td>Structural</td>
<td>When you cross over between your simulations and theoretical work and into the lab, do you think that offers you some additional insight that staying just with theory or just with experiment wouldn’t offer?</td>
<td>Explore the relationship between theoretical and experimental physics.</td>
<td>Situate writing in relation to a specific practice involving a specific set of problems, etc.</td>
<td>Clearer understanding of theoretical and computational physics as a practice.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>So simulations are different from doing other stuff, or are they kind of all of a part?</td>
<td>Explore the relationship between simulation as object and simulation in relation to other work.</td>
<td>Situate writing in relation to objects and relationships between objects.</td>
<td>More precise view of relationship between components of Jordan’s computational system.</td>
<td></td>
</tr>
<tr>
<td>So how do you see [your] work in the context of this lab?</td>
<td>Explore relationship between Jordan’s work and how he perceives it in relation to group’s research goals</td>
<td>Situate writing in relation to a specific practice that takes place among a specific group of people.</td>
<td>Better understanding of how Jordan’s perceives his work and how I can relate his work to that of others in the group.</td>
<td></td>
</tr>
<tr>
<td>How do take the real complicated process or idea and express it in an understandable way to someone with a non-scientific background?</td>
<td>Explore the relationship between writing and communication of findings.</td>
<td>Situate writing in relation to specific rhetorical and communicative objectives.</td>
<td>Nuanced view of the way scientists deploy writing to achieve their rhetorical and communicative objectives.</td>
<td></td>
</tr>
<tr>
<td>Is there a difference between including a picture and words here, or why a picture and not just text?</td>
<td>Explore the relationship between representation and the objective of Jordan’s work.</td>
<td>Situate writing in relation to semiotic modalities deployed in research and communication (affordance) and choices Jordan makes in his representational practices.</td>
<td>Clearer understanding of what writing is and what writing does in scientific research and communication.</td>
<td></td>
</tr>
</tbody>
</table>
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