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ABSTRACT

This paper synthesizes research on the value of writing in learning science at all grade levels. Breakthroughs and barriers to the effective use of writing to learn science are discussed. Differences between elementary and secondary teachers are considered with regard to background in language arts, understanding of the writing process, and the engagement of science-related issues. The results of the Science Writing Heuristic (SWH) used with 7th grade students in the United States and 9th grade students in Australia are reviewed. (Contains 54 references.) (YDS)

Writing-to-Learn Science: Breakthroughs, Barriers, and Promises

by

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WRITING-TO-LEARN SCIENCE: BREAKTHROUGHS, BARRIERS, AND PROMISES

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The prime purposes of this paper are to identify breakthroughs, barriers, and promising practices of writing-to-learn science designed to enhance science literacy for all students. The analyses and recommendations are anchored in the context of current education reform, the recognition of contemporary literacy that goes beyond the 3 R's and refocuses the emphasis from basic literacy and critical literacy to dynamic literacy (Morris & Tchudi, 1996) and the increased communication demands of workplace and adult literacy. Contemporary science literary involves improving people's habits-of-mind, critical thinking, and cognitive abilities to construct understanding; increasing their understanding of the big ideas of science dealing with the nature of science, the practice of scientific inquiry and the big ideas of science; and facilitating their communications to inform others and to persuade others to take informed action. The conceptual and language demands of the current information and technological economy require people to access, understand, interpret, discuss, and produce a variety of documents—forms, applications, flow charts, maps, graphs, instructions, diagrams, persuasive arguments, and other expository genre (Gerber & Finn, 1998; NRC, 1996). Clearly, face-to-face communications and communicating-at-a-distance are both ends and a means to science literacy.

Limited research has outlined the potential value of print-based language in science learning (Holliday, Yore & Alvermann, 1994; Rivard, 1994; Rowell, 1997); and the common-sense and grass-roots supporters of print-based language across the curriculum have purported generic relationships among reading, writing, and learning. Although the relationships among reading to

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learn, writing to learn, and science are not well established, the available "research does not support the concocted claims that reading and writing in science naturally inhibit students' creativity, curiosity, and interest" (Holliday, 1992, p. 60).

Background

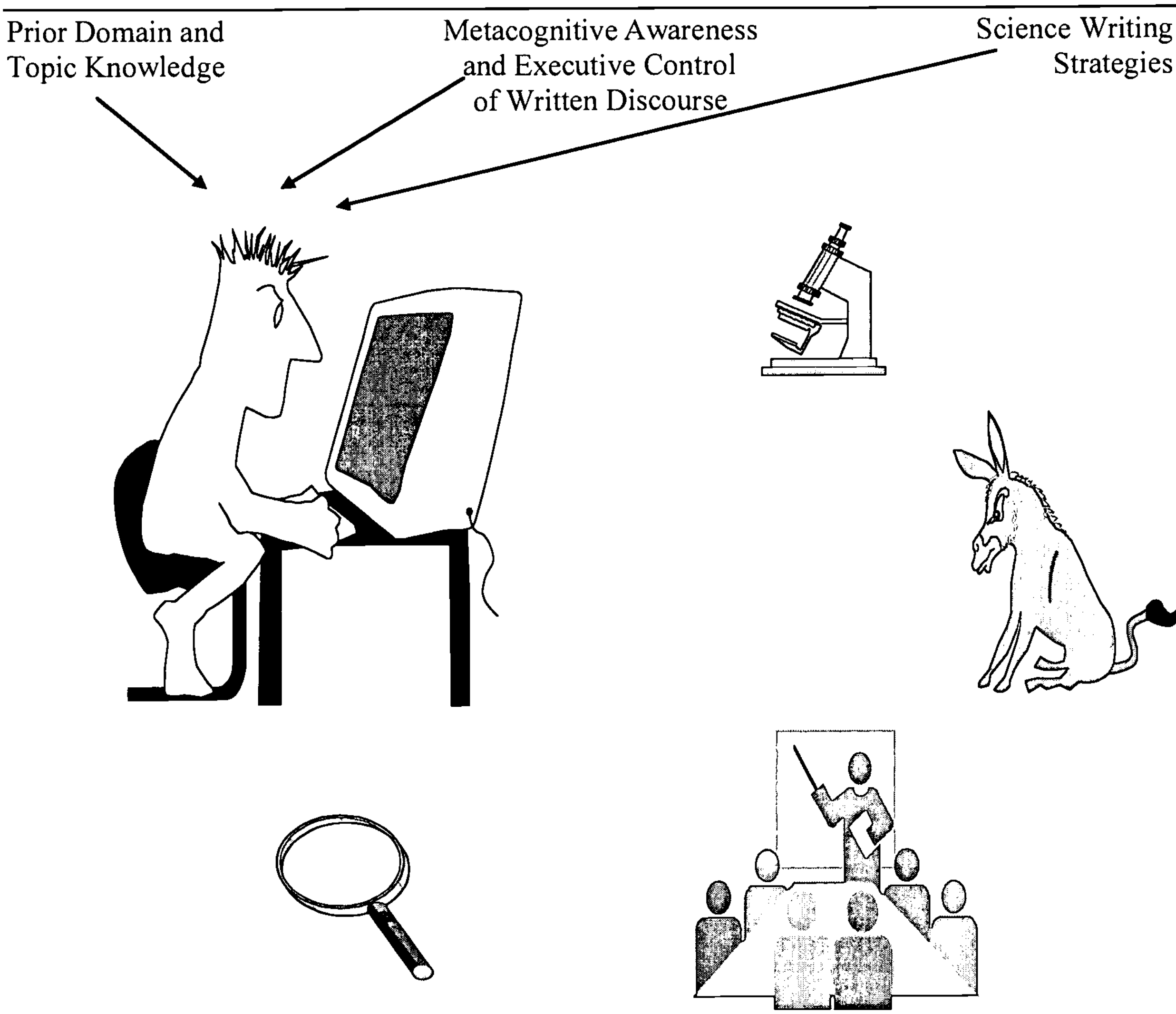
Some years ago the dominant model of science writing did not accurately reflect the transformational and recursive nature of writing, did not consider the unique characteristics of the science domains, misrepresented the pedagogical purposes for writing in science, underestimated the variety of writing tasks in science, and ignored the understandings of the participants—teachers and students. Holliday, Yore, and Alvermann (1994) identified a potential writing breakthrough:

> Writing, like interactive-constructive reading, depends upon the writer's prior domain and strategic knowledge, purpose, and interest. Bereiter and Scardamalia (1987) described the interactive and constructive processes involved in the knowledge-transforming model of writing that parallels the generative model of science learning in that it involves long-term memory, working memory, and sensory-motor activity. The knowledge-transforming model appears to be far more interactive and recursive than linear. The tasks of goal-setting and text production do not fully reveal the complex cognitive, metacognitive, and memory factors involved in the retrieval of conceptual and discourse knowledge from long-term memory and the executive control, strategic planning, and construction taking place in short-term memory. (pp. 885-886)

The mental models that most science educators have about print-based language arts are skills-oriented, unidirectional, text-driven, or text-production processes. They formulated these interpretations from their early schooling that emphasized skills and drills language arts programs involving the controlled language and writing assignments designed to evaluate what the writer knows.

Writing in science utilized a knowledge-telling model of writing. Students systematically select a topic, recall understanding, draft a product, proofread the draft, and produce a final copy. Frequently, the writing process was linear, void of any sociocultural interactions, and emphasized the mechanics of the language. Scardamalia and Bereiter (1986) encouraged teachers to help their students move from the predominant knowledge-telling writing, which involves converting knowledge from long-term memory into written words essentially unaltered, to a knowledge-transforming approach in which knowledge is actively reworked to improve understanding—"reflected upon, revised, organized, and more richly interconnected" (p. 16). The knowledge-transforming model (Bereiter & Scardamalia, 1987) clarifies the role of conceptual knowledge about the nature of science and the target topic, the metacognitive knowledge about and management of written science discourse, patterns of argumentation and genre, and science writing strategies influence on the science writing process (Figure 1). Utilizing the knowledge-transforming model as an operational framework would encourage science educators to get students spending more time setting purpose, specifying audience, thinking, negotiating, strategic planning, reacting, reflecting, and revising. Explicit instruction embedded in the authentic context of scientific inquiry designed to clarify language as a symbol system; what writing is; the purpose-specific nature of scientific genre; the author's responsibilities to the audience; the interactive, constructive, generative nature of science language; the relationship between evidence, warrants, and claims; and what, how, when, and why to use specific writing strategies should be provided as an integral part of science courses (Ferrari, Bouffard & Rainville, 1998). The embedded instruction needs to convert the metacognitive awareness into action to improve self-regulation (planning and generating ideas, translating ideas into text, checking and revising text) and actual writing performance (Hayes & Flower, 1986; Sawyer, Graham & Harris, 1992).

Figure 1
Knowledge-transforming model of writing
(Bereiter & Scardamalia, 1987)



Surveys of teachers and analyses of school writing tasks reveal teachers were unfamiliar with many genres and a dominant use of narrative and factual recounting (Wray & Lewis, 1997).

Gallagher, Knapp, and Noble (1993) suggested the need for explicit instruction in a full range of genre (Table 1). **Narrative** involves the temporal, sequenced discourse found in diaries, journals, learning logs, and conversations. Narratives (document recollections, interpretations, and emotions) are far more personal and informal than most scientific writings. **Description** involves personal, commonsense and technical descriptions, informational and scientific reports, and definitions. Frequently, descriptions will be structured by time-series of events, scientifically established classification systems or taxonomies, or accepted reporting pattern of information (5 Ws). **Explanation** involves sequencing events in cause-effect relationships. Explanations attempt to link established ideas or models with observed effects by using logical connectives of "if this, then this." **Instruction** involves ordering a sequence of procedures to specify directions, such as a manual, experiment, or recipe. Instructions can effectively utilize a series of steps in which the sequence is established by tested science and safety. **Argumentation** involves logical ordering of propositions to persuade someone in an essay, discussion, debate, report, or review. Arguments attempt to establish the boundaries and conditions of the issue and then to systematically discredit, destroy, or support components of the issue, to clearly disconfirm or support the basic premises.

Each genre is flexible, and the writer must control the form to address the function or purpose. No lengthy piece of text uses a single genre (Anthony, Johnson & Yore, 1996). Analysis of effective writing illustrates micro-structures embedded within the macro-structure. In argumentation, a writer might start with a descriptive passage to engage the reader, later use an explanation passage to illustrate a critical cause-effect relationship, and in closing may use an instruction passage much the way a judge clarifies the issues, critical evidence, and the charge to a jury. Prain and Hand (1996a) utilized writing type (booklet, travel brochure, letter to editor,

Table 1

Genre, Purpose, Outcome and Audience of Writing-To-Learn Science
(Adapted from Gallagher, Knapp & Noble, 1993)

Genre	Purpose	Outcome	Audience
Narrative	Recording emotions and ideas	Attitudes	Self and others
Description	Documentation of events	Basic knowledge	Others
Explanation	Causality	Cause-effect relationships	Others
Instruction	Directions	Procedural knowledge	Others
Argumentation	Persuasion	Patterns of argument	Others

article, etc.) to capture the essential aspects of genre, to recognize the variation of micro-structures in text and to represent the variety of writing tasks literate adults and scientists use.

Connolly (1989) suggested that this new writing-to-learn rhetoric was compatible with constructivist perspectives of science learning and illustrated that the symbol systems used to communicate play a critical role in constructing meaning. He emphasized:

> Writing-to-learn is not, most importantly, about 'grammar across the curriculum' nor about 'making spelling count' in the biology paper. It is not a program to reinforce Standard English usage in all classes. Nor is it about … mastering the formal conventions of scientific, social scientific, or business writing. It is about the value of writing 'to enable the discovery of knowledge.' (p. 5)

However, writing-to-learn science tasks do provide authentic opportunities to develop scientific vocabulary, grammar, spelling, punctuation, patterns of argumentation, and technical genre utilized in the science professions. Writing to learn and technical writing have much in common; effective instruction should utilize authentic technical writing tasks to promote science learning, reflection, and practical technical writing for science professionals and adult lay people alike.

Howard and Barton (1986) stated that the "idea is to learn to think in writing primarily for your own edification and then the eyes of others. This approach will enable you to use writing to become more intelligent to yourself—to find your meaning—as well as to communicate effectively with others" (p. 14). Holliday (1992) suggested that effective science writers consider their audience and purpose; strategically plan, draft, revise, and edit; structure writing for maximum effect; typically read, listen, and speak well; and understand language is interpretative, interactive, and constructive.

The following principles should guide the development of writing-to-learn tasks in science (Tchudi & Huerta, 1983):

- Keep science content central in the writing process
- Help students structure and synthesize their knowledge
- Provide a real audience for student writers that will value, question, and provide supportive criticism
- Spend time prewriting, collecting information from various sources (concrete experiences, print materials, experts, electronic data banks, visuals, etc.), sharpening focus, and strategic planning
- Provide on-going teacher support, guidance, and explicit instruction
- Encourage revisions and redrafts based on supportive criticism to address conceptual questions and clarify understandings
- Clarify the differences between revising and editing (format, spelling, mechanics, grammar)

Much has happened recently in the writing-to-learn science community. What are the current breakthroughs, barriers, and promises? The following pages will address these issues from new perspectives and improved optics.

Breakthroughs

A quick survey of the 1988-98 (emphasizing the post-1994 entries) science education research and professional journals confirms the renewed interest in writing-to-learn science and writing in science. Nowhere is this breakthrough more apparent than in universities, but increasingly more evidence of interest can be found in middle and elementary school science journals with less evidence of interest in secondary school science journals. This inter-institutional variation in part reflects the barriers present in different educational environments. Unfortunately, writing-to-learn science and writing in science are more like a technology than a science. Many proposed uses have not been fully verified by associated research.

Universities

Writing in university/college science to promote epistemic insights, thinking, and conceptual understanding requires utilization of science-appropriate genre (Martin, 1993; Mullins, 1989). Moore (1993) found college students' science achievement improved if writing was coupled with explicit writing instruction and embedded in actual science courses. Liss and Hanson (1993) found that students who had an internal locus of control appeared to value writing tasks and worked harder than students with an external locus of control. Generally, application of write-to-learn approaches is being more widely used in university/college level science courses than ever before. The University of Hawaii adopted a writing-intensive course requirement for AA, BA, and BS degrees in 1987 (Chinn, Hussey, Bayer & Hilgers, 1993). All students must complete five writing-intensive courses in their major area. Writing-intensive courses require that:

1. writing be used to promote learning.
2. student and professor interact during the writing process.
3. writing plays a major role in course grades.
4. students produce a minimum of 4,000 words or 16 pages of text.
5. class enrollment be limited to 20 students.

Iding (1994) and Iding and Greene (1995) addressed the type of feedback that influenced university/college writers. Iding (1994) found that college composition students benefited most from comments that described the desired changes, such as additional information, local structure, and global structure. Students believed comments that provided a different perspective were useful. Iding and Greene (1995) found that peer-review comments were useful to education students.

In a recent article, Hallowell and Holland (1998, p. 29) stated that "scientific illiteracy among college students is a persistent problem ... yet the need to understand science principles and to be able to make judgments about the value of scientific knowledge and research has never been greater." Science literacy and the related print-based communication requirements need to address the dual goals (writing-to-learn science and science writing) of literate adults and literate science professionals. Attempts to address this problem are many; for example, Carle and Krest (1998) described a collaborative effort between a science department and university library to improve the access, collection, and evaluation of science information. This program addresses the "out of context" problem that many university library orientation and instruction programs encounter by focusing the effort on science for science majors and instruction on realistic writing tasks for scientists. They utilized print and electronic science citations and references to track the influence of science discoveries and to locate and evaluate information. Koprowski (1997), Rice (1998), and Yore (1996) provided explicit instruction on science writing, exposure to various science writing genre, and actual experience as a reviewer. Koprowski and Yore infused writing instruction, writing assignments, and peer-review into an upper-level general ecology course and an advanced elementary school science education course, respectively. Students were positive about the overall experience. Rice described an advanced stand-alone scientific writing course designed for upper-level science majors in which he served as "guide, coach, cheerleader, critic and occasionally referee" (p. 268). Central to the success of the course were specific instruction and creatively crafted assignments that provided insights into the different genre scientists use to communicate with different audiences: narrative (scientific autobiography), description, explanation, argument, and report of their original laboratory work (mixed genre). Throughout the course, Rice infused explicit instruction on grammar, appropriate voice, word usage and choice, sentence structure, and logical development at opportune times as needs arose.

In chemistry, Burke (1995) asked students to write creative stories about a particular element from the periodic table; and Venable (1998) asked students to re-write articles from the mass media once they identified incorrect reporting of science concepts. Working with journalism professors on a limited basis, Hallowell and Holland (1998) introduced journalistic writing into their freshman program.

Such tasks described above begin to maximize student learning because they require students to reflect, consolidate, elaborate, reprocess concepts and ideas central to the topic, hypothesize, interpret, synthesize and persuade, and hence develop higher order thinking skills and the construction of a deeper understanding of science concepts (Resnick & Klopfner, 1989; Schumacher & Nash, 1991; Sutton, 1992). While these studies have demonstrated potential benefits of writing-to-learn strategies, they have identified additional issues that need to be explored in subsequent research. One issue is the need for more interactions with professional people outside of the academic community in order to understand better the particular writing demands that scientists face in their careers and personal lives. Thus, there is a need for collaboration with journalism or English professors. Another issue is that nearly all the studies were focused on a single writing task that was different from normal lecture notes and laboratory reporting.

Secondary Schools

The major reason for the renewed interest about writing-to-learn science and science writing in public schools of the English-speaking countries is the recognition given to science literacy in major curriculum reform documents, such as the National Science Education Standards (NRC, 1996) and Project 2061 (AAAS, 1990, 1993). These documents place emphasis on students being able to communicate much more broadly than reporting to the teacher. Students are expected to engage in intellectual public discourse and debate in order to be able to communicate their ideas to others and to maintain or enhance their understanding. Such an emphasis places expectations on the expansion of writing in secondary school science classrooms to be broadened from the traditional forms of note-taking, laboratory reports, and tests to incorporate more non-traditional types focusing on encouraging students to inform, explain, defend, debate, and persuade others of their understandings.

The use of writing-to-learn strategies in the secondary school has become much more widespread with Holliday, Yore, and Alvermann (1994) clearly arguing for a broader range of uses for writing within school classrooms. Rivard (1994) expanded on this view to identify a range of crucial factors for using writing within science classrooms including the demands on the learner of the writing task, the learner's metacognitive understanding of appropriate strategies to use, the contextual aspects including a classroom environment focused on deeper conceptual understandings rather than factual knowledge, and a complementary match between genre or type of writing, conceptual structure of the topic, and broader curricular goals. In translating these considerations into a model for implementation, Prain and Hand (1996a, 1996b) provided a framework of five separate but inter-related components to guide improved writing practices within secondary school science classrooms: writing type, writing purpose, audience or readership, topic structure including conceptual clusters, and method of text production including how drafts are produced, both in terms of technologies used as well as variations between individual and composite authorship processes. The framework is intended as both a theoretical model to examine writing-to-learn strategies within science classrooms and as a pragmatic pedagogical model to assist science teachers in the implementation of these strategies.

Harmelink (1998) recognized the dual goals of improved science understanding and enhanced science writing effectiveness with the use of journals or learning logs. She recognized science teachers' reluctance based on lack of professional development related to writing and the time limitations of the secondary science curricula, but believed the constructive aspects of writing structured journal entries and related explicit instruction was well worth the time and personal energy invested.

Elementary Schools

Most of the increased interest in writing in science in the elementary schools has to do with the willingness of elementary teachers to expand their language arts program across the curriculum (Baker, 1996). Contemporary approaches in language arts involve establishing a language community in the classroom that addresses a wider variety of authentic speaking, listening, reading, and writing tasks (NCTE/IRA, 1996; Rowell, 1997). There is some hesitation to infuse these language tasks into science and mathematics, but the recognition of science literacy and mathematics literacy that involves communications to inform others and persuade people to take informed action has encouraged more generalist teachers with strong language arts backgrounds to include writing-to-learn activities in their instructional programs.

Nesbit and Rogers (1997) described how using cooperative learning approaches could be used to improve print-based language arts in science. The use of culminating writing activities can encourage students to reflect, integrate, and elaborate on their science understandings developed during verbal interactions in the cooperative groups. Peer-review and jigsaw writing activities can be very effective.

Wray and Lewis (1997) developed a series of factual writing frames to support young writers in their early attempts to use factual genre. They viewed writing as a social process and the textual product as a social object. The use of teacher scaffolding and structured frames allowed students to develop discourse knowledge about the specific genre used.

Tucknott (1998) explored the effects of writing-to-learn activities infused with an inquiry-based science unit on simple machines and inventions. Grade 4 students used several writing tasks—completion of a patent application, summaries of reading materials, laboratory reports, data displays, labeled diagrams, and explanatory paragraphs. The results indicated that teachers needed to use a series of writing tasks that required students to transform their ideas and writing form to increase higher-level thinking and science achievement. This appears to achieve revision without repletion.

Shelley (1998) describes the use of prewriting activities and writing tasks to improve science understanding and to enhance compare-contrast thinking. She states "prewriting activities, particularly those including visual aids, focus writing so that students can successfully compare and contrast information" (p. 38). Here again, the structured tasks are sequenced to require students to process and internalize information, not just copy textual materials.

DiBiase (1998) and Linton (1997) utilized inquiry letters to seek relevant information to supplement classroom investigations. Letters designed to request information from experts require students to venture into different language and scholarly communities. New information technology makes these approaches much more time efficient and effective.

Barriers

The barriers to effective use of writing in science and writing-to-learn science appear to concentrate around not having a clear image of a successful, efficient science writer; the general lack of evidence-based studies of writing-to-learn activities; and the limited understanding of implementing writing into science instruction.

Desired Image

Ferrari, Bouffard, and Rainville (1998) started to address the desired image issue in terms of a general writer. They documented the discourse awareness of good and poor writers and found that good writers introduce fewer surface errors during revision and produce longer text. Good writers also spend more time in prewriting than do poor writers. Unfortunately, no attempts to describe the characteristics of a successful, efficient science writer could be found. A synthesis of the limited science writing research, the much larger writing research, and an ethnographic documentation of science writers is needed.

Research-based Approaches

Few research studies have documented the effects on achievement and technical writing abilities by various writing in science and write-to-learn tasks. The large majority of writing in science and writing-to-learn science articles are based on unique case studies and testimonials. Fewer research studies have verified their effects with carefully collected qualitative and quantitative evidence. But, there is a growing network of science education researchers and teacher educators who are attempting to document the influences of writing on science literacy and science writing (See the 1997, 1998, and 1999 conference programs for AETS and NARST).

Implementation

When looking at the barriers to implementing writing-to-learning strategies and science writing tasks currently confronting educators, there is a sharp difference between elementary teachers and those in secondary and tertiary settings. Elementary teachers, in general, have a strong language arts background and thus have an understanding of the writing process and the construction of knowledge that results. These teachers are able and willingly implement a range of writing types and processes within their classrooms. However, these teachers are generally science-phobic and are reluctant to engage with many science-related issues within their classrooms. Conversely, secondary and tertiary educators have confidence in their understandings of science but lack knowledge about the writing process. Thus, they are reluctant to implement non-traditional writing types within their classrooms. A lack of knowledge about contemporary models of writing and personal experience with non-traditional writing types means that secondary and university science educators often do not have an understanding of the value of such writing tasks.

In summarizing the outcome of a five-year inservice program with secondary school science teachers, a number of assertions have been generated as barriers to implementation (Hand & Prain, submitted):

1. Teachers view writing in science as primarily as assessment technique since they have not experienced non-traditional writing types. Therefore, teachers limit the use of writing to recalling knowledge (i.e., knowledge-telling model of writing) rather than as a means of constructing knowledge (i.e., knowledge transformation model of writing). Teachers need to change their epistemological commitment to writing as a learning tool to change their understandings of the value of writing.

2. Teachers' lack of understanding of the writing process impedes the planning necessary to provide sufficient support to maximize the learning potentials of non-traditional writing types when used in the science classroom. This is not a criticism of science teachers but rather a comment on their lack of background. Such issues as when to model the particular writing type, what to model, how much explanation of the writing type do students need, the emphasis to be placed on the purpose for the writing, and the value of writing for the audience chosen require specific attention in teacher education and professional development programs.
3. Implementation of writing-to-learn strategies requires adoption of constructivist teaching/learning approaches within science classrooms. Placing emphasis on students' active construction of understanding through writing means that teaching/learning strategies within science classrooms need to reflect this student-centered emphasis. An inherent function of adopting constructivist approaches is the consequential changes in the roles adopted by teachers and the amount of control of learning that by necessity needs to be given to students.
4. Although teachers become comfortable with using non-traditional writing types within their classrooms, they have yet to use them as the major means of assessing students' conceptual understandings. Teachers who have successfully implemented a range of writing types are enthusiastic about their understanding of students' conceptual knowledge, but they have been reluctant to rely on these products as evidence for assessing students. A major problem for the teachers is how to actually mark writing pieces that are centered on conceptual understanding and allow students to have some creative license.

While these barriers exist, they are not insurmountable. As teachers begin to implement a broader range of writing types in their classroom, they will have to engage these concerns and develop pedagogical strategies and procedures to overcome them. Experiencing writing in university science courses will do much to legitimatize writing in elementary and secondary science classrooms.

Promising Practices

The remainder of this paper describes three specific instructional practices that address science writing to enhance students' science literacy, habits-of-mind, critical thinking and meaning-making abilities, their understanding of the big ideas of science, and their communications to inform and persuade others in instructional and professional settings. The process used to select these ideas assessed the power, the appropriateness for the target audience, the background demands placed on students and teachers, and the practical utility for science classrooms of each practice.

Reaction Papers

The reaction paper, a read-write activity, can be used with a variety of students to teach the strategies of summarizing and reflecting and to improve understanding (Yore, 1996). The students read a science education, science, or Science-Technology-Society article and wrote a one-page summary of and reflection on the article. The assignment limited the response space for the article summary to about 125 words and the reaction to about 125 words. The space limitation requires students to be critical, concise, and succinct.

Summarizing is a strategy related to both science reading and science writing, and it incorporates a cluster of subordinate strategies that are characteristic of good science students and respond to instruction. Summarizing requires the writer to recall or comprehend information, to select important main ideas and supportive details, and to craft a concise understandable synthesis of this information while retaining the original author's intent. Hare (1992) provided specific instructional hints and rules for summarizing—delete redundancies, identify relevant and important ideas, synthesize main ideas into a concise, unified text representative of the original author's intentions. The reflection requires the writer to assess the internal consistency, credibility, and applicational value of the ideas summarized. The writer is expected to deliberate, draw conclusions, and articulate a rationale. Reflection involves many critical response skills, such as evaluating sources, questioning claims, evidence and warrants, and assessing research methodology (AAAS, 1993). Furthermore, reflection is designed to encourage writers to make connections among ideas found in the summary with ideas from their knowledge, other articles, and other courses by using cross-references. Quality reflections not only provide a judgment but also specify the criteria and thinking used to reach the judgment, thereby reinforcing critical thinking. The audience for these reaction papers can be the professor, the teacher, or other students. Explicit instruction following each reaction paper focused on exemplary reaction papers and common concerns. The length restriction was a common early concern, but discussions clarified why it was necessary to limit the response space to necessitate the analysis and evaluation of the article and to avoid the "tell all" approach of novice writers and less critical readers.

Breger (1995) used a similar approach called inquiry papers and a variety of publications to encourage middle school students to learn about science or science-related topics. Bringing together reading and writing into one assignment enhances students' science reading strategies and comprehension of the print material. Writing about what they have read encourages students to organize and react to the ideas that they have just read. The use of periodical literature makes a connection between science and everyday life. To start the inquiry paper, students create a reading log in which they write down what they think they will be reading about, based on the title, the pictures, graphs, etc. They write down key pieces of information that may or may not agree with their prediction as they read. These ideas become the "raw material" for the inquiry paper. The summary consists of the main idea with supporting details of "Who? What? Where? When? Why?" Students then reorganize (transform) the summary or key ideas in a visual way, such as a flow chart, concept map, chart, diagrams, etc., showing how the ideas are connected. The third section of the inquiry paper asks the students to choose three words that were important to the concept being discussed in the reading. If any of the words are unfamiliar to the students, the definition should be included in the paper. The final section of the inquiry paper requires the students to come up with three questions that came into their minds during the reading and writing process. At least two of the questions should be science related. These questions allow students to get involved with the topic, to further understand, or to clarify the ideas presented. The audience for the inquiry paper is the other students who are encouraged to respond with a positive comment, another questions, related readings, or related activities.

Collaborative Explanatory Essay

This explanatory essay did not specify a single genre, but the assignment was expected to promote expository-type writing that involved analytic strategies of acquiring information and reformulation of personal understandings to inform or persuade an uninformed audience about a specific issue (Yore, 1996). It was further expected that the task would require an analysis of the audience, an evaluation of the necessity and sufficiency of information, an assessment of the epistemic character and logic of the argument, a clarification of ideas and issues, an explanation of the central position, and an integration of new understandings.

Explanatory essays encourage conceptual change, depth of processing, connecting isolated ideas, and clarification of patterns of evidence, claims, and warrants (Scardamalia & Bereiter, 1986). Kempa (1986) suggested that the following explanatory tasks be used to enhance science learning:

- Developing causal relationships among facts, observations, theories, and models
- Proposing hypothetical relationships between unfamiliar and familiar ideas
- Applying scientific ideas to real-world issues

This assignment was used with upper-level undergraduate students majoring in elementary school science education. The collaborative explanatory essay was designed to:

1. develop insights into the knowledge-transformation model of writing.
2. develop insights about the persuasive, explanatory genre.
3. develop knowledge about central issues, topics, or ideas.

The explanatory essay assignment provided a concrete experience with a collaborative, interactive, write-to-learn strategy. The 10-page essay assignment utilized a jigsaw cooperative learning approach (Also see Nesbit & Rogers, 1997). Each member of the "home" group was randomly assigned one of three topics. Students from different home groups formed topic-specific "expert" groups. Each expert group collaboratively planned, located information, shared resources, and supported one another; but each expert wrote individual papers. The expert group discussions frequently negotiated meaning, evaluated evidence and inferences, elaborated ideas, and provided divergent interpretations.

The non-expert members of the home group (students assigned a different topic) served as an authentic audience for the experts and provided conceptual and editorial feedback on the topical papers for which they were not experts. The peer-reviews assessed clarity, conceptual development, appropriateness of examples and grammar, spelling, punctuation, and writing style. Since students were to be tested on all three topics, they were responsible for developing conceptual understanding by carefully reading these papers and seeking consultation with the author to clarify any fuzzy ideas. The assignment required a progressive development in which each of two drafts was submitted for peer-review by a different member of their home group. Each draft was revised utilizing the peer comments and editorial suggestions. The third draft was submitted to the professor for evaluation. Koprowski (1997) used peer review with explicit reviewer instruction to achieve similar results.

Science Writing Heuristic for Laboratory Work

The problem with "canned" laboratory experiences is that they do not maximize the opportunities for students to construct explanations for the activities they are undertaking. The use of different approaches to laboratory work is the focus of some promising work through the development of a Science Writing Heuristic (SWH) (Keys, Hand, Prain & Sommers, 1998). The SWH, consisting of two components, extends the Vee-diagram to incorporate a greater focus on social negotiation of understanding, negotiation of scientifically acceptable explanations, and reporting using non-traditional writing types. The first component focuses on the role of the teacher in organizing the activities associated with the laboratory work (Figure 2). The teacher scaffolds the inquiry by using a series of semi-structured activities and tasks. Steps 1 and 2 encourage students to access and engage prior knowledge, set purpose, and predict outcome. Step 3 allows students to explore and experience the central idea and to collect evidence. Steps 4, 5, 6, and 7 provide public and private opportunities to make sense of the experience, assess strength of the evidence-inference chains, and internalize and reflect on ideas. Step 8 allows the student to monitor understanding (compare post-instruction and pre-instruction maps) and to integrate the current experience with prior knowledge network.

The second component of the SWH is a template designed to facilitate students in constructing explanations for their laboratory observations (Figure 3). When the questions are carefully answered, students will make connections between their investigation questions, evidence, and claims (inferences). The initial question asks students to put forward what they believe is the central question(s) that should be addressed in the related inquiry to follow. The next two questions are fairly typical of normal laboratory reports in terms of reviewing procedures and observations. However, questions 4 and 5 require students to put forward their understandings gained from the laboratory experience and provide a coherent set of reasons for their claims. Question 6 is intended for students to check their explanations with an authority figure, such as the textbook or the teacher. If there is a difference between the authorized scientific version of the concepts and that which the students have constructed, then there is a need for students to further negotiate their understandings (question 7). By putting the two templates together, the SWH becomes a powerful tool to involve students in constructing explanations and understandings of laboratory concepts.

The SWH has been successfully used with Grade 7 students in the USA participating in a water quality unit and with Grade 9 students in Australia working on an optics unit. After negotiating with each other and the textbook, students working on the optics unit were asked to write a letter to a Grade 9 student explaining what they had done and what they had learned. When tested against a group of students undertaking traditional laboratory activities associated with optics, this group performed significantly better on conceptually orientated test questions. A study is now underway to look at the value of SWH when applied to a first-year undergraduate chemistry laboratory course.

Figure 2
A Template for Teacher-Designed Activities
to Promote Laboratory Understanding

1. Exploration of pre-instruction understanding through individual or group concept mapping
2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions
3. Participation in laboratory activity
4. Negotiation Phase I. Writing personal meanings for laboratory activity: Example- journals
5. Negotiation Phase II. Sharing, comparing individual data interpretations in small groups: Example- group chart
6. Negotiation Phase III. Comparing science ideas to the textbook or other printed resources: Example- writing group notes in response to focus questions
7. Negotiation Phase IV. Individual reflection and writing for communicating: Example- creating a presentation for a larger audience (poster, report, power point)
8. Exploration of post-instruction understanding through concept mapping

Figure 3
A Template for Student Thinking

1. Beginning Ideas — What are my questions?
2. Tests — What did I do?
3. Observations — What did I see?
4. Claims — What can I claim?
5. Evidence — How do I know? Why am I making these claims?
6. Reading — How do my ideas compare with others?
7. Reflection — How have my ideas changed?

Concluding Comments

The most difficult issues involved in writing-to-learn activities and technical writing tasks is to convince science teachers and science professors who did not receive such instruction or experience that such activities are valuable. It is easy to see by a quick review of the references in this paper that many university/college science professors realize that students, even good students, can benefit from explicit science writing instruction. A trip to your teaching and learning center or visit with your reference librarian will reveal many things you can do to help your students become better communicators.

The amount of emphasis placed on writing to learn within science classrooms is increasing. Educators at all levels of education, elementary, secondary, and tertiary have begun to realize the cognitive value of encouraging learners to engage in writing activities that ask them to do more than simply record or recall knowledge. Such writing incorporates the nature of science-related concerns about evidence, claims, and warrants. By using a broader range of writing types within classrooms, science educators can promote an enriched conception of science literacy within their students. This array of genre will serve these students well as they become literate adults and workers.

However, while there have been many breakthroughs and promising practices, there are some barriers that need to be addressed by teacher educators. In particular, there is a need to address the pedagogical implications for teachers when using writing-to-learn strategies. Science teachers are not educated to use a broad range of writing types within their classrooms, and thus there is a need for the development of appropriate preservice and professional development programs to help them construct meaningful pedagogical strategies. Along with the development of pedagogy is the need for relevant assessment strategies for marking students' written products.

How best to assess unfamiliar writing types in terms of the conceptual science knowledge and the actual writing product are issues with which science teachers are unfamiliar and uncomfortable. These need to be addressed in pragmatic and useful ways so that science teachers can monitor and assist student learning within their school settings. This may mean that science teachers at all levels begin to use the total learning community by seeking cooperative ventures with people from other disciplines, for example, graphic design faculty when constructing posters and brochures, and English faculty.

Another issue that has to be addressed by both researchers and teacher educators is what writing type best fits the particular learning situation. The use of inappropriate writing types may be a barrier to maximizing conceptual understanding in a particular situation, while in another situation may provide the breakthrough needed for students. There have been many promising developments in the use of writing-to-learn strategies in science classrooms, but there is still much that needs to be done. More well designed studies using a broad range of writing types need to be conducted within actual learning settings to judge the relevant merit of particular writing types in particular situations. Further studies need to be conducted that examine the possibility of cumulative benefits when using multiple writing types within an instructional unit.

As an introductory writing activity, students can be exposed to laboratory experiences, video materials, Internet information, and science text on a specific topic, e.g., pill bugs. The information can be recorded in an information matrix (Anthony, Johnson & Yore, 1996). Students randomly draw a synthesis question to write about (100-150 words) that is crafted to stress a form-function genre—describe the organisms investigated, explain how the organisms are adapted for survival, establish an argument that indicates if the organism is an insect, or provide directions for building an appropriate cage for the organism. Another assignment could explore the appropriate and inappropriate use of graphs, diagrams, and visuals in science materials. Information technology needs to be incorporated into writing tasks to increase response rate and to document its influence on reading and writing as linear technologies (Hedges & Mania-Farnell, 1998/1999; Maring, Wiseman & Myers, 1997; Martin, 1993). PowerPoint presentations, evaluating the accuracy of specific web sites, resolving discrepant information, and creating multi-media, non-linear text are interesting possibilities.

Your efforts to enhance students' reading and writing will pay off with increased science literacy, realized academic potential, and effective professional careers. The students you teach will appreciate your efforts to enhance their print-based communications.

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