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New directions in language and science education research

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Recently there have been attempts to enhance the interaction between the literacy and science education communities. These attempts have begun to provide researchers with a more enlightened perspective of the *fundamental* (being fluent in the language, discourse conventions, and communication systems of science) and *derived* (being knowledgeable, learned, and educated in science) senses of science literacy (Norris & Phillips, 2003). This synergy has started to define research into language and science literacy, the influences of the ontological and epistemic nature of science, and the importance of discipline-specific domain, topic, and discourse knowledge on the language arts in science (Yore, Bisanz, & Hand, 2003). However, one of the major challenges confronting science education is to shift the pedagogical culture from an authoritarian sociointellectual discourse that emphasizes abstract knowledge separated from societal issues and views language activity as marginal to a culture that places strategic language activity, critical thought, and social relevance at the core of science learning.

Science is a unique mix of inquiry and argument that attempts to establish clear connections between claims, evidence, and warrants (Haack, 2003). While there are commonly held myths and some disagreements about the nature of science, three viewpoints of science encompass most of the current considerations in the debate (Hand, Prain, & Yore, 2001): traditional science as induction, modern science as falsification, and postmodern science as relativism. These three views parallel underlying ontological assumptions about reality (realism, naive realism, idealism) and epistemological beliefs about knowledge (absolutist, evaluativist, multiplist). The dominant perspective suggests that science is people's attempt to systematically search out, describe, and explain generalized patterns of events in the natural world and that the explanations stress natural physical causalities. It is important to note that "explanations about the natural world based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not science" (National Research Council, 1996, p. 201).

Language is an essential technology and thus an integral part of science and science literacy, particularly written language. Language is a means of doing science and of constructing science understandings; language is also an end, a fundamental goal of science literacy, in that it is used to communicate about inquiries, procedures, and science understandings to other people so that they can make informed decisions and take informed actions. Thus, science is a process of inquiry conducted through the use of language that establishes knowledge claims based on arguments that draw on the available evidence and canonical science. Scientific explanations must be consistent with observational evidence about nature, emphasize physical causality, and facilitate accurate predictions. Language serves parallel functions for science learning by facilitating negotiations and reflections about learner-developed and metacognitive-managed knowledge claims constructed from a collection of sensory experiences, conversations, print information sources, and prior knowledge in an interactive sociocultural context. This article explores three language activities in an inquiry context of interest to science education and in service of science literacy.

Argument in science education

The notion that argument was something central to science—that is, scientists are engaged in finding data and utilizing warrants in the form of theories that relate their observations to their causal claims (e.g., SARS is caused by a mutated virus)—was made credible by the work of the sociologists of science. The insights that science as a form of social activity in which rhetoric and persuasion were core activities, together with the work of linguistic studies, have led to the realization that language, particularly argument, is a central feature of science. Yet, ironically, the work undertaken by cognitive psychologists has shown that adolescents have limited capabilities at constructing warrants that relate data to explanatory theories, and that the study of school science appears to do little to improve such reasoning. Hence, if the development of scientific thinking is to be a meaningful goal of science literacy, it is essential to examine how critical thinking and argument can also become a central feature of school science. Results from studies show not only evidence that argument can be incorporated by structuring lessons to consider plural theoretical accounts of science but also evidence of cognitive gains in students' understanding and a change in the nature of the traditional discourse pattern that dominates science classrooms. Thus, the value of and interest in argumentation reside in a view that "truth and understanding" are the child of argument.

The idea that learning might be enhanced by considering the standard misconceptions as well as the canonical representation of natural phenomena was pursued initially by the literacy community. This approach used texts to activate students' prior knowledge—essentially common misconceptions—and to refute these explicitly. Nevertheless, while refutational text often generated cognitive conflict, it was not always sufficient to effect conceptual change; engagement in small-group discussion and oral argument was recognized as a significant learning activity required to achieve this end.

It is essential that those working in "science literacy for all" look to the large body of research and scholarship that has been undertaken in writing, reading, and argument; work collaboratively; and not only explore how to teach the language of science—the fundamental sense of science literacy—but also demonstrate that the regular use of effective argument and small-group discussion enhances cognitive and affective outcomes—the derived sense of science literacy.

Critical stance in science comprehension

Scientists rely on printed text for ideas that inform their work before, during, and after the experimental inquiries. Cognitive processes that are central to understanding text include activating prior knowledge of the specific topic, genre, and rules of evidence; analyzing and synthesizing the new information; evaluating the new information with respect to criteria for scientific evidence; and integrating the text-based message with prior conceptions. Taken together, these habits of mind constitute a *critical stance* toward information (Goldman & Wiley, 2002). A critical stance—an essential attribute of the fundamental sense of science literacy—can be contrasted with an approach that is relatively passive and oriented toward acceptance and memorization of presented facts, procedures, and principles. The noncritical approach is particularly problematic in an information communication technology age of webpage proliferation, where there is very limited control over the quality of the science information made easily accessible over the Internet (Goldman & Bisanz, 2002).

Scientists read articles in their fields from a critical stance in which new information is analyzed, evaluated, and, if deemed trustworthy, synthesized with what is already known. Scientists interpret the validity and certainty of knowledge claims by contextualizing them in their sociohistorical context. That is, new knowledge claims need to be related to previous knowledge claims while taking into account the researchers, their biases, the hedging language used, and the circumstances under which the claims were established. This intertextual process relates information in one science communication to information in other communications and long-term memory. If inconsistencies among canonical ideas, evidence, and knowledge claims are detected, scientists typically work to resolve them—a process that often results in deeper understanding of the scientific phenomenon.

Like scientists, the general public (who may be the intended or unintended audience for specific text) needs to evaluate information, language, and arguments, questioning the biases and reliability of the information source as well as the coherence of the information within the text and with other sources (Goldman & Bisanz, 2002). There are many differences between scientists (experts) and the general public (novices) that contribute to how they process informational text and other forms of representation used in science (e.g., gestures, graphs, figures, formulae, symbols, diagrams). Disparities between novices and experts include differences in content knowledge of the domain (e.g., geophysics), the general topic area (e.g., plate tectonics), and the specific topic (e.g., causes of earthquakes). The two groups also differ in their knowledge about the guidelines for inquiry, standards of evidence, epistemic rules for establishing findings and explanations, the tentative nature of knowledge claims, and the expository genres of a specific discourse community. A scientific literate reader learns, first, to distinguish the elements of argument and the epistemic language of science in the context of varying genres and, second, to evaluate the knowledge claims' credibility, certainty, and reasonableness. Despite the importance of a critical stance in the fundamental sense of science literacy, it is a stance that readers of science communications rarely adopt. Two interrelated strands of research are needed: one focused on the cognitive and metacognitive processes (what to do) and mechanisms (how to do it) involved in adopting a critical stance toward science information, and the other focused on instruction, collaboration, coaching, and other forms of scaffolding promoting their adoption.

Writing in school science

Writing is an essential feature of all science-related endeavors, such as health care, agriculture, computing, and engineering, as well as the work of professional scientists. Practitioners of science regularly write in a variety of forms including personal notes, memos, diagrams, graphs, grant proposals, and reports. Effective use of different writing forms to address specific purposes with various audiences is part of the fundamental sense of science literacy in which students are expected to "become competent at communicating experimental methods, following instructions, describing observations, summarizing the results of other groups, and telling other students about investigations and explanations" (National Research Council, 1996, p. 148). Writing in science classrooms serves two primary learning purposes: enculturation of learners into the discourse practices (genre perspective) and personal engagement of learners (diversification perspective).

The genre perspective

Writing in school science can provide opportunities for learners to compose high-quality texts in those discourse forms generated and used by scientists to address a specific purpose. Understanding and using genres such as description, directions, explanation, and argumentation are central components of the fundamental sense of science literacy, and their use may enhance the derived sense of science literacy. But it is through writing an argument that learners become most familiar with those reasoning forms that are particular to science, including questioning, interpreting data, making claims, and providing evidence for those claims. Thus, learning to read, write, and evaluate scientific argument provides learners with opportunities to develop language as a scientific technology and to learn about the nature of science as a unique way of reasoning.

The articulation of understanding into writing provides a rich arena for cognitive activity of the learner that enhances science learning. A compelling perspective for generating new knowledge through science writing, the knowledge-transforming model, indicates that learners organize and manipulate their content knowledge about the domain of science and the topic in the content space, then express that conceptual construction using discourse knowledge in the rhetorical space (Keys, 1999). The requirement of language choice may cause students to make recursive, interactive moves back to the content space for more evidence or to reconsider the content or forward to additional inquiries and evidence supporting new learning. Recent research into how writing supports conceptual understanding demonstrates improvement in students' cognitive processing, understanding, and writing and supports a variety of promising classroom approaches (Hand, Wallace, & Yang, 2004; Mason & Boscolo, 2000).

An issue worthy of research is how to promote both the fundamental and derived senses of science literacy effectively in the classroom. These purposes are not mutually exclusive. One cannot communicate effectively in science without having constructed an in-depth, meaningful understanding of the science concepts and the nature of science. The challenge for teacher educators, curriculum directors, and literacy and science teachers is to clearly define their pedagogical purposes for any particular writing task—such as epistemic form and function, illustration of the nature of science, relevancy to students, or motivation—and to be explicit with students about those purposes and how to achieve them.

The diversification perspective

The desire to engage a broader range of students in the study of science has led science educators to consider diverse writing tasks beyond the traditional expository genre to motivate and challenge students with a rich science literacy that evolves through developing facility with both the language and the concepts of science. This will involve putting effort into teasing out the complexities of the language/learning/writing interface and a more thorough foregrounding of the specifics of all language practices so that every genre required of students is explicitly unpacked and taught.

Generating pedagogical opportunities that draw on hybrid creative/scientific genres is one vehicle to motivate disenfranchised students previously discouraged by language barriers to engage with scientific ideas (Hildebrand, 2001). Scaffolding access into the powerful language of science, and hence into science itself, through the judicious use of, for example, anthropomorphic writing ("Write a series of postcards home from your trip down the human gut") can provide a tool for synthesizing new learning while considering scientific concepts from an alternative frame of reference. This style of writing has questioned some of the conventional wisdom in science education and led to innovative tasks that have provided successful experiences for previously underserved groups—females, working class students, and students from families who have few discussions about science-related issues (Freedman & Medway, 1994). Boundaries that constrict writing in science classrooms to a narrow range of genres can perpetuate the exclusion of many students from achieving science literacy.

Writing to learn science does not need to be a one-to-one correspondence with scientists' writing practices, as *learning* science and *reporting* science have distinct social purposes and underlying epistemic and pedagogical principles (Hildebrand, 2001). Thus, constructing understanding in science may be intertwined with learning to write scientific genres; conversely, conceptual understanding can be developed through writing to learn activities in vernacular language and nonscientific genres. Current research is unclear on what works and whether writing in service of science literacy approaches is robust enough to be effective in large-scale implementations.

Concluding remarks

A growing number of science educators are now aware of the importance of the research being conducted by colleagues in the language and literacy research community. The Island Conference (funded by the National Science Foundation, Iowa State University, and the University of Victoria and attended by cognitive scientists, literacy researchers, science educators, and graduate students from Australia, Canada, Italy, the United Kingdom, and the United States) focused on linking these researchers, enculturating the next generation of researchers, and generating a number of issues and controversies for future literacy and science education research, teacher education, and classroom practice. (See www.educ.uvic.ca/faculty/lyore/ScienceLanguage for participants and papers.) Two issues involving tangential extensions of science literacy identified by the final deliberations of the Island Group were multiple representations and the international political demands to improve literacy.

The first issue is the emphasis on oracy, argument, critical reading, and writing to learn, which cannot be divorced from the reality of multiple representations that are now central to science and computer technologies. While the consideration of multiple representations in the science education community is relatively new, this issue could become a central focus of collaborative work with the literacy education community so as to better understand theoretical positions and the related pedagogical actions. For example, representations can be internal to the learner—such as those created by the use of analogies and metaphors—or external to the learner—such as those offered by computers to complement existing learning, to constrain interpretations, or to construct deeper understandings (Ainsworth, 1999). Science educators acknowledge that multiple representations of mental models need interrogation, including a reactivation of inquiries into written text and to its problematic nature, even for apparently capable readers. Furthermore, the multiple representations of an idea through sequential transformations of inquiry and sensory experiences into group discussions, data tables, graphs, pictures, diagrams, and written descriptions, arguments, or explanations have demonstrated positive influences on elementary and secondary school students' achievement (Hand et al., 2001).

The second issue is in response to the political demands being placed on education systems more globally in terms of improved literacy, the need for regular and reliable information on educational outcomes across countries, and politicians believing that this can be achieved through assessment-driven teaching and learning. One example is the Organisation for Economic Co-operation and Development's Programme for International Student Assessment (2000), which surveyed 15-year-olds to assess aspects of their preparedness for adult life by measuring their competencies in three domains of contemporary literacy: reading literacy, mathematical literacy, and scientific literacy. This broad notion of contemporary literacy is seen to require mastery of a body of basic knowledge and skills that can be assessed only in a context. The assessment items in these three fields require reading of scenarios and responding to both multiple-choice and open-response questions. Consequently, there appears to be a growing awareness among those researchers involved in PISA that disciplinary literacy involves both a fundamental and a derived sense. Similar outcomes in the United States under the No Child Left Behind legislation may be possible if the emphasis can be moved beyond testing to focus on teaching and learning. It is now timely for colleagues in science education and language and literacy education to jointly construct initiatives that investigate both the fundamental and derived senses of science literacy.

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