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Analysis of Expert Readers in Three Disciplines: History, Mathematics, and Chemistry

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Abstract

The purpose of this study is to describe educationally relevant differences in literacy use among three subject-matter disciplines—history, chemistry, and mathematics. These analyses were drawn from an investigation of the teaching of disciplinary literacy in high schools. The purpose of the overall project was to improve the literacy-teaching preparation in a secondary preservice teacher education program, but this study sought to identify specific features of literacy and literacy use only in the three disciplines. It is the first expert-reader study to consider the reading of mathematicians and chemists (though other kinds of scientists have been studied in this way). To conduct this investigation, three teams were assembled, one for each discipline, including two disciplinary experts (historians, chemists, and mathematicians), two teacher educators who prepare high school teachers to teach those disciplines, and two high school teachers from each discipline. Using think-aloud protocols, transcripts from focus group discussions, a recursive process of member checking, and a cross-disciplinary consideration of reading approaches identified in each discipline, the study identified important differences in the reading behaviors of the six disciplinary experts. Although much of the work was based on think-aloud protocols and interviews with the disciplinary experts, the teachers and teacher educators participated with the disciplinary experts in focus-group discussions of the protocols, and their reactions and insights helped the disciplinary experts to articulate their approaches and to determine implications of the reading behaviors that were observed. Differences were evident in sourcing, contextualization, corroboration, close reading and rereading, critical response to text, and use of text structure or arrangement and graphics.

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The purpose of this article is to describe educationally relevant differences in literacy use among three subject-matter disciplines—history, chemistry, and mathematics. These analyses were drawn from an investigation of the teaching of disciplinary literacy in high schools funded by the Carnegie Corporation. The purpose of the overall project was to improve the literacy-teaching preparation in a secondary preservice teacher education program by (a) identifying specific features of literacy and literacy use in the three disciplines, (b) examining the appropriateness of current approaches for supporting literacy learning in those disciplines, (c) developing and trying out instructional procedures for addressing disciplinary literacy in high school classes, and (d) developing and field testing modules aimed at teaching those approaches in a preservice secondary teacher education program. The study reported here is focused on the first of these issues, the identification and characterization of the literacy of history, chemistry, and mathematics.

To conduct this investigation, we assembled three teams, one for each discipline, with teams including two disciplinary experts (historians, chemists, and mathematicians), two teacher educators who prepare high school teachers to teach those disciplines, and two high school teachers from each discipline. Using think-aloud protocols, transcripts from focus group discussions, and a recursive process of member checking, we investigated observed differences in the reading behaviors of the six disciplinary experts. Although much of what we did to identify the disciplinary literacy approaches was based on think-aloud protocols and interviews with the disciplinary experts, the teachers and teacher educators participated with the disciplinary experts in focus-group discussions of the think-aloud protocols, and their reactions and insights helped the disciplinary experts to articulate their approaches and helped us to understand the implications of the reading behaviors that we observed.

Background

Secondary teacher education often requires candidates to complete a course in content area reading and writing. Unfortunately, there has never been much disciplinary specialization in such efforts (Moore, Readence, & Rickelman, 1983), and the knowledge base on which to formulate such curricula has been woefully limited. Even when the rhetoric promoting content area reading has been appropriately deferential to the disciplines (e.g., Henry, 1948; Herber, 1970), the major emphasis usually has been on general reading comprehension or study skills strategies within the context of subject-matter materials (Herber, 1970; McKenna & Robinson, 1990; Moje, Young, Readence, & Moore, 2000; O'Brien, Stewart, & Moje, 1995; Rycik & Irvin, 2001; Vacca, 2002). Thus, instead of focusing on the literacy of the disciplines, content area reading has emphasized the reading used in trying to learn about a discipline (for a more complete comparison of content area reading–literacy and disciplinary literacy, see Shanahan & Shanahan, in press).

On the other hand, subject-matter specialists have tended to teach their subjects with little consideration for the literacy dimensions of these subjects (Draper, 2002; Siebert & Draper, 2008), even ignoring the foundational role of literacy in the definition and development of the disciplines themselves. As such, methods courses in the content areas often give short shrift to reading and writing (Alexander & Murphy, 1998; Ruban, McCoach, McGuire, & Reis, 2003), and students in these courses have often demonstrated a marked reluctance to take on the reading methods suggested (e.g., Bean, 2000).

Thus, teachers of science, math, and history often do not know how to support their students' reading in the disciplines and often avoid the use of text, just telling students what they want them to know (ACT, 2006). This problem persists even though there is a growing body of support for such teaching, including articles, position statements, lesson plans, and other supports for teachers on the websites of major professional groups such as the National History Education Clearinghouse, National Science Teachers Association, and the National Council of Teachers of Mathematics.

Literacy avoidance in content area classes is at odds with student learning needs and the reality of the subject matters. One can look to the field of science for an example. Bench scientists and technical workers estimate they devote a large percentage of their work time to reading and writing (Guthrie, 1984), writing lab reports, research papers, briefs, proposals, and patent applications, and reading explanations of theories and procedures, research studies, and communications from other scientists. Research has articulated some of the specific demands of scientific literacy (Bazerman, 1998; Gee, 2001; Holliday, Yore, & Alvermann, 1994; Hynd-Shanahan, Holschuh, & Hubbard, 2004; Lemke, 2001), and scholars have charted the pivotal role of textbooks in the preparation of scientists (Kuhn, 1996).

The point holds for other disciplines and technical specializations as well. In addition to the "domain knowledge" of the disciplines (Rouet, Favart, Britt, & Perfetti, 1997), each discipline possesses specialized genre, vocabulary, traditions of communication, and standards of quality and precision, and each requires specific kinds of reading and writing to an extent greater than has been recognized by teachers or teacher preparation programs. Disciplines, as Bazerman (1997) writes,

> draw on a common body of resources, cope with the same body of material and symbolic artifacts, master the same tools, and gain legitimacy for any new resources they want to bring into the field by addressing the same mechanisms of evaluation. (p. 305)

Such insights about disciplines slowly have begun to be translated into new models for addressing literacy instruction within the disciplines. Wineburg (1991), for example, found that historians engaged in contextualization, sourcing, and corroboration as they read historical documents, and researchers have studied attempts to teach students to use these strategies to comprehend and critically analyze history texts, albeit with mixed results (Hynd-Shanahan et al., 2004; Nokes, Dole, & Hacker, 2007). Similarly, in science, researchers have been developing approaches and strategies based on emerging descriptions of how scientists read (Hand, 1999; Hand & Prain, 2002; Holliday & Benson, 1991; Hynd, McWhorter, Phares, & Suttles, 1994). These studies show the potential value of such instruction, but there are still too few analyses of literacy use in the disciplines to guide the formulation of such instruction.

The research described here aims to contribute to the expansion of discipline-specific literacy strategies by identifying specialized properties of disciplinary reading (Draper, 2010; Moje, 2008; Moje, Overby, Tysvaer, & Morris, 2008; Moje, Stockdill, Kim, & Kim, 2011; Shanahan & Shanahan, 2008). This approach posits that disciplinary knowledge—knowledge of how information is created, shared, and evaluated, as well as an awareness of the nature of the conceptual "lenses" employed by disciplinary experts and the implications of these epistemological tools—is essential to understanding and learning in a discipline, and that teaching should foster such disciplinary sensitivity and practice.

Based on our review of the research on this topic, we conclude that this expert-reader study is the first cross-disciplinary analysis of reading behaviors. Past research has focused on how disciplinary experts read differently than novices, rather than on comparisons of reading practices across disciplines (an approach that has confounded the possible effects of reading proficiency, age or maturation, domain knowledge, disciplinary knowledge, and status differences between the researchers and subjects). In this case, comparisons were made across the disciplines of history, chemistry, and mathematics, rather than across proficiency levels, since all six of the readers examined were expert readers; age differences were minimal also, as were status differences between researchers and participants (all were professors at the same university). Past expert–novice comparison studies have examined how historians and scientists (though not chemists) read, but they have not considered the reading of mathematicians.

Expert Readers

Cognitive science research has long used the expert or expert–novice paradigm to discern what constitutes quality performance (Newell & Simon, 1972). In this approach, expert performances are examined, often through observations and think-aloud protocols, to identify the use of cognitive algorithms for solving problems or executing complex performance. The expert paradigm has been used in literacy to examine writing (Best, 1996; Crammond, 1998; Flowerdew, 2003; Hayes & Flower, 1986; Longo, 1994; Oatley & Djikic, 2008; Olive & Piolat, 2005; Ravid, & Zilberbuch, 2003; Roussey & Piolat, 2005; Stolarek, 1994), reading comprehension (Afflerbach, 1986; Garner, 1982; Gaultney, 1995; Graves, 2001; Johnston & Afflerbach, 1985), and computer reading and information use (Britt & Aglinskas, 2002; Salmeron, Canas, & Fajardo, 2005; Wen & Shih, 2008).

We limit this review to studies that have examined expert performance in literacy within disciplinary contexts such as literary, historical, and scientific reading and writing (Bazerman, 1985; Latour & Woolgar, 1979; Peskin, 1998; Rouet et al., 1997; Wineburg, 1991). For example, experts in literary reading (doctoral students in English) were found to read poems differently than advanced high school and college students (Peskin, 1998). The novices understood the nature of poetry as a discourse, but they lacked the disciplinary-specific interpretive strategies that the experts used to make their interpretations of the poems coherent, and, consequently, their understanding and appreciation suffered. Because we are considering only expert performance studies here, mathematics is not included, since ours is the first expert performance study in mathematics.

In science reading, Latour and Woolgar (1979) noted that scientists' reading processes changed if they were reading their own colleagues' texts, and they theorized that reading was a social, not just an intellectual pursuit. And a study of the reading of seven physicists (Bazerman, 1985) found that the physicists' purposes for reading and the background knowledge they brought to a text determined how they approached that text. With regard to the selection of texts, the physicists engaged in a version of what Wineburg (1991) later called *sourcing.* That is, they were attracted to articles based on the reputation of the authors, and they used technical terms to ensure that the materials matched their interests. While reading, they paid particular attention to new information—specifically, to surprises—and they jumped around in an article to figure out where to spend their effort, with experimentalists focusing more on methods and theorists more on theory. When they had comprehension difficulties, and they often did, they weighed effort against benefit and were more critical when reading work that was related to their own. If they thought the information was not directly applicable to their work, they tended to read relatively uncritically, accepting its accuracy and appropriateness and focusing more on learning the information. This alternation between learning and critiquing was a characteristic observed in each of the physicists as they read, except one, whose broad knowledge of the field allowed for a constant critique.

Expert historians have exhibited somewhat different disciplinary patterns while reading historical documents. A study comparing expert and high school readers as they read a set of documents about an historical event (Wineburg, 1991) showed that the historians engaged in processes that were different and more sophisticated than those of the high school students, even though the high school students had previously studied the topic and the historians had not. The high school students read each of the documents as if it had no connection to the others and focused mainly on fact collection, but the historians in addition to "learning" the information, engaged in three processes: *sourcing*, *contextualization*, and *corroboration.* That is, they paid attention to the author, what kind of document it was, and where it came from (sourcing), they thought about the time period in which it was written and considered what they knew about the political, social, economic, or cultural conditions of that time (contextualization), and they looked for agreements and disagreements across the text and with their own views (corroboration). Unlike the physicists, they did not suspend their critical stance when they read information about which they knew little.

Another study of history reading compared eight graduate students in history to a group of nonhistory students (Rouet et al., 1997). This study provides a useful counterpoint to the earlier Wineburg investigation because the “novices” were much better readers than those in the earlier study, and their general reading abilities and knowledge of the world were better matched to the experts; the novices were graduate students in psychology. This comparison found fewer differences in sourcing, collaboration, and contextualization, but there were still unambiguous disciplinary differences across the groups. For example, the psychology students read with a clear purpose of building up their knowledge, whereas the history students, though having little knowledge of the events, focused their attention more on interpretation and use of evidence. This meant that that the history students were better able to connect the information sources to their interpretations, even though there were no apparent differences in their abilities to judge the trustworthiness of the various documents. Of course, disciplines share similarities and differences, so the psychology students may have been applying analogous and workable heuristics drawn from their own field of study.

Discourse Patterns

Academic texts have been characterized as being more explicit, distanced, and complex or highly structured when compared to oral language and nonacademic texts (Snow, 1987). But those who have studied the discourse and linguistic features of academic texts have found them to differ, depending on the specific discipline, not only in genre but also in the nature of the linguistic elements used. For example, theorists in the field of functional applied linguistics have analyzed the discourses of science and history. Martin (1993), Veel (1997), and Wignell (1994) classified common genres of science to include (a) procedure (to provide instruction for experiments), (b) procedural recount (to record what has already been done in an experiment), (c) science report (to organize information by setting up taxonomies, parts, or steps, or by listing properties), and (d) science explanation (describing how and why phenomena occur). Coffin (1997) classified common genres of history to include (a) historical recount (to retell the events in a sequence), (b) historical account (to account for *why* things happened in a particular sequence), (c) historical explanation (to explain past events by examining cause and effect), and (d) historical argument (to advocate a particular interpretation). Procedures and explicit explanations are frequent in science and less so in history. Science and history, then, have adopted distinct genres to provide information to readers reflecting the unique purposes of these disciplines.

In addition, grammatical resources are deployed differently in these two disciplines. A key characteristic of scientific writing is nominalization. Rather than saying, “They compressed it,” science texts tend to nominalize, that is to change the verb *compress* to a noun, *compression*. Nominalization transforms information from the everyday and specific to the abstract and general (Halliday & Martin, 1993). *Compression* becomes part of the technical vocabulary of science. In history texts, nominalizations occur rarely with technical terms, but more often with general vocabulary terms such as *unemployment.*

Science text is about things and processes, and it, thus, uses technical vocabulary in ways aimed at suppressing agency. Accordingly, science text is written to be an authoritative account of things. This suppression of agency is an important contrast with history text. Cause–effect relationships are important in both fields, but in history there is human intention, whereas in science that is not the case. Atoms are not driven by intentions to act in any particular way; Adams, on the other hand, make choices, and those choices are governed by experience, bias, limitations of knowledge, and other intentional shapers.

In addition, science text, when classifying phenomena, uses the processes of identification and attribution (Halliday, 1994). Definitions are often identifications; the definition and technical term can be reversed (e.g., solutions are mixtures; mixtures are solutions). Attributions place the term within a particular complex of terms (e.g., a neutron is part of an atom) and cannot be reversed.

History text, on the other hand, construes actions and events, verbal and mental processes, and descriptions and background information (Schleppegrell, 2004). Classification is not a main function in history, but it is in several scientific fields. Thus, verbs carry much of the meaning in history. Nominalization does exist, but for different purposes. Indeed, abstraction can be very challenging in history. Note the following sentence:

> The enlargement of the nation's industrial capacity, including the making of barbed wire and the advent of western train transportation, served the demands of the west.

In this sentence, the events (i.e., enlargement of the nation's industrial capacity, the making of barbed wire, the advent of western train transportation) are nominalized as participants, that is, they are the subjects or agents in the sentence. The process, *served*, is realized with a verb. The reasoning in this sentence is not overt but buried in the clauses through nominalization. That is, you know after reading the sentence that the nation has more industry than it used to, that they make barbed wire, and so on, but those discrete pieces of information are ultimately not the point of the sentence. Burying the reasoning in the clauses contributes to the difficulty of reading the sentence with full understanding.

Another characteristic of language in science texts is the extent to which such texts are explicit about the degree to which phenomena occur. For example, such texts use words such as *likely* or *it is thought that*, which temporize the extent to which something is true. History texts, on the other hand, temporize much less and in different ways than science texts. In addition, science texts often include a combination of mathematical expressions, graphical displays, and prose (Lemke, 2001), but all of these elements are central to the interpretation of the information. Such elements may not be as central in disciplines such as history, and they might be combined or prioritized in different ways.

Functional linguists have not yet placed mathematics under the same kind of scrutiny as these other disciplines. With one exception, the “mathematical discourse” studies that do exist have focused entirely on the discourse of mathematical pedagogy and have focused on issues of story problems or how children talk about mathematical concepts (e.g., Abel & Exley, 2008; Ares, Stroup, & Schademan, 2009; Fang & Schleppegrell, 2008; Zevenbergen, 2001). As valuable as this work is, because of its pedagogical or developmental nature, it does not attempt to determine a normative standard of use among proficient populations. The one exception to this is the work of Joseph S. Fulda (1989, 1992, 2009a, 2009b), who studies philosophy and mathematics. Nevertheless, his analyses, which do not emanate from functional linguistics, although very useful, are not as thorough as the analyses that have been carried out on the discourses of science and history.

Fulda (2009a, p. 1437) explains the purposes of mathematical discourse, “In general, mathematics is concerned with definitions, axioms, theorems, and problems,” and he shows that mathematical definitions, because they must be reversible, have to be quantified at least implicitly (Fulda, 1989). Similarly, he emphasizes that mathematical discourse is not so much about “specific objects as about place-holders for objects that lie within specified ranges” (Fulda, 2009a, p. 1436), and because it is about such placeholders it, too, has to have a quantificational structure. Fulda gives the example of the importance of abstract discourse in mathematical thinking with the mathematical sentence, $x > y$; if it is particularized, $5 > 3$, $4 > 3$, or $3.1 > 3$, then the discourse is altered in an important way, and the truth value of the statement is destroyed. Thus, readers of mathematical texts have to develop a proficiency in making sense of this quantificational structure, particularly when it is implied rather than expressed explicitly.

These insights on mathematical discourse stand in sharp relief to the earlier noted studies on the discourse of mathematical pedagogy. Mathematical discourse is heavily involved in the consideration of placeholders for specific objects, which requires particular abstract mathematical interpretations, whereas pedagogical mathematics tends to instantiate these placeholders, rendering them as specific objects and changing the discourse emphasis. This important alteration removes the pedagogical discourse from the realm of mathematical discourse, since, according to Fulda (2009a), “prototypical mathematical discourse is meta-logical or meta-arithmetic” (p. 1436), and this meta-logical emphasis is undermined by instantiation. This sharp juncture in discourse affordances between mathematical and pedagogical discourse about mathematics contrasts markedly with the apparent continuities between history and history pedagogy and science and science pedagogy. Mathematics is difficult to grasp or learn without instantiation, and yet instantiation itself renders the discourse nonmathematical.

The contrasts among history, mathematics, and the sciences, then, was something we wished to explore further. The purpose of our study was to identify additional reading differences among the disciplines as the basis for developing appropriate instructional strategies for fostering disciplinary literacy instruction. Specifically, this study sought to answer the following question: How do historians, chemists, and mathematicians differ in how they read disciplinary texts?

In the rest of this article we describe our study and its findings. As we do, however, we acknowledge the limitations of this study. Our small number of participants was drawn from one university in one urban community, and claims of generalizability would be without merit. However, since there is so little understanding either in the field of literacy or in the disciplines about the reading demands of the various disciplines, we believed that the exploratory nature of this study was warranted (especially with regard to mathematics and chemistry), and that a deeper look at fewer participants was more appropriate than a more superficial examination of a larger group.

Method

Our methods enacted the notion that in-depth study of a few participants would provide us with the most fruitful path, given the exploratory nature of this investigation.

Participants

The participants were recruited through the Secondary Teacher Education Advisory Committee at our university. This committee consists of program coordinators and faculty in the liberal arts and sciences, architecture and arts, and education who are engaged in preparing secondary-school teachers. The teacher educators who became a part of the research teams were members of this committee. The researchers asked these teacher educators to identify exemplary high school teachers in their disciplines as well as disciplinary experts—historians, chemists, and mathematicians—who were tenured professors engaged in scholarly work in their field. We contacted these experts, explained the purpose of the investigation, and invited them to take part. Each disciplinary team consisted of two disciplinary experts, two teacher educators, two high school teachers, and the two researchers.

Disciplinary experts. The experts in history were associate professors, one specialized in U.S. history and the other in African and environmental history. The experts in chemistry were full professors, one in physical chemistry and one in biochemistry. The experts in mathematics were both full professors, and both were mathematical theoreticians, one an expert in algebraic geometry. Our choices of experts were limited to those at our university who not only were researchers in the appropriate fields of study but also were willing to participate in a study of the literacy of their discipline. It is possible that if other individuals had been included, or if individuals representing different branches of these disciplines had been included, our findings would have differed. Nevertheless, even though the participating historians and chemists were drawn from different branches of their fields, we found coherence in the way they approached reading. Similarly, the historians examined here demonstrated significant agreement with the historians examined in past studies.

Teacher educators. The teacher educators were full-time faculty members at the university, all of whom had high school teaching experience, and most of whom engaged in field observations in their teacher education program. In our university, secondary teacher education is distributed across the disciplinary departments, rather than concentrated in the college of education. As such, these participants made up a significant portion of the faculty who would be involved in teacher education in these departments.

Teachers. The teachers were from Chicago high schools and taught in schools with diverse populations including 50% to 90% proportions of students from low-income families. The teachers had at least 3 years teaching experience and mentored student teachers. All were highly regarded by the teacher education faculty for their ability to teach subject-matter content to high school students.

Research Design and Procedures

This research focused on the approaches to text that disciplinary experts used that might have relevance to teaching high school students to read disciplinary texts. Individual interviews, expert think-aloud protocols, and focus group meetings were the investigative tools. We audiotaped and transcribed all of these interactions. Originally, the first author coded the transcripts, using constant comparison (Glaser, 1992). She coded reading processes and strategies identified in interviews and focus groups. From these codes, she made lists of the processes and strategies identified. Focus group members also read transcripts, and at the focus group meetings the first author shared the lists of processes and strategies with the participants, asking for verification and refinement and insights into themes. These discussions were also audiotaped and transcribed. For example, in the first focus group meeting, a historian brought up the fact that he looked for evidence of "pastism"—a view that things were better in the past and that the situation just keeps getting worse and worse. This item was coded and added to the list of processes brought to the second focus group meeting. The focus group verified that this was something historians looked for in text and contrasted it with "presentism"—the view that things are just getting better and better. Presentism was then part of the transcript of this meeting and became incorporated into the codes. The two phenomena describe ways in which historians view the past, and so these codes were combined and categorized as epistemological. The same process was repeated during the rest of the focus group meetings. By the end of the study, each of the study groups had at least three chances to provide input into the processes and strategies used by their discipline and the transcripts in each discipline had been recoded at least three times. At that point, the first author engaged in cross-coding. That is, she coded the transcripts from all three disciplines using the codes for each single discipline, which allowed her to engage in comparison and contrast of the processes used across the disciplines. For example, historians identified sourcing as a major process they used when reading, so transcripts in all three disciplines were coded for sourcing. Mathematicians identified rereading as a major process, so all transcripts were coded for rereading. These cross-codes were then aggregated within each discipline for the authors to determine the extent to which disciplines engaged in particular processes and strategies. The final categories of codes used in cross-coding referred to the reading strategies that we explored with the experts, and they included sourcing, contextualization, corroboration, text structure, graphic or mathematic elements of text, critique, rereading or close reading, and interest, and these are discussed in the findings section of the article.

Initial meeting. During the first meetings of the three teams (chemistry, mathematics, and history), we explained the project, asked for informed consent, and provided each team with a schematic of a literacy framework that emphasized the importance of vocabulary, comprehension, fluency, and writing. The literacy framework provided a structure to guide discussion of the literacy challenges faced by high school students in the various disciplines. We then introduced a short discipline-related text that the team members read, and then we asked them to reflect on their reading practices. This served as a model for the think-aloud procedure to be used with the experts and provided us with initial insights into how reading might proceed in each of the disciplines. We did not prompt the participants to approach the reading in any particular way but asked them to discuss how they processed the text and what might be challenging about the text for students (the literacy framework was used to structure this part of the discussion). Finally, we provided copies of discipline-relevant chapters from *How People Learn* (Donovan & Bransford, 2005), asked the team to share work that they knew and thought about, and discussed and scheduled expert interviews.

Expert interviews. Each disciplinary expert was interviewed individually and engaged in a think-aloud while reading discipline-specific texts. These interviews consisted of having the expert read three text excerpts, at least 1.5 pages in length: one of these excerpts was from a self-selected text that they were currently reading. One chemist chose a research article, and another chose a trade magazine. The historians chose books, the standard genre for the discipline. The mathematicians chose theoretical papers. All explained that they chose these texts for their relevance to the field in which they were working. The excerpts were divided into two sections, and the experts were asked to stop and think aloud about their processes for each section.

Then, using the same process, they were asked to read two text excerpts typical of what might be used in a content class. Historians were asked to read excerpts from two readings about Lincoln. The chemists were asked to read two textbook explanations of osmosis, and the mathematicians were asked to read two explanations of linear equations.

After the think-alouds, the researcher who was conducting the interviews asked probing questions based on the think-aloud comments made by the experts—an essentially open-ended process that differed depending on the specific think-aloud but that converged on identifying more information about the reading approaches used in making sense of text and in the ways their discipline viewed the act of reading and understanding text. For example, when a chemist mentioned a recursive reading of text and graphic, the interviewer asked if that kind of reading was typical for him and how it aided his understanding. Questions about typicality and queries about why a particular approach was used were the two most common probes. If, at the end of the think-aloud, the informant had not mentioned a particular process or strategy (i.e., processes or strategies that had appeared in the disciplinary literature or that had arisen during the discussions during the initial meetings), the interviewer asked about it. When a mathematician, for example, had not made reference to the text authors, the interviewer would ask a somewhat general question about this omission, such as, "Do you think about the author when you read?" Thus, if the expert responded in the affirmative to such a question, any explanation of how and why this was done would come entirely from him or her. Often the expert would spontaneously comment on his or her field in general (a mathematician, for example, explained why theoretical mathematicians do not collaborate as much as in other fields).

The interviews were audiotaped in the experts' offices and lasted an average of 90 minutes each (producing approximately 13 hours of tape and more than 50 pages of typed transcription).

Reflections on think-alouds. These think-aloud transcripts were then reviewed three times by the teams over a 10-month period of time. At the first meeting after the completion of the think-alouds, the eight-member teams (the two disciplinary experts, two teacher educators, two high school teachers, and two literacy experts—the first two authors of this research study) read the think-aloud transcripts of their disciplinary experts and discussed them at length. At subsequent meetings, the teams examined the preliminary coding of the transcripts to verify, extend, and alter the analyses. We discussed more refined ways to describe the processes and how the information could be better categorized and reorganized to most accurately represent the actual reading approaches engaged in by the disciplinary experts.

In addition to the ongoing analysis and reanalysis of the various read-aloud transcripts, the teams continued to work on the problem of helping high school students to read disciplinary text more effectively. Thus, the members of the team examined high school textbooks and content area reading methods texts; team members also brought in readings, from websites, the popular press, or disciplinary sources. We shared such texts and reflected on the disciplinary practices necessary to understand and think about the information in them. In each meeting, we tried to both refine the descriptions of disciplinary reading revealed in the think-alouds and to consider the relevance of these reading approaches to disciplinary high school texts. Transcripts were produced for each meeting, and these were similarly reviewed at subsequent meetings (the transcript of the end-of-year meeting was distributed electronically to participants to allow for verification and further comment).

The teacher educators and teachers described high school students' reading challenges and their own instructional approaches for supporting students' text reading. The discussions in each case were open-ended, with participation from all team members. Thus, the focus groups served two purposes—one purpose was to define expert reading in each discipline (the focus of this article), and the other was to determine what high school students needed to be taught about disciplinary literacy.

Both strands of the study were ongoing and intertwined, and it is possible that teacher insights about the reading of high school students or the experts' own examinations of high school textbooks, the literacy framework, or the content area reading texts somehow influenced their insights and commentary on their own reading practices. But at no point were these experts guided to talk about the implementation of specific strategies or insights within their own reading other than those that were self-initiated or arose from the neutral or general probes that were used. The researchers were also careful not to characterize the experts' reading practices positively or negatively either during the think-alouds or the focus group discussions. Also, it should be remembered that these individuals were truly experts in their fields, in the middle to end of their careers, who were very accomplished and who would draw no obvious benefit from making any particular assertions about their own literate practices. The interviewer, a professor at the experts' university, developed rapport with each of the informants, and the engagement with them around their think-aloud transcripts was ongoing and included input and insight from other focus group members and not just from the experts alone. As a result, they appeared to be very reflective and forthcoming about their approaches to reading.

Results

The purpose of this study was to identify how historians, chemists, and mathematicians differ in how they read texts in their fields, including texts they use themselves within their work and the texts that are meant to be used by high school students. To learn how the experts read, we identified reading approaches within each of the think-aloud and focus group protocols and then cross-coded each approach. The cross-coding involved searching for all of the strategies in all of the protocols across disciplines, not just in the discipline in which it was first identified. That meant, for example, that when we earlier identified (Wineburg, 1991) sourcing, contextualization, and corroboration approaches that were manifest in the transcripts of the history focus group, we subsequently analyzed the chemistry and mathematics transcripts for those approaches as well. Similarly, any approaches identified in mathematics reading or chemistry reading were then sought in the analyses of the transcripts from the other two disciplines. These analyses showed that, across the three disciplines, these experts differed in the approaches that they used in reading and in the degree to which they engaged in the use of particular approaches. The reading differences among the disciplines are summarized in Table 1.

Sourcing

Sourcing (Wineburg, 1991) includes a consideration of where information comes from (e.g., primary or secondary sources), who the authors are (e.g., affiliations, what their "politics" are, how they were trained), and what kind of document it is (e.g., newspaper article, editorial, diary, speech). High-quality sourcing requires knowledge of the

Table 1. Summary of Differences in Disciplinary Reading Processes

	History	Chemistry	Mathematics
Sourcing: Consideration of text source or author perspective	Explicit and thorough consideration of author perspective	Use of source as a text selection factor, but not an interpretive one	Active effort to not use source as an interpretive consideration
Contextualization: Consideration of when text was written and influences on it	Important interpretive device; concerns about what authors knew and when they knew it	Time placement of source is important in determining value of information given the rapid changes in scientific information; some evidence of contextualization with other theories	Text is not contextualized for interpretation
Corroboration: Consideration of agreements or similarities and disagreements or differences across texts	Intertextual connections are essential for determining author's argument and for interpreting perspective differences	Text is corroborated to identify material differences that could explain outcome differences	Text is reconciled with reader's knowledge to focus attention and limit misinterpretation
Text structure: Consideration of how the information in text is organized	Use text structure to determine the relationship between narrative elements and the author's argument	Use text structure to support understanding and to locate particular information	Use text structure to support understanding and to locate particular information
Graphic elements: Consideration of pictures, charts, tables, and other graphics	Said they evaluated graphics in same manner as prose but did not evidence this in these think-alouds	Different text elements seen as alternative forms of overlapping information that has to be translated and compared	No distinction between graphics and prose, both must be interpreted together in a unified manner
Critique	Critical analysis is essential and thorough to determine author's credibility; reading to critique is a central reading stance in historical reading	Examined plausibility of scientific information and its congruence with other scientific evidence (but suspends criticality when reading unfamiliar content)	Strong emphasis on accuracy to ensure clear understanding (not much attention to credibility)

(continued)

Table 1. (continued)

	History	Chemistry	Mathematics
Rereading or close reading	Close reading is important; rereading is focused on information identified to be important	Close reading is important; rereading is focused on information identified to be important	Consistently rigorous and intensive rereading that allows reader to weigh all information
Interest	Selects texts that match with the reader's historical interests and uses personal interpretive perspectives for examining author perspectives	Selects texts that match the reader's scientific interests and actively separates the new and known information to allow greater attention to the new information	Selects texts that match the reader's mathematical interests and actively separates the new and known information to allow greater attention to the new information

discipline. The disciplinary experts we interviewed actually knew the authors of many of the texts they read and had a sense of these authors' standing or prestige within the field. This familiarity with the field is unlikely to be a condition that is present in readers who are competent in a field but not experts, as we discuss in a later section.

If the judgments of the disciplinary experts were placed on a continuum representing the importance they attributed to sourcing, history would be on one extreme of the continuum, mathematics would be on the other, and chemistry would be somewhere in between, sometimes closer to history, sometimes closer to mathematics.

Historians. As in the Wineburg (1998) study, these historians engaged in extensive sourcing. They speculated about who the author was and what he or she represented. For example, while reading an essay on whether Abraham Lincoln was the greatest president, the U.S. historian said,

> I saw, oh . . . I don't know him very well, but he [the author] is part of a right-wing group of southern conservatives who is a secessionist. I'm not sure that the best model for thinking about Lincoln as a president is one that comes from a racist. So I have my critical eyes up a little bit, so it's a bit of a stretch to be friendly to, so I wanted to make sure to read it fairly.

The other historian said about a different text,

> This is from Stephen Oates. It's an excerpt from that book that's been edited to a greater or lesser degree. I have to be careful about making generalizations about what Oates is about and what he's doing, and how this fits into his larger argument.

The historians also thought about where an author obtained his or her information. The African historian said,

> And I'm looking at specifically the kind of evidence there, when they quote a primary source or go back to a primary source, I'm looking at what kind of primary sources they're quoting and drawing from and registering. Am I familiar with that or not and is that going to be useful to me in the future.

Mathematicians. In stark contrast to the historians, the mathematicians tried to read documents without specific consideration of an author. Even though they were cognizant of the field's leading mathematicians, they argued that what really mattered was what was on the page. One mathematician mentioned he knew the author of the paper he was reading, and because English was not the author's first language, he expected grammatical errors, but the quality of the ideas, to his view, could only be evidenced in the work itself. Because the other mathematician did not mention the author during the think-alouds, we specifically asked what role the author played during reading. He answered,

> Yes, it's interesting [who the author is], but it doesn't really matter. The title and what I know of the review of these papers tells me that these methods are interesting to me. I don't care whether this person has name recognition or not.

The mathematicians (and the math teachers and professional educators) explained to us that, ultimately, the author did not matter in interpretation. Math reading is more about interpreting what is actually written on a page than about perspective, point of view, bias, or any other manifestations of the author.

Chemists. The chemists paid more attention to the source of information as a predictor of quality, much like the previously studied physicists (Bazerman, 1985). As such, chemists used the author to determine what they wanted to read. Although the chemists did not allude to the author on their own, when asked, one of the chemists said,

> Yes. I pay attention in two ways: who wrote it and what is their affiliation, to see, is this somebody I recognize in the field, and also, I suppose, where the affiliation is, which, right or wrong, gives more or less credibility. If it's from a third world country, it may have a little less, I'd read it with a little more suspicion than if it came from a highly ranked university. I look to see who is the individual and see whether or not I've encountered their research in the past.

The other chemist chose to read something outside of his area of expertise because he was interested in the technical aspects of an experiment the authors carried out, but he also discussed a "seminal" article. About the first article, he explained,

> I'm basically a physical chemist and I know my colleagues, and I usually know them personally, and I think of something else they've done as I'm reading. These researchers I don't know, and I'm not even sure where they are from. I don't know why they're doing this. I can imagine, I can put the story together, but with my colleagues, I know more of the story.

About the "seminal" article, he said, "I know them [the authors] very well. I know I'm reading something by the authorities in the field—one I've known one most of my life—when he speaks everybody listens."

The chemists also made judgments about the quality of an article depending on where it was published. For example, the physical chemist said,

> An article in *Science* counts, because it's a premier journal and something you read here should be taken very seriously. Every field has its own journals. If you're in the field you know who the good people are. In the first one, the journal is obscure, and I don't think it's a first-ranked journal, and I don't know the authors.

The chemists paid attention to the citations within the documents they read, showing that they looked not only at the sources of the text itself but also at the sources the author's used in their construction of the text. The physical chemist, for example, said of the two articles, "I don't recognize the references in the first paper, and I might look them up. For the first paper, it's an entry into the field (it's not entirely new, but I'm at an entry level). The second one, I already know the references."

So the chemists saw sourcing as a tool for determining what to read, and this use was more evident in chemistry than in mathematics. Chemists knew they could not read everything, so they were selective in their choices, and an author's name recognition and quality of credentials were important determiners of what would be worth these readers' efforts. However, neither the chemists nor the mathematicians showed any evidence of using author awareness in any interpretive way during the reading itself, and in follow-up discussions they categorically rejected the idea of using author awareness in that way. Thus, historians and chemists used author or source to help determine what to read, but historians continued to use author as a tool of interpretation during the reading as well (something that mathematicians and chemists did not do).

Contextualization

Contextualization is paying attention to the context in which a text is written (Wineburg, 1991). For the purposes of this investigation, it includes consideration of the time period in which something is written including political, economic, and social influences, and the expertise represented in the text (such as social vs. political history or physical vs. organic chemistry), and what that means for the presentation of evidence and the degree to which context is taken into account in the text itself. Again, these historians engaged in contextualization to a high degree, the mathematicians not at all, with the chemists somewhere between.

Historians. To the historians, contextualization is a key notion. In the following comment, one historian muses about the time period in which a text was written.

> I'd want to take up this book. It's a 1984 book, and in Lincoln scholarship, that's ages. There have been many books written since, and I would want to know how the arguments changed since 1984.

Note the following comment by the historian (whose expertise was in African history) as he read a book about African safari parks. In this excerpt, the historian is comparing the time period discussed in the text to the time period he knows about in relation to the topic:

> Uh, one thing I'm kind of looking at carefully when I read this kind of text is uh, kind of a periodization. In other words, is what they're talking about earlier than I . . . is the evidence they're giving earlier than what I would have guessed or is it later than I would have guessed or does it fit into the way I'm already thinking about the topic? Or does it contradict that and kind of push my chronology back a little bit? Uh, that's one thing I think about. And this is about African Safari

> parks in Europe and the U.S. and this is post–World War II, so it's the sixties, and so, one thing I try to do is locate when this started.

The historians also wanted to know what kind of history was being depicted in a text:

> In general, I'm looking at whether they're doing more cultural, what kind of history are they doing? Are they doing cultural history, or are they doing economic history or are they doing a social history? So are they looking at the construction of meaning or are they doing more of a straightforward social history of "who, what, where, when?"

The historian who studied U.S. history thought about the controversies over theories in his field and tried to contextualize what he was reading within a particular controversy.

> Uh, and then, my response is first of all, I'm always kind of very suspicious and weary of the kind of "great man in history" approach, so I'm looking kind of carefully at how the author is embedding this argument. In other words, are they trying to undermine that great man in history, are they addressing the problem and dealing with the problem, or are they letting the problem just kind of fester without addressing it? Uh, so I'm looking carefully at how they're kind of wording and locating the individual in history.

The historians discussed thinking about the time a text was written, the time frame being written about, the branch of history a text represented, and the particular stance a text took relative to the theoretical controversies existing in the field. They tried to situate a particular text, and this analysis depended more heavily on their own knowledge of the discipline than on the text itself.

Mathematicians. In contrast to the historians' approach, contextual factors of the texts, such as the time periods when they were written, were not interpretive tools used by the mathematicians in their reading of math texts. Neither mathematician mentioned such contextual information in their think-alouds. But even when questioned about it, one of the mathematicians said,

> Sometimes, it takes about 10 to 15 years to find a response to a problem. So, an article written in 1985 is just as important today as it was in 1985, and is not dated, like it is in other fields.

He explained that, if an individual were to go into the mathematics library, he or she would find that texts from all time periods were read over and over again.

Neither of the mathematicians said that they interpreted a text in relation to the branch of mathematics, the theoretical approach, or any other contextualizing category. In other words, they tried to read each text for what was represented on the page alone.

Though a mathematician said when he read statistics texts he had to pay greater attention to vocabulary because it was somewhat unfamiliar to him, but it was the strangeness of the new vocabulary, not that it was a statistics text, that triggered this approach.

Chemists. The chemists engaged in contextualization to a modest degree, but used this approach for somewhat different purposes than the historians. As with sourcing, contextualization had more to do with what the scientists chose to read than how they read it. For example, the physical chemist explained that the time period in which something was written was important:

> For my kind of science, information loses its relevance, because the principles are changing. In other fields, it may not be that way. The second paper [the *Science* article] is very driven by theory, as is the field. A paper 20 years old would be totally irrelevant.

Also, just as the historians tried to place the text within a particular controversy in the field or a particular branch of history, the chemists sought such information about chemistry, but mainly to determine the relevance of the text to their interests. One explained,

> And then, I ask, are they doing something in time or frequency? Are they studying a sequence of things? There are two different ways of solving a problem: there are time-domain experiments and frequency-domain experiments. A pulse of sound—short chirp—a bleep will contain all frequencies. A long note (a pure C) will contain only one frequency. If you study time—short pulses, the frequency is not well defined, and a frequency experiment does not pay attention to time.

Corroboration

Corroboration is an intertextual consideration of agreements and disagreements across texts or between the text and one's own knowledge (Wineburg, 1991). As mentioned, during the interviews, we had each of the experts read a text they had chosen from their field, and we also had them read two texts on the same topic that were typical of what high school students might read. The reason for reading the two texts was to explore the intertextual construct to see if the experts would make connections between these texts in their think-alouds. All of these participants—historians, mathematicians, and chemists—tried to corroborate what they were reading with their own background knowledge. All of them also made ties to other texts as they read. There were both similarities and differences in the intertextual connections drawn by these disciplinary experts, but the historians made more explicit and unsolicited remarks about the interpretive use of corroboration than did the mathematicians or chemists.

Historians. The historians explained that they explicitly thought about the connections between the texts they were reading. Note this historian's discussion of the differences between the two pieces on Abraham Lincoln. It compares the sources of information, and prior to reading the second piece, the historian already had an idea about what he was going to be reading and how it would differ for the first text he read on the topic.

> How does it relate to the other piece I just read? . . . The title in the Oates book doesn't imply a particular perspective, except to say that it is published by Harper and Row, so it is for a popular audience interested in history. It may also be trying to reach the professional audience as well. Many historians try to write to both audiences simultaneously. When you compare that with the Bradford piece, it's a very different impression. The title indicates that the author is writing from a particular perspective—Southern and conservative. Immediately, that colors how you read the piece. You expect it to be critical of Lincoln. If anyone is critical, it would be a southern conservative. A southern scholarly press means it was probably not intended for a wide audience like the other book.

These kinds of intertextual comparisons or corroborations may be used to help determine historical facts, but as in this case, corroboration is often a way to evaluate the author's perspective (or his or her use of facts).

The historians also thought about the way their own ideas corroborated a text:

> I guess I'm looking to see, is this something I'm familiar with or is this something new and interesting to me. In this paragraph for example, there was kind of an interesting twist about technology in the part, so I'm noticing a new argument and then formulating a response, a kind of critical response—do I agree with it or not, and where would that take me in my own thinking.

Later, this historian said, "So I guess, I'm looking, I respond that, 'I like things, I don't like things.' I'm looking for flags that either I don't like or I like in order to locate the argument in a political spectrum." Thus, to the historians, a text is an argument or a series of arguments, albeit a subtle argument, and a reader has to compare the author's assertions with his or her own perspectives, if only to identify what the author's argument may be.

Mathematicians. Although the historians clearly used corroboration as a way of making sense of intersubjectivity or multiple interpretations, the mathematicians appeared to use it more to try to limit the possibility of interpretive differences. For example, one of the mathematicians referred to corroboration as "reconciliation." When asked what he meant by that, he said that he thought about whether he had seen the fact before or had seen a specific instance of the fact. When reading an excerpt of a statistics explanation, he said, "It starts right away—you try to reconcile. The way that it describes the solution is not exactly the same as I know it. Is it similar?" In other words, he recognized that he himself might introduce interpretive differences, and that he needed to clarify, from the beginning, what was new and what was already known and accepted. Like the historians, this mathematician viewed reading as an interpretive act: with the historians trying to interpret the various interpretations and the mathematician trying to limit one's own tendency to interpret by using corroboration to identify what has already been proven and accepted.

Although this mathematician did not compare one excerpt with another, the other did, saying, "This is a very intuitive paper—it is much easier to read than the previous chapter. It describes the notion of 'randomness' the way it is usually described." In other words, he compared the two texts regarding how easy they were to understand, but not as an interpretive tool, a very different approach from that evidenced by the historians.

Chemists. The chemists also made comparisons between the two excerpts they read on Boyle's law. After reading the second excerpt, one said, "This, well, this comparison, reads more like an abstract, and my first impression is that it is more difficult to assimilate without the figures, without the detail that I saw in the other book." The other chemist made a similar comment. Like the mathematicians, their comparisons focused on the understandability, or in this case the relative value of the texts, rather than comparing the stances or perspectives of the authors.

Both made connections between the text and their own knowledge, especially on the articles they chose to read. For example, one of the chemists said,

> I'm asking how their experiment is different from ours. I'm doing a very, very similar experiment. And then, what can I get out of this paper? Can I improve on my experiment based upon what theirs was? . . . The results are very different—qualitatively—and so I'm asking myself why they are qualitatively different, and so they also propose an explanation for their results that if, they were true, it would demolish my research if it were true for my experiment. So outside of the paper, we looked at our data more carefully and decided their conclusion did not explain my work.

This use of intertextual information required a kind of pattern matching to identify the similarities and differences between a written report and the chemist's own experience in conducting a scientific study. The studies were similar, and yet the results were apparently different. This led to a closer comparison of the texts, similar to that demonstrated by one of the mathematicians, though their purposes were different; the mathematician was trying to minimize the introduction of his own interpretations, to get closer to the text, whereas the scientist was trying to identify the material reasons why the results would be different. Unlike the historians, who saw these kinds of differences as resulting from differences in authors' perspectives and biases, the chemist sought for differences in the experimental conditions themselves. They did not attribute differences in results to bias in the author or experimenter, and although we did not probe the issue, based on our extensive conversations with them on related issues, we believe that they saw their focus on a thorough comparison of the research methods and conditions in such a situation as typical engagement in the conventions of their discipline.

Also, as with sourcing, the scientists showed a tendency to use corroboration as a way of determining reading choices. The second chemist said, when explaining why he chose the article he did,

> One of the reasons it caught my attention is that I've been interested in environmental issues. I've taught environmental chemistry. I'm also interested in it because using fluorescence in this way relates to some research that I'm doing, not for sensors, using fluorescence as a measure of something else.

The strategies of sourcing, contextualization, and corroboration are largely about evaluating the information found outside a text and that exist in a reader's understanding of the field and his or her place in it. These strategies rely on knowledge of the particular discipline rather than merely a command of specific domain knowledge. They allow a reader to make a determination or a predetermination of how credible a text is, and so they are part of critical reading. Regarding the experts in this study, the historians engaged in these types of interpretations to a high degree, the chemists to a lesser degree, and the mathematicians to a very small degree, and when they did, such as with corroboration, the purposes were quite different. Within mathematics, this kind of peripheral interpretation was discouraged, in favor of more text-based critique. But the think-alouds and interviews reveal that they engaged in other reading strategies when reading disciplinary texts.

Text Structure

Experts in all three fields evidenced a sense of the role text structure played in disciplinary argument, though these text structures were quite different across these disciplines. That is, all the experts showed sensitivity to the text structures that were specific to their fields, and they used that structural knowledge in ways that were somewhat unique to their disciplines.

Historians. The historians were attuned to the relationship between the structures of narrative and argument. As one of the historians read from the book *The Orphan Induction*, he continually tried to analyze the way in which the author was using argument, and where the important information might be.

> The argument was not straightforward, but roundabout, so clearly a part of to make analytical history as a kind of a narrative to raise big issues indirectly (reader friendly) so I had to be more active in distinguishing the arguments. Her most important statements were at the end, rather than at the beginning of paragraphs.

Thus, this historian was claiming that the author was softening or obscuring the main claims within a narrative, making the argument less straightforward.

Later, the historian used his perspective that history is a form of argument to guide his reading toward determining what in the text was contentious (the aspect of history that he believed to be most important):

> I always look for contention. I look for the contentious argument. This is a very direct argument. I could immediately by the third sentence tell what it was, so I was interested in *why* he was making the argument. What were his political and moral questions, and whether he would express them, and whether he had real evidence for his ideas.

The other historian appeared to do the same kind of thing:

> Um, then I'm kind of at a more meta level, I'm trying to, is the direction they're going in their discussion a direction that I'm kind of interested in or are they kind of going off in a direction that's less interesting to me? In other words, where are they going with their argument?

Mathematicians. In their think-alouds, both mathematicians explained how the authors were structuring their presentations, much as the historians did. Note what one mathematician said as he began to read:

> It starts with a historical paragraph. It took me a while to visualize what he meant by an explanation he made. In the next paragraph, it gave some more explanation, and I would have been better to read ahead. He poses a question he is going to give a partial answer to.

Both mathematicians paid attention to what each paragraph was doing as they read. The second mathematician said,

> What is it about? What are they trying to say in this piece? After that is understood, then, that was actually in one paragraph, the second paragraph deals with the basic approach with the kinds of problems they consider here. I am trying to get the realization of what's going on, to find out what else the author is concerned with.

Historians and mathematicians paid attention to how texts were structured, but they used this information in strikingly different ways. The historians saw structural analysis as a way of determining the author's position—"where the author is going with the argument"—so that they could engage in critique. The mathematicians, in contrast, were more focused on using text structure to help determine what the problems and solutions were and were less aimed at author awareness or rhetorical interpretation (Shanahan, 1992, 1998).

Chemists. The chemists used structure similar to the way the mathematicians did. That is, they used it to build an understanding of the ideas in the text rather than for critique or interpretation. However, it seemed like the static structure of the research article provided even more of a guide to chemists than it did mathematicians. One chemist said,

> In *Science*, the first paragraph or two should be intelligible to all scientists. That's one reason why it's the premier journal for scientists, because any scientist can read it. . . . The first two paragraphs set the stage and what the field is about. After that it goes into the technology of the apparatus.

The other chemist explained how he would read an article:

> Each of those articles have an abstract, and I'd read the abstract before the article, and I'd be reading the other parts of the manuscript, which would give the background to this work, what is the importance of this work and what has been done in the past—how the present work relates to it. Then there would be an experimental part, a results part, and a discussion and conclusion.

Graphic and Mathematic Elements of Text

Readers in any discipline read texts. Texts, for the purpose of this study, are any written or printed representations of language and thought, and as such, "the features of any given text have a large impact on comprehension" (Snow, 2002, p. xv). Many disciplinary texts feature graphics, pictures, and other explanatory elements in addition to the element of prose. In both chemistry and mathematics texts, equations, diagrams, graphs, and charts are prevalent, and sometimes so are pictures (Lemke, 1998). Although equations are not common in history texts, photographs, artwork, and in some cases graphs and charts are used. Therefore, to read successfully in these disciplines, it is necessary for readers to not only construct mental representations of the prose elements of text but also likewise make sense of the graphical elements and, ultimately, to develop a coherent body of knowledge based on the text in its entirety. Importantly, the experts differed in how they interpreted these graphical elements of text during reading.

Historians. The high school texts that the historians were asked to read did not include pictures. However, with the texts the historians selected themselves, there were photographs, and yet these were not mentioned in their think-aloud protocols. In the later focus group meeting, the historians noted that the photographs should be critiqued in the same way as the prose, but they noted this not spontaneously, but in response to our pointing out their earlier omission of this kind of interpretation.

Mathematicians. The mathematicians did not make a distinction among the text features, in this case between mathematical equations and prose; the two elements appeared to be treated as unified and of equal importance by the mathematicians. This may be a function of the way mathematics texts are structured, with prose–equations–prose, alternating in a more or less linear series from the top of a page to the bottom. Both prose and equations were referred to as sentences or concepts by the mathematicians. When explaining how he thought about the ideas in a text, one mathematician said that he asks himself questions:

> Did I see this fact before? Did I see a special instance of this fact before? Do I know if the statement is correct? Can I prove it?
>
> If yes, matter closed, and I move forward. If no, if I don't see why this is true, maybe I need to read further to get more explanation.
>
> It's about how things are related. I don't think that much in terms of formulas, but concepts. In my work, it's more like how the concepts are related. Like, what is the source of these formulas? Why are they here?

Because the mathematicians thought of equations and texts as a continual explanation of concepts, their think-aloud protocols rarely signaled a point where they were reacting to equations alone or the prose alone. One exception to this highlights a specialized strategy for dealing with the symbolic structure of much mathematical text; one mathematician noted,

> In this paper, there are a lot of notations—background for what follows. So I try to memorize what symbols designate what. After a while, all statements will be a combination of symbols. It would make it impossible to understand what's going on later if I didn't try to remember them now.

In the introduction to this section of this report, we defined text as the written or printed representation of language and thought, which included both prose and graphical elements or features. According to this definition, both the prose and graphics are text, but they could be treated as separable sources of information within the text. This separation, whatever its value may be for those of us who study text and reading, was not evident in the discourse of these mathematicians.

Chemists. Chemists treated graphs, charts, diagrams, and equations as sources of information that were equivalent to prose, and they rejected any notion that the graphic elements were in any way "ancillary" or subordinate to the text. In their reading, they moved from text to graphic and back to text, recursively. For example, one of the chemists said,

> They give you the structure, the structure of the sensor is given, so I was looking at the picture as I was reading, and I tried to relate what was in the picture to what they were saying about how mercury binds to one part of the molecule.

When queried about this recursive approach to the graphics, the chemists revealed that, different from the mathematicians, they saw the graphic and prose elements as usefully separable in science text. The chemists explained that these different elements include overlapping but different information, and that to read such material properly it was essential to be able to cognitively "translate" or "transform" the information from one form to another. Thus, they would need, for example, to visualize what was described in the prose and then seek correspondences between that visualization and the graphic to properly interpret the material. Similar correspondences would be sought in equations, tables, and charts.

The other chemist noted the importance of equations. "I think in terms of equations—I want to write down the mathematics—I'm algebraically related, so I'd start writing down a mathematical expression while I'm reading." Later, as he was reading the texts for high school students, he said,

> The graph is nice. Seeing the geometry of the graph is very nice. When I read something new, I'll take anything I can get. I know it, and to put yourself in the mind-set of someone who doesn't know. The picture with the syringe is simplistic, but at the high school level it may be useful. In your reading—it's data. Graphs and pictures give you concepts and data.

The Role of Critique

All of the experts engaged in a good deal of critique as they read. However, the nature of critique differed by discipline. To historians, everything was a focus of critique, with the intent of determining the credibility of the author's argument, and the historians indicated that high school students should engage in this kind of continuous critique, as well, even with textbooks.

The mathematicians, on the hand, were more focused on the *correctness* of information (or its internal consistency), and they were very critical of the texts they read. The mathematicians weighed each word carefully and explained that there was error in everything so they read to find the error. One of the mathematicians explained to the focus group that it was vitally important for a mathematician to choose every word correctly as he wrote; even "a" and "the" mean different things. Note the way he approached the text he had chosen to read: "I try to determine whether it's [the solution to the problem] correct. That's the important criteria, and it's by no means assumed. It would be unusual to read a paper like this and not find something incorrect." As he continued to read, he noted problems with the text:

> The first definition is 1.1. Then he gives another definition that is not numbered. They are the same level of significance, so they should be both numbered. He makes an assumption that describes the context with which he's looking at this paper. "Our assumption is sufficiently natural," I don't know if that's grammatical or not. He uses a counterexample. He makes another grammatical mistake, saying "of" instead of "to."

The point of this thorough effort at error detection was not to counter the author's presentation or to act as a kind of master editor or proofreader but rather to ensure an accurate understanding of the problems and solutions presented in the text (since a presentation may be imperfect, it is always necessary for the mathematics reader to be vigilant in recognizing ambiguities or errors that may introduce substantive inaccuracies to their own interpretations).

The chemists, as noted, did weigh a text's credibility. They were not as painstaking as the mathematicians in this reading process but did consider a text's plausibility or its congruence with scientific evidence. For example,

> There are certain basic laws of science that can't be violated—does it make physical sense? Does your answer violate the principle of conservation of energy? For example, getting off the topic—they say there are two sides of one issue—intelligent design or evolution. That's silly. Certain things are canon. Certain things are speculative. Textbooks present canon. But if they get an answer that violates the idea that there is no perpetual motion, they need to rethink.

Also, on examining a newspaper clipping about the greenhouse effect, both chemists reacted strongly to a misreporting of the unit of measurement. One later explained that unit of measurement was one of the main concepts of chemistry. And although the chemists were sticklers about such accuracy, they did not believe that chemistry students should read textbooks in a particularly critical fashion, as the development of a canon of knowledge in such reading was the highest priority. This recommended approach was not something just for the students however, as it closely reflected how they themselves read scientific information when they had limited familiarity with the particular topic or approach covered in the text.

Rereading or "Close Reading"

Although all of these experts demonstrated a "close" reading of the texts (i.e., they analyzed particular words, sentences, and paragraphs rather than merely reading for the gist), it was only the mathematicians who overtly mentioned that this was a particular strategy that they used in reading. By close reading, the mathematicians meant a reading that thoughtfully weighed the implications of nearly every word. One of the mathematicians, for example, said it usually took at least 4 or 5 hours to work his way though a single journal article for the first time. The other said that it sometimes took him years to work through a theorem so that he clearly understood it—a reason why the field does not place a high value on contemporaneousness. During the focus group readings, the mathematicians always took markedly more time than the other readers. Reading and rereading were the strategies they said they used and also the ones they wanted students to use.

The historians and chemists were more selective in their use of rereading. The texts that they read tended to be relatively more extensive and less dense than the mathematical texts. Part of the historians and chemists' reading routines was to determine which parts of a text to pay attention to. This might be determined structurally, such as when a chemist turns specifically to the results section of a text to examine particular information, or it might be implemented by a historian reading a text to identify information that is new, and then reexamining this information more carefully. We never observed the historians or chemists reading and rereading the text word by word, though occasionally they evidenced this with a small portion of a text that they had identified as requiring greater attention (the historians because the selection somehow revealed the author's perspective, and the scientists when considering information that they suspected may be discrepant with their own work).

The Role of Interest

The three pairs of experts were quite similar on another dimension—interest. Like the physicists in Bazerman's (1985) study, all of these experts used interest and familiarity to guide the ways in which they read.

Historians. One of the historians explained,

> I'm always looking for gender because I'm interested in gender. This source is not particularly interested in gender, and again, I am looking, since my project is specifically about the modification of African species, I'm looking closely for some flags where they're talking specifically about, um, a specific species and the organization and the differentiation between the ways the animals are marketed and portrayed. . . . I certainly am noticing, I guess this relates to something I mentioned before, but I am noticing something that's new and different, like some argument that, I guess I'm looking to see, is this something I'm familiar with or is this something new and interesting to me. In this paragraph for example, there was kind of an interesting twist about technology. . . .

Mathematicians. One of the mathematicians said,

> A lot depends on how deep the paper is itself. If it's consistent with what I know, it doesn't take much. But some papers have deeper ideas and a different perspective and that requires a lot of thinking. Some bring in technical tools about which I'm not familiar.

It was at that point that he described how reading an article might take him years to understand. Also, note his concept of "perspective," which refers to an author's approach to a quantitative or spatial problem, rather than as rhetoric, bias, or opinion.

Chemists. One of the chemists explained that if he were familiar with the information, then he would skim a text until he came to something new or interesting, and study that information. The other described how he would read an article if he were reading more than an excerpt.

> If I was reading the full article, I think I would be reading it with a more critical, reading it more critically, to make sure that I understand it fully, and then see if the author has really proven his case. Is it done correctly? Are there proper controls described? What are the experimental results? In this case, is the fluorescence directly related to the concentration of mercury? What are the error limits? Things like that. And I would suppose I would tend to read it. How carefully I read an article depends on how well it relates to my research. If it doesn't relate closely, I'll read it more casually, but if it relates to my research, I want to know what this person has done. I might consider citing this paper in a future manuscript of my own.

Implications

In comparing and contrasting the reading strategies of the three pairs of experts, we found many instances in which they engaged in similar strategies (sourcing, contextualization, corroboration, critiquing of the argument, use of text structure, paying attention to visual or graphical information and chemical and mathematical equations), but to varying degrees and in unique ways. They used these strategies differently and sometimes even for different purposes. For example, although these historians contextualized to come to terms with an author's perspective—an interpretive purpose, the chemists did so mainly to determine if a text was worth reading since if it was too old it would not be consistent with the latest scientific evidence. Although all of these disciplinary experts engaged in critique during reading, critique had a very different character in each field, with these mathematicians much more engaged in identifying error and internal inconsistency, these chemists seeking for consistency with external scientific evidence, and these historians trying to weigh the implications of differences in perspective and context. The three pairs of disciplinary experts differed in the frequency of their implementation of these critical reading responses, as well; with these historians engaged in a, seemingly, continuous critique, these mathematicians being especially critical when reading material that presumed or explicitly presented quantification, and these scientists reserving their critical responses for texts for which they had strong background knowledge (otherwise, the chemists thought it better that readers focus on coming to terms with the unfamiliar scientific information, an approach evident both in their own reading, but also in their stated beliefs that school science time should not be devoted to critical analysis of science texts—texts, that they note, should be "nearly authoritative").

Only one frequently used strategy was evident in only a single discipline—and that was the intensive rereading that characterized mathematics, a rereading demanded by both the dense presentation style of mathematics text, but also by these readers' emphasis on error identification. The mathematicians in this study were quite forthright about it: If a text includes mathematics, then it is likely to contain error, and part of the math reader's challenge is to be aware of such error. For the mathematician, precision is at a premium in all aspects of a text. The chemists and historians noticed error, bias, or discrepancies, too, but their reading did not hone in on these problems as intensely and thoroughly as was evident during math reading.

The influence of disciplinary text on patterns of disciplinary reading is an important one. These historians, though indicating the need to approach graphics in the same critical manner that they read the prose, tended to ignore this material or at the very least to treat it as subordinate to the arguments in the text (in fact, the graphics in history often take an illustrative or evidentiary role, supporting argument, but rarely are central to it). These chemists, on the other hand, approached the graphics as being every bit as important as the prose, and read these recursively toward accomplishing some kind of cognitive translation or transformation since they recognized that these different forms of information may carry unique insights to the phenomenon under study. These mathematicians, too, saw formulas and equations to be coequal with prose, and even used the same language to speak about them. However, their reading appeared to be less recursive than that of these chemists, but this may have been more the result of differences in math and chemistry texts than how the readers approach the texts, since math tends to be written in a linear fashion, alternating prose and equations, in a way that fosters a more unified presentation and a kind of tacit recursiveness as a reader moves forward (readers have to choose whether, how, and when to go from prose to graphics to prose in a science text because of the somewhat more haphazard arrangement of these sources on a page).

These historians, during the focus group discussions, expressed abhorrence at the idea of instruction including only on a single textbook in a high school history class because sourcing and corroboration are so central to history reading, and neither would be possible with only a single text. It was not that they were opposed to the idea of using a textbook for such classes, but only that such a textbook would have to be supplemented with other primary and secondary sources if students were to be afforded the opportunity to engage in authentic history reading. On the other hand, these chemists approached reading, at least once a text had been selected for reading, as requiring more of a close analysis of the material on the page and less consideration of author, context, or critical response, and so they supported the use of a single authoritative textbook for high school teaching. They were sometimes devastatingly critical about the design of current high school textbooks but indicated that, to learn science, students had to master a current account of "how the world works" and that a good textbook should be able to provide such an account. (These mathematicians were generally in agreement with the scientists on this point of pedagogy.)

As noted at the outset, this study has several important limitations. Only six disciplinary experts participated in this investigation, two from each discipline, and each was asked to read a small collection of disciplinary texts. Both the number of experts and number of texts limit the generalizability of the conclusions that can be drawn, a fundamental limitation of the expert-reader paradigm as it is usually implemented. The expert-reader paradigm, however, is intended to identify potentially valuable insights about how reading may proceed, rather than to warrant claims about universality (i.e., all chemists read all texts in this way). For example, the chemists in this study did not seem to look for potential experimenter bias when reading experimental studies, whereas the historians were always looking for bias. We hypothesize that is because chemists have faith in the potential for experimental methodology to eliminate or reduce bias whereas historians have less faith in the retrospective and partial analysis of historical documents to do so. But this observation is exploratory, at best, and is something that will need to be pursued further in future studies. How readers read depends on many factors, including their level of domain knowledge, their purposes for reading, the characteristics of the text, and whether there was one text or multiple texts that had to be interpreted together (Hynd-Shanahan, 2008). Studies like this one and those reviewed here are providing clear evidence that disciplinary expertise is one of those influencing factors, though the reader's specialization within a discipline may also be important as it appears that taxonomic or classificatory scientists such as botanists may read quite differently than other kinds of scientists, such as physicists (see, e.g., Bazerman, 1985; Halliday, 1994; Halliday & Martin, 1993). Future research will have to determine how characteristic the strategies and approaches identified here are of the disciplines and specializations from which they were drawn and whether these strategies can be taught to students in any way that will effectively improve their academic performance. That past research has demonstrated that strategies identified through studies like this one can be effective is hopeful. Of course, there are still few of these expert-reader studies focused on disciplinary reading, so there is a need for more investigations into how reading is done in the various disciplinary fields.

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