Revitalizing Instruction in Scientific Genres: Connecting Knowledge Production with Writing to Learn in Science

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ABSTRACT: This article explores the history and theoretical paradigms associated with writing to learn in science, including the debate surrounding the teaching of traditional scientific genres that has received attention in Australia and the United Kingdom. It is asserted that unique features of writing in traditional scientific genres, such as *experiment, explanation,* and *report,* promote reflection and the production of new knowledge, especially through the formation of meaningful inferences for data. The author presents sample data illustrating the potential for meaningful learning associated with writing in communicative genres, considers the limited potential of creative writing for developing scientific understandings, and recasts a description of scientific genres in light of contemporary classroom practices. © 1999 John Wiley & Sons, Inc. *Sci Ed* **83:**115–130, 1999.

INTRODUCTION

Humans have the unique capability to represent interactions with the environment through the use of symbol systems. Sensory impressions, feelings, thoughts, and actions are most often translated into verbal language that we process as inner speech. It is the intimate connection between processing new sensory information and formulating verbal meanings for the information that underlies the complex relationships between thinking, speaking, and writing (Britton, 1970). In the field of science education, several researchers have promoted the view that language does not merely describe or reflect preexisting conceptual structures; language actively creates those structures (Glasson & Lalik, 1993; Halliday & Martin, 1993; Lemke, 1990; Roth & Roychoudhury, 1992). Over the last couple of decades, there has been increased interest in using writing in science as a mode of learning science, in addition to its traditional role in evaluation. The movement to incorporate informal writing into all the subject area disciplines is known as *writing to learn* (Connally, 1989; Rivard, 1994). Many teachers from college, secondary, and elementary levels have embraced the concept of writing as a form of learning in science. In

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fact, a substantial amount of research on the use of informal writing to facilitate concept learning in science has accumulated (Rivard, 1994).

However, some foggy issues continue to surround the teaching of writing in science, including: teacher and learner purposes for writing; the ownership of the writing content; whether to teach writing genres; and how writing for an audience may change text production. In a recent assessment of writing in science, Holliday, Yore, and Alvermann (1994, p. 885) stated, "Currently, conceptions of writing to learn appear to be embryonic and fragmented." In particular, while the benefits of informal writing for personal understanding have been fairly well articulated and applied, research and teaching of communicative genres, those designed to inform others about scientific ideas, have been misunderstood and diminished. The purpose of this study is to develop a case for the revitalization of writing in scientific genres (also called transactional or communicative) as a mode of learning in the science classroom. While the ideas in this article may be applied to any grade level, introducing students to scientific genres at the upper elementary and middle school years may be especially important, as children begin to develop connections between scientific content and the process of knowledge production in the scientific community. I begin with a brief history of the movement to incorporate writing to learn in the content areas, review arguments for and against teaching scientific genres, then present a new perspective and relevant theoretical frameworks for writing in science. I continue with the presentation of some data relevant to writing to communicate as a form of writing to learn, develop a case against the overuse of creative writing in science, and finally make some suggestions for the suggestions for the teaching and research of scientific genres in the contemporary classroom.

EXPRESSIVE OR INFORMAL WRITING AS THE DOMINANT PARADIGM FOR WRITING TO LEARN

A Brief History of Writing to Learn in the Content Areas

Research on language and learning in the content areas was initiated in the United Kingdom by Britton and colleagues (Britton, 1970; Britton, Burgess, Martin, McLeod, & Rosen, 1975; Martin, 1992) during the late 1960s. Britton posited that speech plays a major role in learning based on the observation that, for a young child, every new area of interest is first organized, explored, and investigated through talk. Britton asserts that ordinary speech is the natural starting place for writing. The writing of young or immature writers, as well as early drafts of more experienced writers, may be labeled as *expressive,* because it resembles the type of language used in everyday conversation. Expressive writing both conveys information and reflects on that information. Since expressive writing is usually done informally, without concern for the judgment of others, the writer may concentrate on making connections with prior knowledge, clarifying understanding, and otherwise "explaining the matter to oneself" (Britton et al., 1975, p. 28). Because expressive writing can be a very powerful tool for associating concepts with language, it has come to be known as writing to learn (Connally, 1989). Advocates for incorporating writing to learn in science have promoted the use of short impromptu paragraphs (known as free-writes), journals, questions, various forms of creative writing, and content summaries (Ambron, 1987; Connally & Vilardi, 1989; Mullins, 1989; Santa & Havens, 1991; Strauss & Fulwiler, 1987).

Britton's (1970) model posits that as writing becomes more mature and purposeful, it evolves into either *poetic* or *transactional* forms. Poetic writing is characterized by the voice of the spectator and is commonly recognized as the language of novels and poems.

The purpose of poetic writing is to detach oneself from the action and reflect on experiences and emotions. Transactional writing, which is used by science writers, is characterized by the voice of the participant in action. The purpose of transactional writing is to convey information to others. Transactional forms of writing have often been called "writing to inform" or "writing to communicate" (Freisinger, 1980; Fulwiler, 1980). The development of a conceptual framework for writing, including expressive, transactional, and poetic modes, provided a lens through which Britton and his colleagues researched writing practices in middle and secondary classrooms (Britton et al., 1975; Martin, 1992). They found that as "students moved up the school from age eleven to age seventeen, their writing became increasingly directed toward an audience of the teacher in the role of examiner or assessor, and that the function of writing became increasingly informational" (Martin, 1992, p. 18). These findings prompted Britton and his research group to advocate language development through expressive writing across the curriculum. Language scholars who were simultaneously interested in more student-centered educational philosophies, especially the ideas of Piaget, Bruner, Chomsky, and Vygotsky, quickly embraced the idea of informal and exploratory writing as a form of learning (Martin, 1992).

The Current Paradigm of Writing to Learn

The seminal work of Britton's group was absorbed into a "Writing Across the Curriculum" (WAC) movement in the United States and elsewhere, especially at the college level, throughout the late 1970s and 1980s. Many science and mathematics professors incorporated writing as a means of improving content learning, and have provided quite a large action research base on writing in their own classrooms (Ambron, 1987; Connally & Vilardi, 1989; MacDonald & Purdy, 1989; Madigan, 1987; Mullins, 1989; Powell, 1985) Writing in the content areas at the high school level, especially in science and social studies, was also identified as fruitful area of instruction and research in the mid-1980s (Langer & Appleby, 1987). In the following statement, Connally describes the evolving nature of the WAC movement, as it matured in the late 1980s. "At first, the WAC movement seemed, and seems still to some, to be primarily a way of improving exposition of knowledge. The practice of writing regularly in all classes, using the forms and conventions of various 'communities of discourse'—scientific, social scientific, as well as literary—promised to clarify meaning and reinforce memory. More recently, the phrase 'writing to learn' has replaced 'writing across the curriculum,' however, because it suggests the powerful role language plays in the production, as well as the presentation, of knowledge. 'Writing to learn' is less about *formal* uses of writing to display memory and test mastery than it is about *informal* writing; about language that is forming meaning; about writing that is done regularly in and out of class to help students acquire a personal ownership of ideas conveyed in lectures and textbooks (Connally, 1989, pp. 2–3)."

Connally's remarks point to an increased emphasis on expressive writing to promote personal understanding and a parallel decreased interest in teaching the forms and conventions of communication in various subject area disciplines. A related view is that informal writing is a natural language medium that can be used to promote the gradual building of meanings in a learning community (Connally, 1989; Roth & Rosaen, 1991). Therefore, in recent years, expressive writing has been portrayed as an activity that helps students make connections, think deeply, and facilitate conceptual change, while writing to communicate has been portrayed as a medium to "display memory and test mastery," controlled by the teacher's goals and knowledge. A view of writing to communicate as the transmission of learned knowledge for the teacher's approval is illustrated by some recent articles on writing to learn. For example, Rivard (1994) purposely chose to exclude all research on writing to communicate from his recent review of writing to learn in science. Similarly, Miller (1997, p. 1), who has extensively researched writing to learn in mathematics, recently defined writing to communicate in the following way, "*Informational* or *transactional* writing conveys verifiable information and tests previously learned knowledge."

Berkenkotter and Huckin (1995) explain that, while the explicit teaching of writing in scientific genres (e.g., laboratory reports and explanations) has been hotly debated in Australia and the United Kingdom, there is a lack of interest in teaching communicative genres in the United States. They attribute this lack of interest to Britton and his colleagues' (1975) profound impact on the expressivist writing movement that gained rapid support in this country. While contemporary researchers have identified the significance of writing to inform and persuade an audience (Holliday, Yore, & Alvermann, 1994), little attention has been given to writing to communicate as a form of learning in science classrooms. The topic is rarely included in published curriculum materials, teachers' guides, or textbooks for teaching science methods to preservice teachers. For example, a 1997 edition of a popular elementary science methods textbook (Carin, 1997), devotes only 2 pages to any type of writing in science out of a total of 342 pages. Within those two pages, the majority of suggestions are for creative writing in science including narratives, "Just So" stories, creative magazines, poetry, and writing about the motivations and attributes of different characters that appear in narrative stories. Carin addresses only one form of science writing that might include description or explanation of science concepts and processes, student-created trade books. Similarly, books published for teachers usually contain ideas for implementing expressive and creative writing in science, rather than scientific writing (an exception is Scott's *Science and Language Links*, 1993, originally an Australian publication).

THE DEBATE OVER TEACHING TRADITIONAL SCIENTIFIC GENRES AND A NEW PERSPECTIVE

The popularity of expressive writing and its association with emancipatory forms of language use has provided the impetus for some educators to actively reject teaching traditional scientific genres. Seen as dry, voiceless, and positivistic, traditional forms like *experiment, report,* and *explanation* (Halliday & Martin, 1993), are blamed for "turning off" interest in science, especially for women and people of non-European cultures (Hildebrand, 1996; Spanier, 1992). Feminists have criticized conventional scientific discourse as being the authoritative and positivistic domain of white males (Hildebrand, 1996; Spanier, 1992). Following this argument, researchers such as Hildebrand (1996) have been promoting creative writing to make science more appealing to girls (Hildebrand, 1996; Warner & Wallace, 1994). A feminist, postmodern view of science writing promotes the production of multiple and expressive genres that critique the status quo of the scientific enterprise (Prain & Hand, 1996). Hildebrand (1996) posits that creative writing provides both a sense of personal voice and connections to realistic scenarios that enable girls to relate science to their own lives.

The opposing view, led by Halliday and Martin (1993) is that scientific writing genres should be explicitly taught, so that all children might have access to the discursive power of scientific texts. They argue that scientific genres have arisen in response to the need for specific kinds of communication in the scientific enterprise and should be taught in parallel with scientific bodies of knowledge. Researchers such as Christie (1985) assert that stressing the development of narrative writing, while ignoring the teaching of scientific genres, puts certain segments of the population, such as poor children, at a disadvantage for learning to read and write scientific texts. This argument resonates with the writing of Delpit (1986) who advocates the direct teaching of conventional writing skills and genres to children who have no resources for learning them on their own. Berkenkotter and Huckin (1995) agree that the recent emphasis on expressive writing in the United States raises critical questions about the current direction of science writing instruction, including the implications of ignoring genre conventions that students must master to succeed in secondary schools and universities.

While I tend to agree with those that advocate the teaching of scientific genres as access to mainstream scientific texts, I would like to assert another compelling reason for the increased teaching of scientific genres. *Writing in scientific genres promotes the production of new knowledge by creating a unique reflective environment for learners engaged in scientific investigations.* The argument for expressive and creative writing has been placed in the context of learning scientific concepts, facts, and principles that are produced and transmitted by the authority of teachers and textbooks. Connally's (1989) statement (above) stresses "personal ownership of ideas conveyed in lectures and textbooks." I propose that learners involved in authentic scientific inquiry will take *personal ownership of their own scientific ideas* and should learn to write in scientific genres to express those ideas. Learning to write in traditional scientific genres is a natural outgrowth of the inquiry process, fostering a profound understanding of the connections between inquiry problems, procedures, data, and knowledge claims. In the context of authentic investigation, students will not find scientific writing voiceless or impersonal; they will, in fact, find the voice of ownership of scientific knowledge. Further, there are some unique features of writing to communicate that make it better suited for generating new knowledge from data than expressive writing. Writing in the accepted scientific genres can provide opportunities for understanding the relationship of evidence to knowledge claims, and the tentative nature of the scientific enterprise. Coupled with opportunities for authentic investigation, writing to communicate science will provide the opportunity for in-depth scientific thinking and will promote the crystallization of new understandings through verbal modes of discourse. I explore these ideas in more depth in the following sections.

RELEVANT THEORETICAL FRAMEWORKS

Constructivist Learning Theories and the Movement Towards Pedagogies that Emphasize Authentic Investigation

Research in cognitive science over the past few decades has been profoundly impacted by paradigms that take into consideration previous knowledge of the learner (Wittrock, 1974). The generative theory of learning advanced by Wittrock (1974) and developed for science by Osborne and Wittrock (1983) asserts that learners selectively attend to incoming stimuli, then actively generate associations between relevant knowledge from long-term memory and the new sensory information. Science learners have sets of tentative constructions for scientific phenomena that may be continually modified by experiences in the classroom. Language is essential for the generative process, because verbal representations are needed to link ideas from long term memory to new information (Osborne & Wittrock, 1983; Wittrock, 1974). Learning science involves extending conceptual structures by generating new meaningful inferences for incoming data and information.

Instruction that emphasizes inquiry and problem solving within social, cultural, and technological contexts is consistent with constructivist theories of learning science. Many formulations of constructivist-oriented learning environments include inquiry activities in which students have the freedom to select their own methods of investigation and even their own investigation problems (Roth & Roychoudhury, 1993; Yaeger, 1991), although the degree to which the teacher should structure the activities to guide students toward acceptable scientific knowledge remains a point of controversy in the literature (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Lijnse, 1995). A shift toward instructional practices in which students solve problems, seek out information, pose questions, build devices, create their own investigation plans, and collect authentic data will have a considerable impact on the way students view and implement writing tasks. Students involved in investigative activities have authentic purposes for writing that might include keeping track of procedures and data, reflecting on the quality of designs, brainstorming new ideas, making meaning of results, and communicating what they have found to others. From this perspective, both writing to learn and writing to communicate take on new connotations. Writing to communicate within the context of inquiry-based instruction should not be equated with testing the mastery of teacher-transmitted knowledge.

Bereiter and Scardamalia's Knowledge-Transforming Model of Writing

Bereiter and Scardamalia (1987) have formulated two theoretical models of the composing process, the knowledge-telling model and the knowledge-transforming model. The knowledge-telling model is a common response to the challenge of generating content for discourse in written text. The basic steps include the mental representation of the writing task, the generation of topic identifiers, and the use of these topic identifiers as cues to retrieve information through a process of "spreading activation" (Bereiter & Scardamalia, 1987, p. 7). The writer tends to retrieve and write down all the ideas she has, until the use of the cues is exhausted. At the same time, the writer draws on appropriate identifiers of discourse knowledge to match the task (e.g., opinion essay). The knowledge-telling model, while appropriate for routine writing tasks, does not foster the generation of new knowledge, because it relies on already established connections between content elements and readily available discourse knowledge. In contrast, when writers engage in the knowledge-transforming model of writing, they increase their knowledge acquisition through content processing and discourse processing interaction (see Fig. 1). In the content space, the problems of knowledge and beliefs are considered, while in the discourse space, the problems of how to express the content are considered. The output from each space serves as input for the other, so that questions concerning language and syntax choice reshape the meaning of the content, while efforts to the express the content direct the ongoing composition. It is this interaction between the problem spaces, according to Bereiter and Scardamalia, that provides the stimulus for reflection in writing.

The dynamic relationship between the content space and the rhetorical space in the knowledge-transforming model illuminates why writing is such a critical part of science learning. In the context of scientific investigation, the content space consists of prior knowledge and new data (first-hand observations or second-hand information from print or non–print-based media). Work in the content problem space will encompass reflection on the meaning of the data in terms of the investigation problem, while work in the rhetorical space will encompass the communication of that meaning to the audience. The requirement to formulate language and syntax choice for written text, especially when writing to communicate to an audience, promotes direct connections between data as evidence and knowledge claims in the form of meaningful inferences. Cognitive engagement in the rhetorical problem space will stimulate reconsideration of the meaning of the data: Is this what the data really shows? As a result of this iterative and dynamic process, new knowledge is created in the form of meaningful inferences for the data. Examples of how these processes

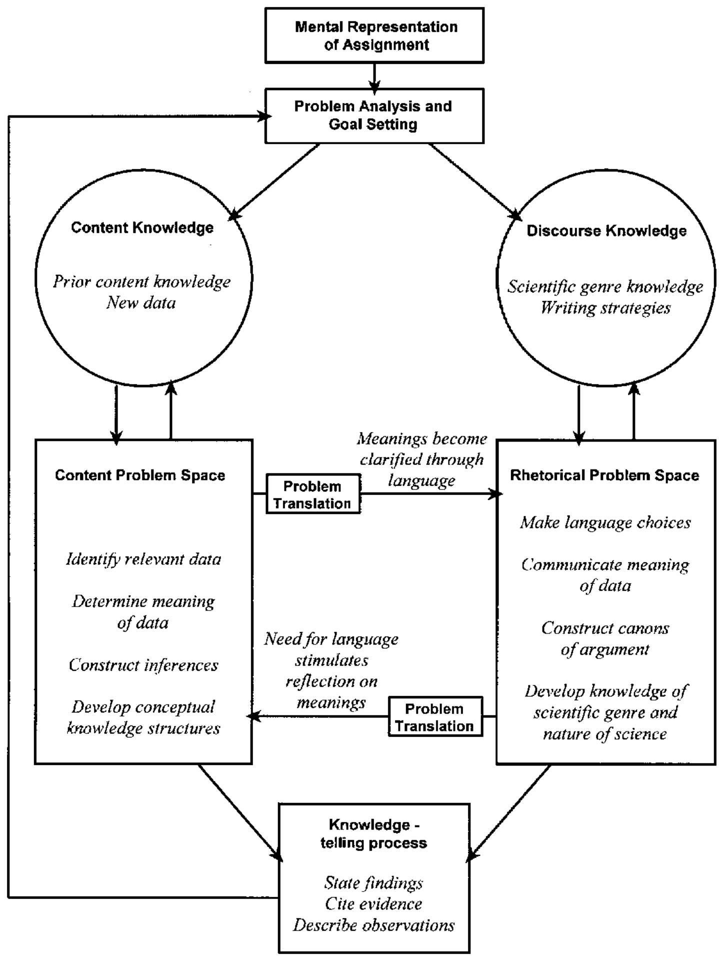

Figure 1. Bereiter and Scardamalia's (1987, p. 12) knowledge-transforming model of composition. Applications and reflections relevant to scientific investigation have been added by the author (italics).

might be operating in the production of children's scientific texts is illustrated in what follows.

Advantages of Writing to Communicate

Advocates of informal writing argue that writing to communicate information is constrained by the need to appear correct in public (Connally, 1989). It is this very quality, however, that may promote the use of scientific thinking processes and develop deeper understandings of knowledge production in the scientific community. When learners write expressively, they include records of their own reflections and speculations into the writing. Expressive writing represents an important phase in the meaning-making process and should be used to scaffold more formal writing products, as well as the inquiry process itself. However, when writing to communicate, the learner can no longer speculate to herself. She must present her most complete and warranted understandings to the public for consideration. This transformation from written speculation to commitment in language choice, as illustrated by the knowledge-transforming model just described, calls upon the writer to exercise the most important scientific thinking strategies that are associated with inquiry, the connections between problems, methods, observations, patterns, data as evidence, and knowledge claims. When the learner knows a good deal about her own investigation, she has the opportunity to tell others about its meaning: she becomes the expert voice.

Writing for an audience requires a degree of self-questioning and metacognition that informal writing does not (Holliday, Yore, & Alvermann, 1994). Holliday, et al. (1994, p. 886) relate writing for an audience to Bereiter and Scardamalia's knowledge-transforming model in the following way, "Questions that writers might ask themselves in the knowledge-transforming model include: What evidence do I have? What warrants, claims, and logical arguments should I use? What are the array of alternative explanations? What do these ideas mean to the target audience?" Writing for an audience requires the writer to be sufficiently detailed and explicit that the text may be interpreted beyond the limited context in which it was written (Langer & Appleby, 1987). The requirements for logical presentation, linear organization, explicitness in connections between concepts, and coherence in conventional scientific genres can foster deep thinking about science.

EXAMINING LEARNER'S SCIENTIFIC WRITING IN AN INSTRUCTIONAL SETTING

Some samples of students' writing in the context of science inquiry illustrate how writing in a communicative genre has the potential to foster the production of new scientific knowledge. The following investigation reports were written by African-American middle school students who attended a summer science camp in an urban setting. During the camp, students participated in a zoo animal behavior project that lasted approximately 3 days. The students were engaged in preinvestigation activities including class discussion, and informal writing on animal behavior and the concept of habitat. On the day of the zoo investigation, each pair of students chose a particular animal to investigate and completed drawings and descriptive paragraphs about their animal. The students' actual investigations were comprised of recording their animal's behavior at least once each minute for a 30-minute period. They recorded the behaviors on data log sheets. Upon return to camp the following day, each pair was asked to complete a zoo behavior report about their animal, responding to the following writing prompt, "The director of the zoo needs a written report detailing the behaviors that your observed while watching your animal. Be sure and use your notes for accuracy." As in most science classrooms, the students did not receive any explicit writing instruction. However, the camp teachers verbally requested that the students state why they believed the animals behaved the way they did and reminded the students to write in complete sentences.

A content analysis of the data indicated that approximately one-third of the zoo behavior reports included the generation of new meaningful inferences for the data. Consider the following zoo memo written by a pair of 12-year-old girls:

> On Monday, July 17, DC and I observed the Muntjac. We learned that this animal comes from Asia. And that they eat the bottom part of the grass because its fresher. We also learned that Muntjacs are very secretive animals. We also observed the difference between a male and female. The male has a [sic] earring in his left ear and he has horns. To urinate they stand on three legs. They like to disappear into the bushes. Their habbitat [sic] is bushy land.

> Another behavior that we observed was the adult Muntjac often moved toward the fence and sniffed. We believe he was sniffing for food. He also rolled back his ears and stuck out his neck. We think he is always alert to protect his family from danger. On one occasion, the male Muntjac came towards the fence. KT [another student] held her shirt towards him. He ran away quickly.
>
> In conclusion, we can say that the Muntjac constantly hunts for food, but is always alert to protect itself and its family.

The writers of this report made inferences about the observed behaviors, apparently drawing on prior knowledge, background information available at the zoo, and their own interpretation of the context. Inferences directly corresponded to data, for example, "and sniffed," corresponded to "We believe he was sniffing for food," and "He also rolled back his ears and stuck out his neck," corresponded to "We think he is always alert to protect his family from danger." The girls apparently related background information from zoo postings directly to observations as they transformed the recorded observation on their data log, "disappeared into the bamboo" to the report formulation, "They like to disappear into the bushes. Their habbitat [sic] is bushy land." Since none of these inferences appeared in the girls' original data log, we can conclude that the inferences were constructed during reflection in report writing. These young writers took advantage of the communicative writing task to move beyond descriptive information and hypothesize about the meaning of the animal behaviors, in the manner suggested by Bereiter and Scardamalia's knowledge-transforming model of writing. Five of the 16 reports analyzed provided similar evidence of generating new knowledge in the form of meaningful inferences and hypotheses about zoo animal behaviors.

The remaining two thirds of the reports (11 out of 16) were characterized by recounting recorded observations or facts with few meaningful inferences. The following is a typical example written by two 13-year-old boys:

> Today we went to the Atlanta zoo where we looked at different animals such as zebras, giraffes, gorilas [sic], monkeys, and orangatangs [sic]. From my observations of the giraffe I found out that they are rather slow and are always eating. They do many strange things, such as wagging their tails, wiggling their ears, and poking out their tounges [sic]. They are very large and I read that they weigh more than a rhinoserous [sic], which is close to 2 or 2½ tons, and their necks extends out 7 ft. long. Their tails are 3 ft. long and are sometimes used for swating [sic] flies. At times the giraffes will stand completely motionless.

The writers listed several observations of giraffe behavior, yet there is little inference drawn between the observations and their meanings. For example, the giraffes' size and the observation that they are always eating are both mentioned but are never connected. The boys relate several behaviors such as, wiggling ears, poking out tongues, or standing motionless, but they do not construct hypotheses about the meaning of these behaviors to the giraffe's lifestyle or habitat. While these writers may have learned some descriptive information about the giraffes, there is no evidence that they have generated new meanings for the animals' behavior. Like many other students who wrote zoo animal reports, these boys appear to have used a knowledge-telling mode of writing (although we cannot adequately judge this from the writing alone). The implication is that some of the children had a natural sense of how to move from data to meaningful inference in writing, while many of the children could have benefited from more explicit writing instruction in the context of meaningful scientific inquiry. The data also provide evidence that writing in a traditional scientific genre may stimulate connections between data collection, knowledge claims in the form of reasonable hypotheses, and previously established scientific knowledge.

WHAT'S WRONG WITH CREATIVE WRITING IN SCIENCE?

In the sense that creative writing engages students in science ideas, it may be an improvement on some traditional forms of instruction. However, considering how little science time most teachers have with their students, there should be careful assessment of the fit between writing assignments and the goals of science instruction. Creative writing not only takes precious time away from other kinds of science learning, but it may actively work against many of the goals for reasoning, learning about the nature of science, and communication recognized by the majority of science educators. First, creative writing promotes the use of language skills that are associated with poetic writing, and thus detracts from the learner's focus on science understandings. While writing creatively, students are called upon to exercise many poetic forms such as creating interesting settings, characters, poetic rhythms and rhyming words. These language skills compete for time and energy with thinking about science concepts. For example, Warner and Wallace (1994) found that fifth and sixth grade students writing narratives about a bridge-building activity negotiated the use of descriptive words such as "expertise" and "chiseled," but there was little negotiation about the meaning of science words, such as "force," "lever," and "pulley." Furthermore, these science words were often used incorrectly to describe the construction of the bridges.

Second, teaching creative writing rather than scientific writing reinforces the idea that scientific writing is inaccessible to most people and is inherently boring. Rather than capitalizing on the excitement of discovery and curiosity in science, creative writing assignments communicate to students that science is not intrinsically interesting, but must be infused with artificial excitement. A more productive use of science time would be to engage students in making sense of investigative activities. When students take ownership of the inquiry question or problem, they usually accept writing about their investigation experiences as a natural outgrowth of the process, and can become enthused about communicating their findings to others. Writing in authentic scientific genres does not preclude presenting them in imaginative ways, such as student books, multimedia software, or posters. Third, there is no conclusive evidence about gender-related attitudes toward either scientific or creative writing. This is simply an area where there has been little research. Hildebrand (1996) admits that, thus far, she has not been able to detect any gender-based differences in students' reactions to creative writing in her research. Warner and Wallace (1994) found that most of the pairs of girls in their study created male characters as bridge builders in their stories. Perhaps instead of writing about fictitious male bridge builders, these girls should have written scientific genres about their own bridge building with their names proudly displayed as authors. Finally, as just mentioned in the arguments for the teaching of scientific genres, creative writing fails to develop students' facility with reading or writing mainstream scientific texts such as those they will encounter in college or technical school. An extension of this idea is that most high school seniors have such a limited understanding of scientific writing that they fail to understand the meanings of scientific popular texts (Norris & Phillips, 1994). Learning scientific genres promotes reasoning from data to conclusions, and thus should prepare students to become better consumers of scientific information as well as producers.

REVITALIZING SCIENTIFIC GENRES: CONNECTING KNOWLEDGE PRODUCTION WITH LANGUAGE USE

Berkenkotter and Huckin posit that teaching writing in scientific genres may be problematic due to the fact "the connection between academic discourse and knowledge production is not made explicit until the college years, [even though] children are exposed to many of its grammatical, syntactical, and lexical features in elementary school through their reading and in the course of classroom talk" (1995, p. 154). The key may then be introducing students to authentic knowledge production at a younger age, in parallel with teaching scientific writing genres. While the new reform rhetoric refers often to students communicating about their inquiries (NRC, 1996), there are few documented cases of teachers using scientific genres effectively to stimulate scientific thinking and synthesis of information (Holliday, Yore, & Alvermann, 1994; Martin, 1993; Rivard, 1994). In the subsection that follows, I review the major established genres of scientific writing as outlined by Martin (1993) and elaborate on how they might be bridged with contemporary, inquiry-oriented learning environments for both research and teaching purposes. An accompanying graphic (Fig. 2) orients the reader to the placement of these genres in the context of Britton's original framework for language and learning. While many good teachers already use formulations of these genres, scientific writing deserves much more attention from both the research community and those involved in teacher education. At the same time, clear descriptions and examples of writing in these genres should be made available to preservice and in-service teachers.

Experiment. Martin identifies the genre, experiment, with the symbolic representation of the scientific method and as the traditional form evolved to "enable scientists to document their research" (Martin, 1993, p. 192). The format for writing in the experiment genre includes stages for aim (purpose), methods, results, and conclusions. This genre is often explicitly taught, especially in secondary schools, but usually in the context of laboratory activities that are designed to exemplify already well-understood facts and concepts. When all the students in the class obtain the same results to an activity, and there is only one scientifically acceptable outcome, the learners quickly realize that they must somehow generate, copy, or paraphrase the knowledge claim that is desired by the teacher. Thus, writing in this genre can easily become a rote activity, especially when the students have no opportunity to determine the appropriate methods for the investigation, ways to display the data, or new meanings for the data.

Instead of applying this genre to all hands-on or laboratory activities, writing in this genre could be used effectively with two kinds of scientific investigations that are becoming increasingly popular in inquiry-oriented classrooms: (1) investigations in which the students design part or all of the experimental methodologies; and (2) investigations in which students may collect data that may authentically vary from others in the class. In the first case, students will benefit from verbally establishing connections between their methodologies and the results they obtained. For example, when students construct two designs for building a bridge and collect data on how well each bridge performed, learning may be enhanced by communicating to others the connections between the design features (the methodology), the performance data, and conclusions about the best design. In the second type of instruction, students may use similar methodologies, but the investigation is sufficiently open-ended that students may collect data that is unique to a particular context. In the zoo animal behavior project, described earlier, the animals could have behaved in an infinite pattern of ways and the behavior differed among the animals, as

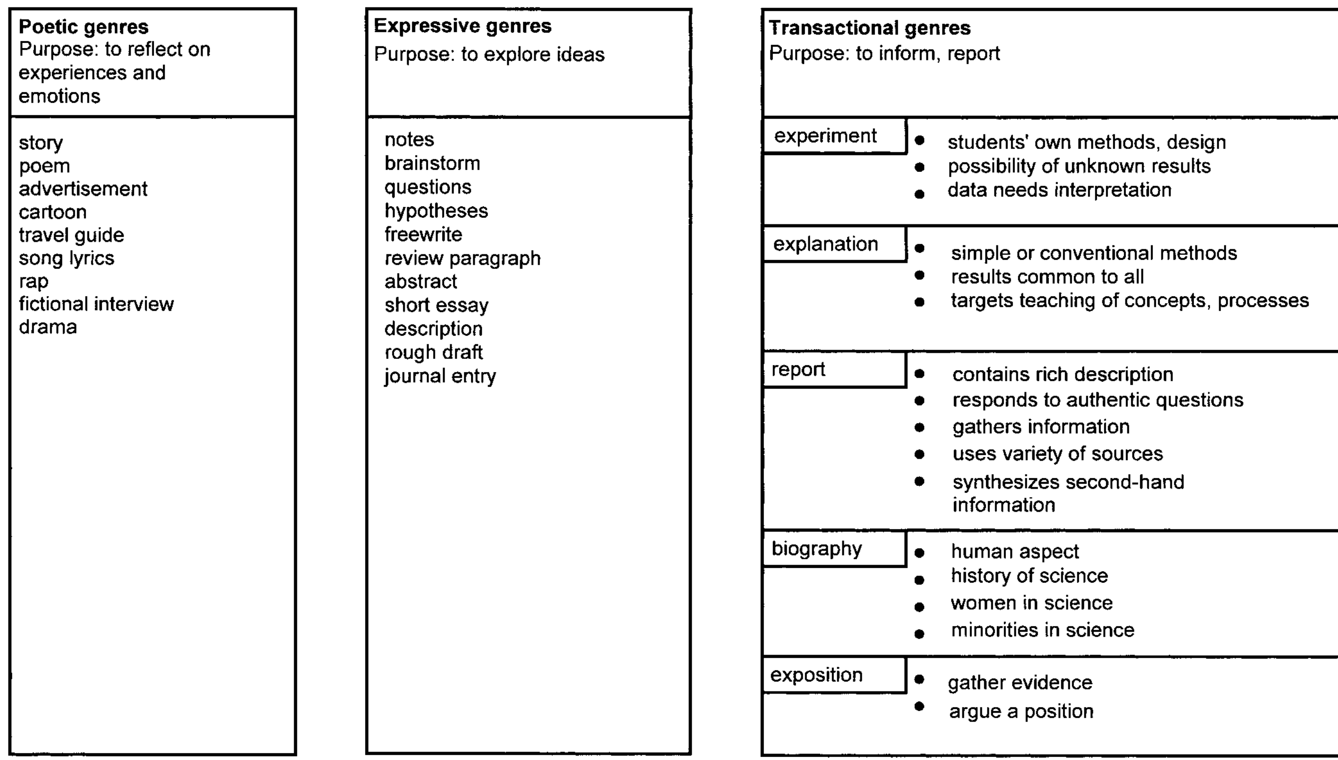

Figure 2. Some examples of writing genres within the context of Britton's (1970) original framework for language across the curriculum. Specialized scientific genres (right-hand side) are elaborated with suggestions for contemporary use.

well. These unique observations (at least at that time) allowed the generation of many different interpretations and inferences. When writing from this type of data set, the learner must evaluate evidence carefully, to determine which interpretations or hypotheses may be best supported. Many projects involving real-world data such as enviromental studies, design studies, and weather explorations support writing in authentic experiment genres.

Explanation. According to Martin, explanations are small reports that focus on scientific processes. They are characterized by large numbers of action verbs and are organized in a logical sequence. A number of contemporary research projects, especially those related to conceptual change learning in science, have demonstrated the power of writing explanations for developing targeted science concepts from hands-on activities (Coleman, 1992; Fellows, 1994; Keys, 1994; Palincsar, Anderson, & David, 1993). For example, Fellows (1994) attributed better logical argument and concept attainment to more opportunities for writing explanations about science activities. She reported that providing students with at least 15 opportunities for explanation writing in different contexts produced posttest written explanations that contained more scientifically accurate language than previous instruction that did not include as much writing. Students were able to express abstract ideas about molecular events in dissolving, such as "Molecules break out of a rigid pattern, move father apart, vibrate faster in hot water. Water molecules put pressure on sugar" (Fellows, 1994, p. 995).

Explanation may be a more productive writing genre than experiment for many science activities that are designed to teach specific concepts (e.g., osmosis, air pressure). When all the children have identical or very similar sets of materials and procedures and the activity conclusions should be the same for everyone, the focus of writing should be on developing an understanding of the process, not recounting the materials and procedures. Writing in the explanation genre is well supported by expressive forms of writing, such as journal writing, in which the student may speculate privately on how the scientific concepts fit together to build the explanation. The construction of explanations is also greatly enhanced by collaborative conversation among students (Brown & Palincsar, 1989; Coleman, 1992; Keys, 1995). This kind of talk and writing about science activities is now viewed as an essential component of activity-based learning (Palincsar et al., 1993). Explanation as a genre of scientific writing could be better articulated by curriculum developers in a way that is commonly understood by teachers.

Report. Report is usually a more descriptive form of writing that serves the purpose of organizing information such as classification, composition, and functions of scientific structures. Report is the genre most commonly used in science textbooks. While a few teachers have successfully used report as form of reteaching text information to peers (Santa & Havens, 1991), report may become more meaningful to students if framed in an authentic investigation context. For example, allowing students to brainstorm questions about scientific phenomena that cannot be investigated in the classroom, but can be researched from second-hand sources, can be a springboard for meaningful report writing. Students then seek out information from a variety of sources, books, journals, the internet, personal interviews, etc. Report writing can be an important tool for learning organization, linear sequencing, and synthesis of information. Some examples of topics that have been successfully researched and developed into report writing include: global warming; *Ebola* virus; AIDS and HIV infection; geothermal energy production; and the nature of light energy.

Biography. Biography is an underused scientific genre that focuses on the life and contributions of one or a group of scientists. Recent interest in using historical cases as a vehicle for teaching science concepts might capitalize on biography as a substantive genre of student learning. As in writing all of these communicative genres, biography writing can be imaginative in the sense that the learner seeks out answers to authentic questions. The cognitive undertaking is rigorous, because the writer must communicate the information well enough to be understood by the audience. Writing in the biography genre may be an invaluable method for teaching about the contributions of women and non-Europeans in science, especially if learners are able to select scientists and periods of history that interest them. Girls may be attracted to exploring the lifestyles and feelings of women scientists in parallel with their scientific accomplishments.

Exposition. Another little used and potentially powerful scientific genre is exposition. Exposition presents arguments for a position on a controversial topic, such as whether dinosaurs were warm- or cold-blooded (Martin, 1993). Students prepare for this writing through investigation of first- or second-hand sources of data. Writing in this genre can encourage students to be immersed in an understanding of evidence to support a particular point of view and formulate understandings of scientific argument.

SUGGESTIONS FOR FUTURE RESEARCH

There are several potential avenues for future research on writing in scientific genres, from both learning and teaching perspectives. Theories developed in this article have suggested that writing in scientific genres has a unique potential for fostering the generation of new verbal knowledge from inquiry experiences. Studies of student learning in association with science writing may provide evidence for such a theory. Questions such as the following may be investigated: (1) How do informal and communicative writing support learning from inquiry-based instruction? (2) How does writing in scientific genres foster conceptual knowledge development, metacognitive development, and an understanding of the nature of science? (3) What special features of scientific writing specifically support cognitive and metacognitive development? (4) What types of explicit writing instruction foster students' understanding of scientific writing? (5) What types of classroom activities may be developed to support integrated inquiry and science writing? Some of these ideas are currently being explored by the present author and colleagues (Keys, Hand, Prain, & Sellers, 1998).

A second potential avenue of research is related to how teachers view scientific writing. To date, we have little information on the degree to which elementary, middle, or secondary teachers use scientific genres, their goals and purposes for using these genres, their expectations for student products, or the way they integrate science writing with other instructional strategies. Studies of teacher beliefs and knowledge about science writing are needed to assess the current state of practice in the field. To encourage lasting reform, we will need to invite teachers to collaborate with us in the development and trial of modes for writing instruction in the classroom at various grade levels. Lijnse (1995) suggested that "development research," that is, reform oriented instruction created and assessed in the local context, is necessary to bridge the theory–practice gap in science education. A program of developmental research centering around the concept of integrated inquiry and writing in scientific genres holds promise for engaging teachers in the creation of meaningful science instruction.

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