A writing in science framework designed to enhance science literacy

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Science education reforms in Australia, Canada, England, New Zealand, and the United States promote a constructivist pedagogy of science leading to a contemporary view of science literacy. The reform documents provide somewhat fuzzy descriptions of critical philosophical, epistemological and pedagogical dimensions and underlying assumptions and relationships. An adequate conception of the desired science teaching and learning requires an interdisciplinary awareness of the nature of science literacy, the nature of science and scientific inquiry, the role of reasoning, and the role of epistemological beliefs. (Abd-El-Khalick, et al. 1998, Holliday, et al. 1994, Tyson, et al. 1997). However, there are contested viewpoints about what should be emphasized within and across each of these dimensions of learning science. This article attempts to clarify these dimensions, assumptions and relationships, to provide a practical framework for utilizing writing in science to enhance science literacy, and to present illustrative classroom examples.

Science literacy

Recent descriptions of contemporary science literacy have acknowledged the need to broaden the traditional focus on technical conceptions and terminology to include and emphasize cognitive abilities, reasoning, habits of mind, unifying concepts, and communication (AAAS 1993, NRC 1996). Contemporary science literacy involves the abilities and emotional dispositions to construct science understanding, the big ideas of science, and the communications to inform others about these science ideas and to persuade them to take informed actions. The enlarged definition of science literacy subsumes the interdependent dimensions of the nature of science and scientific inquiry, reasoning and epistemological beliefs in the construction, dissemination and application of science knowledge.

Contemporary science literacy entails positive dispositions towards participation in public debate on scientific issues. Kyle, et al. (1991) noted that secondary school students should understand that science literacy promotes lifelong learning rather than simply the acquisition of school-based, examination-focused information. Science literacy involves a continued willingness to apply scientific habits of mind in a wide range of social contexts, such as asking at a town meeting how the planning agents know that their recommendations are justified, personally
buttressing a claim about what car to buy with economic data and efficiency information from credible sources, and constantly seeking the most current information on what to believe about a local environment issue (AAAS 1993). The National Science Education Standards (NRC) concur with this broader view of science literacy as the development of educated citizens who can `engage intelligently in public discourse and debate' (1996: 13), can `construct explanations of natural phenomena, test these explanations in many different ways and communicate their ideas to others' (1996: 20), and ensure that they `develop a rich knowledge of science' as they become familiar with `modes of scientific inquiry, rules of evidence, ways of formulating questions and ways of proposing explanations' (1996: 21).

Contemporary science literacy entails more than familiarity with the procedural and conceptual knowledge; it includes a capacity and willingness to contribute to public discussion about the application of scientific principles to social issues. This implies that science literacy should mean broad-based community understanding of the procedures and claims of science rather than the understandings of experts in different science fields (Bybee 1995, Cobern et al. 1995).

Bybee (1995) claims that science literacy extends beyond the acquisition of relevant vocabulary, conceptual schemes and procedural methods to include multidimensional perspectives about science and its relationship to other fields of study. Students need to understand the nature and relationships between science as inquiry and technology as design, to know the history of science ideas, and the role of science and technology in personal life and society. The American Association for the Advancement of Science (1990) contends that science literacy encompasses other domains, such as mathematics and social sciences. Cobern et al. (1995) argue that if students are to develop the habits of a scientifically literate person then they need to know how to apply basic scientific concepts to everyday situations. Students must be given opportunities to identify situations where science literacy would be an advantage. Such opportunities should be integrated into the curriculum and revisited throughout each year of science instruction.

Hurd (1998: 409) believes that science literacy focuses on the `utilization of scientific knowledge for the benefit of individuals, the common good, or social progress'. He describes the performance of a scientifically literate person as one who distinguishes and recognizes expertise, dogma, pseudoscience, epistemic limitations, the temporal nature of knowledge, effective argumentation, and relationships among claims, evidence, and warrants. Furthermore, scientifically literate people exhibit these habits of mind and strategies in their daily lives. This view of science literacy provides an overarching vision for effective science teaching and learning that incorporates recent understandings of the nature of science and inquiry and the roles and functions of reasoning and interpretative beliefs.

This broad definition of science literacy has various implications for the aims, readerships, and diverse kinds of writing students should practise in the science classroom. Students will need to continue to write traditional reports and records of experiments to demonstrate they can understand and use the terminology and discourse of the science community. However, they will also need to practise writing about science for non-expert readerships, using other kinds of writing types such as letters, brochures and non-technical reports, if they are to achieve the border crossing of readerships implied in these new accounts of science literacy. As well, such writing should foster in students an ability and willingness to
contribute to public debate over the application of science to social issues. In other words, science literacy now emphasizes the centrality of communications skills and a commitment to informed and accessible contributions to public debate over the uses of science. Writing tasks in science classrooms will need to provide opportunities for students to learn how and why they should aim to meet these goals.

The nature of science

While contemporary science literacy includes an account of the nature of science, there is far less consensus about the essential character of science. The nature of science from a philosophical perspective has been highly contested in recent years (Norris 1997), with cultural relativists refusing to accept science's traditional claims to durable standards of truth, objectivity, and reputable method. The National Science Education Standards (NSES) emphasize the provisional nature of knowledge claims in science but also argue that there is a general consensus about how knowledge is claimed, tested, and refined in this field (NRC 1996). According to this view all science ideas are tentative and subject to change and improvement in principle. The NSES acknowledge that scientists differ routinely about the interpretation of the evidence, the meaning of theory, and publish conflicting experimental results or draw different conclusions from the same data; however, ideally, scientists recognize this conflict and work towards finding evidence to resolve disputes. This evaluativist view of science and scientific inquiry entails evaluation of the results of scientific investigations, alternative interpretations, theoretical models and the explanations proposed by scientists against evidence from nature. Evaluation includes reviewing the experimental procedures, examining the evidence, identifying faulty reasoning, pointing out statements that go beyond evidence and suggesting alternative explanations for the same observations. Although scientists may disagree about explanations of the phenomena, about interpretations of the data, or about the value of rival theories, they do agree that questioning, response to criticism and open communication are integral parts of the scientific enterprise. Scientific knowledge evolves, and major disagreements are eventually resolved through such interactions between scientists. In this sense the nature of science is conceptualized as a form of inquiry that both shapes a world view and generates an accepted body of explanations.

Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments and skepticism to generate the best temporal explanations possible about the natural world. Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature; and they must make accurate predictions, when appropriate, about the systems studied. Evaluations should be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. 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. However, Cleminson (1990) argues that science literacy should incorporate a conception of science as a human construction of knowledge from which the human or fallible element has been limited but not fully excised.
Science knowledge is temporary, since this knowledge is not proven, only disconfirmed. Therefore, this knowledge is subject to change as new evidence becomes available. The core ideas of science, such as the conservation of energy and the laws of motion, have been subjected to a wide variety of disconfirmation and are therefore unlikely to change in the areas in which they have been tested. At the leading edge of science where data or understanding are immature, such as the details of human evolution and global warming, new data may well lead to changes in current conceptions or resolution of current conflicts. Situations where information is still fragmentary and scientific ideas are incomplete provide opportunities for making the greatest advances.

The AAAS (1990) concurs that, while science cannot provide complete answers to all questions and scientific ideas are subject to change, scientific knowledge generally remains durable. While science demands evidence, its constructive nature also requires logic and imagination to be combined. Scientists invent hypotheses, models, and theories to imagine how the world works and then work out how they can put these ideas to the test of reality. Scientists try to identify and avoid bias and are not authoritarian, but the history of science documents cases where these goals were not achieved.

However, Lederman (1995: 373) argues that a single unitary image of science ‘presents a narrow view by promoting a particular conception of the nature of science’, whereas there are quite contrasting assumptions, procedures and evidential claims in different science specializations. Brickhouse and Stanley (1993: 372) argue that if students are to understand science as the construction of persuasive explanations about the natural world, then ‘science teaching might best be constructed as an apprenticeship in which students are given genuinely problematic tasks and are aided by the teacher in developing ways of thinking through problems’. It is not an easy task to get students to alter their personal view of science even in a rich inquiry-oriented, problem-centred context.

It is essential that students understand that science is an intellectual activity requiring more than technical competence. Students must engage their own epistemological beliefs about knowing, scientific proof, justification, and logic with those central to scientific reasoning. Addressing the lack of congruence between the students’ beliefs and the modern epistemological commitments of science is central to promoting student learning. Activities in the classroom should take on the authentic characteristics of scientific inquiry as students develop their epistemological commitments and understandings about the nature and rationale of science. Critical discussions of these inquiries can help students begin to understand science as a way of knowing related to, as opposed to distinct from, other ways of knowing.

This account of the nature of science as a method of inquiry with an evaluativist view of evidence also has implications for the kinds of writing tasks students should attempt in the classroom, and for how students should understand the rationale and claims of these tasks. If students are to understand science as the construction of persuasive but ultimately provisional explanations of the natural world, then they will need to tackle writing tasks that enable them to understand and practise this kind of inquiry, its procedures and basis. Students will also need to learn from tackling this writing the basis on which scientific explanations are considered convincing by the scientific community. Later in this article we outline some examples of kinds of writing designed to achieve this student knowledge, but
clearly this broad view of the nature of science implies that students need to learn about and practise what counts as acceptable reasoning in developing scientific explanations.

**Epistemology and reasoning**

Hofer and Pintrich (1997) believe that reasoning should be seen as embedded within a broader conception of epistemology. They emphasize that epistemology needs to focus on 'individuals' beliefs about knowledge as well as reasoning and justification processes regarding knowledge' (1997: 116). Reasoning from this perspective is critical in developing learners' epistemological understandings in that they function to heighten learners' understanding of the processes and basis of knowing.

Students' epistemological beliefs are centred on their understandings of the nature of knowledge and the nature of knowing (Carey and Smith 1993). Frequently, students ascribe greater certainty to science speculations than intended by the scientists and authors (Norris and Phillips 1994). These interpretative beliefs are not viewed as being composed of fixed entities but rather as continuums of evolving complexity. Students' understandings of the nature of knowledge are perceived as being a progression from viewing knowledge as absolute to a more relativistic view to an evaluativist view (Kuhn 1991). Students move from conceiving of knowledge as fixed, where absolute truth exists with certainty, to knowledge as tentative, where temporary truth exists within limits. Understanding of knowledge moves from accumulation of facts to highly interrelated concepts and from discrete, concrete, knowledgeable facts to knowledge as relative, contingent and contextual. These changes in epistemological conception of knowledge will be reflected in their understandings of the nature of knowing. The continuum of knowing, viewed as the source of knowledge and justification for knowing, moves from knowledge originating outside the self and residing in external authority that transmits the knowledge, to self as knower where knowledge construction occurs in interactions with others, prior knowledge and concurrent experience with the environment. Thus, learners are viewed as shifting from being spectators to active constructors of knowledge who evaluate knowledge claims using evidence, expertise, and creditability of source. Moving to active construction of science knowledge means that learners will have moved from accepting absolute authority or multiplistic acceptance of opinions to reasoned evaluation of knowledge claims.

Examination of students' movement to higher order understandings of the nature of knowledge and knowledge claims requires an investigation of students' reasoning within their epistemological frameworks. The study of reasoning is centred on students' development of logical patterns, identifying what students can do, determining the different reasoning levels at which students function, and examining the domains or contexts in which different reasoning patterns are used and developed. Thus, reasoning and critical thinking are viewed as influencing students' epistemological categories, conceptual understandings and science literacy.

In seeking to explain general patterns of reasoning and argumentation, Kuhn (1991) proposed a three-step model: reasoned argument, which requires the ability to reflect on one's own thinking; dialogic argument, where the individual recog-
nizes an opposition between a minimum of two assertions, with evidence related to each assertion, weighed in an integrative evaluation of the relative merits of opposing assertions; and rhetorical argument, which is similar to dialogic reasoning except it is not interactive. Kuhn points out that:

> critical to this ability [to use reasoned arguments] ... an understanding that this process of contemplation and evaluation figures centrally in knowing. The most important, valued kinds of knowledge are neither certain beyond question nor the arbitrary product of personal opinion. Instead, they are the product of effortful cognitive work in which possibilities are generated, contemplated, and evaluated, and reasoned judgments reached. (1991: 64).

Promoting the higher order requirements of argumentative discourse, such as being able 'to situate ideas in place of the possible, the probable, and the disputable', requires particular strategies (Pieraut-Le Bonniec and Valette 1991).

These critical thinking strategies are consistent with the goal of contemporary science literacy (Ford et al. 1997). Critical challenges about what to believe and what to do help promote and encourage learners to develop multiple causal hypotheses about issues. As students develop their reasoning, causal hypotheses shift on the continuum from rudimentary informal beliefs to complex, systematized, formal scientific theories (umbrella concepts). The use of evidence in reasoned arguments about cause shifts from pseudo-evidence to non-evidence to genuine evidence when the learner seeks to establish plausible accounts of causality. Kuhn (1991) suggested an important component of the development of causality is encouraging learners to generate alternative causal hypotheses about what they should believe or do. Again, students adopt varying positions when generating alternative interpretations, ranging from an absolutist position, where the expert is correct, to a multiplist position, where all alternatives are equally valid.

The conception of science that learners bring to the classroom is fundamental in shaping the development of epistemological reasoning. When learners view knowledge as absolute, they think the source of knowledge is authority and thus resist any moves toward an epistemological position reflective of an evaluativist view of science. Hofer and Pintrich (1997: 117) have proposed 'that individuals' beliefs about knowledge and the process of knowing be considered as personal', but they also suggest that 'individuals' knowledge in a domain is structured in ways analogous to how theories are structured in science'. Thus, there exists a potential conflict among how science is perceived from a philosophical perspective, how students perceive science, and how teachers present the subject within schools. Roth and Roychoudhury (1994) have argued that objectivism is the default epistemology of western schooling and that a shift towards constructivist approaches to epistemology is needed to promote alternative views of contemporary science.

Clearly, school science must promote philosophical and epistemological views of science that accurately portray contemporary science, not the historical science of Bacon nor the relativistic science of the radical postmodernists. Writing in science recognizes that scientifically literate people need to cross boundaries of learning communities between the scientific community and broader society. This transition requires literate people to understand the traditional language and patterns of argumentation of scientists and to be able to use effective communication and persuasion with non-expert readerships.
This discussion about students' understanding of knowing, and their patterns of reasoning in engaging with the epistemological commitments of science also has implications for the kinds of writing tasks students should attempt in science. If students' development of multiple causal hypotheses is viewed as desirable evidence of higher order thinking and reasoning, then teachers need to frame writing tasks in science in such a way as to encourage this kind of mental work. As Applebee (1984: 1993), Langer and Applebee (1987), and others have noted, different kinds of writing tasks promote different kinds of thinking, and writing tasks that require students to solve problems can lead to changes in their reasoning abilities. If learners are to be encouraged to see themselves as active constructors of knowledge who can evaluate rival claims, sources, and the creditability of diverse evidence, then they need opportunities to tackle writing tasks that require this kind of decision-making and problem-solving.

Framework for writing in science

The nature of science literacy, science and inquiry, and the roles of reasoning and epistemology imply a constructivist teaching and learning approach in school science. A closer analysis of the philosophical, psychological, and epistemological dimensions in light of the practical realities of the classroom support an interactive-constructivist model (Yore and Shymansky 1997). The interactive-constructivist approach utilizes a hybrid world view, evaluativist view of science, public-private perspective of cognition, a teacher-student shared role for directing the learning agenda, and a two-way communication role for discourse that reveals ideas and possibilities. This interactive-constructivist approach differs from many social constructivist perspectives in that it discounts the consensuses requirement for discourse and the belief that knowledge is constructed at the group level.

Interactive-constructivist approaches subscribe to the basic principles of constructivism: prior knowledge influences learning; prior knowledge may include misconceptions; and learning is a process in which students make meaning from concrete experiences, external information, and prior knowledge in a sociocultural context. Meaningful learning involves the integration of new ideas into existing knowledge networks such that ideas are connected with each other and with real-world examples and application. Interactive-constructivist teaching incorporates some unique pedagogical principles with the basic constructivist principles - alignment of learning outcomes, instruction and assessment, direct instruction embedded in the context of authentic inquiry - and utilizes print-base resources and language arts.

A typical interactive-constructivist teaching and learning experience involves engagement of the students' prior knowledge, exploration of problems, challenges and alternative ideas, consolidation of the new ideas into existing understanding by assimilation or accommodation, and assessment of understanding in one or more of the engage, explore, and consolidate phases (Shymansky et al. 1997). A lesson introduction might involve a small group discussion of a topical problem in terms of what the group knows about the issue and what the group wants to learn about the issue. Each student might complete the know and want to learn columns of a KWL chart. This requires the students to access prior knowledge and to set purpose for future learning. The introduction leads to the exploration of teacher-directed activities, student-generated inquiries, or search for solutions and
information related to the central issue. During these explorations students are constantly talking science, exploration, inventing conflicting interpretations, and designing alternative explorations. Individual students might make dual-entries in their learning journal such that observations and measurements are linked to speculations and further explorations. During the consolidation phase, students might collaboratively construct a concept map, draw a pictorial model or labelled diagram, prepare speakers’ notes for a presentation, and compose an exploratory essay. Finally, they might complete the third column of the KWL chart with what they actually learned and reflect on whether they had achieved their purposes. Each of these actions is designed to integrate new ideas into their prior knowledge network. The products produced and actions taken in the engage, explore, and consolidate phases (KWL chart, learning journal, concept map, pictorial model, labelled diagram, speakers’ notes, explanatory essay) are authentic evidence of science learning.

Writing in an interactive-constructivist science classroom has great potential to enhance learning. Writing in science is conceptualized as a process that develops reasoning, inducts students into the discourse of science, and promotes personal meaning making in relation to scientific explanations. Writing in science can serve to engage students’ prior knowledge, facilitate exploration of alternative ideas or reveal new possibilities, consolidate new concepts into prior understanding or integrate divergent concepts, and assess understanding, reasoning and argumentation. The implications of using writing in science relate to students’ understandings of the nature and purposes of writing in science, to the issue of which kind of writing tasks and demands are desirable for developing students’ reasoning, understandings of the nature of science, and beliefs about knowledge claims and their bases, and to identifying writing tasks that address a pedagogical function in an interactive-constructivist science lesson.

If students are to use writing effectively for learning, then they need to understand that writing can serve a range of purposes in learning science and in representing scientific ideas within the broader community. These purposes, in relation to learning, include traditional roles, such as keeping accurate records and demonstrating understanding of concepts for assessment purposes. However, writing can also be used to solve problems, to clarify ideas, to speculate about possible alternative causes and explanations, and to make preliminary observations. In terms of the broader purposes of writing about science, students also need to understand that part of being scientifically literate entails a willingness and a capacity to contribute in writing to public debate on science issues, and that such writing will often need to inform, explain, and clarify concepts for a non-expert readership and to persuade them to take informed action. In these ways students need to understand that the nature and purpose of writing in science incorporate various opportunities and requirements in relation to pedagogical, epistemological and science literacy issues.

Students need to understand that their own writing, and responding to the writing of others, can provide interactive and constructive opportunities to clarify their own knowledge about particular concepts and the bases of this knowledge as well as clarify their understanding of scientific methods and their representation in writing. This knowledge of transformational writing requires writers to establish purpose and to search for forms, styles, and language that address the purpose. They actively rework the text and the embedded knowledge to achieve their
purpose more effectively. The recursive aspects of writing - reflection, revision, reorganization - produce a more richly connected text and persuasive argument. Frequently this kind of writing can develop their reasoning skills, epistemological processes and understandings, as well as broaden their conception of the nature of science as they become scientifically literate (Scardamalia and Bereiter 1986). In this way, writing is an epistemological tool that enables the construction of knowledge and understanding, the induction of student-writers into the linguistic traditions and the canons of evidence in the science community, enhances self-concept, and leads to science literacy.

What kinds of writing tasks and demands are likely to develop these student understandings? Prain and Hand (1996a) outlined various considerations that should inform the design, selection, implementation and evaluation of writing tasks in science. These considerations include attention to intended readership (audience), writing purpose and type (function-form), method of production, and the use, in some instances, of structural models to guide student efforts in addressing meaningful problem-solving. However, these tasks should also require students to come to understand the particular kinds of reasoning entailed in science literacy and to understand the goals, rationale, and epistemological criteria that guide work in the scientific community. To achieve these linked understandings, students will need to write for a diverse range of purposes using different writing types, rather than the traditional narrow focus on documentation of classroom experiments, accounts of concepts, and assessment. These diversified tasks encourage students to link their own engagement with scientific explanations in school to broader issues of what counts as scientific thinking and how this can be represented effectively in writing for broader readerships. Furthermore, the choice of writing task selected may be driven by pedagogical reasons as well as epistemological reasons.

A teaching example

The development of students’ science literacy through engaging their epistemological understandings, reasoning and understanding of the nature of science occurs when they are given many opportunities to connect these dimensions. Thus, in planning to use writing in the science classroom as a means to promote science literacy, rather than as a process for recording, teachers need to incorporate a series of different writing types for different purposes and different audiences. The following teaching unit was designed for a Grade 11 Environmental Education class in a midwestern state, USA, as a means to encourage the students to engage all the dimensions of science literacy. No single writing task can achieve all these outcomes, nor is it feasible to attempt such a complete integration in such an activity. Within this teaching unit, each of the writing tasks enabled the teacher to provide students with opportunities to engage each dimension - nature of science, ways of knowing, patterns of argumentation, reasoning, big ideas of science, communications, and evidence. Each task had a particular dominant dimension that became the major focus of that task. However, the main content outcome of each task was to strengthen students’ understanding of scientific knowledge. Thus, the global emphasis was on constructing scientific knowledge and on understanding how scientific knowledge is constructed.
Three writing tasks were designed for the unit: a newspaper article, a concept map, and a report to peers. The different tasks were chosen to provide a variation in audience and different contexts for writing that reflected the broadened dissemination and persuasion requirements of science literacy. A central pedagogical function of each task was to provide the students with feedback on the science content and writing at various stages of production. This series of tasks encourages refinement without repetition. The intention was to focus on the link between students' general epistemological beliefs and science literacy in writing for peers rather than for the teacher. Thus, students not only had to engage their own sense of knowing through their writing and dissemination but had to examine other students' epistemological beliefs and reasoning, thereby further developing their own epistemology.

The newspaper article

The dominant focus of this writing task was reasoning, in particular, the development of students' reasoning when dealing with a controversial science issue. The instruction attempted to shift students' reasoning and patterns of explanation towards incorporating an expanded understanding of the different reasoning and argumentation used by people with different positions on an issue. Students were required to be aware of the various claims, evidence, and warrants associated with each of the particular arguments and to include these patterns of argumentation in their article. The authenticity was enhanced by asking the editor of the local newspaper to become part of the class for this exercise. The editor provided the students with a set of guidelines for writing a newspaper article and clearly emphasized the need to empower the newspaper's readers to make up their own minds based on the informed arguments presented. Students were required within their groups, as a prewriting activity, to present a debate to the class on the arguments at the centre of the issue. The students and teacher provided written feedback on this debate and the persuasiveness of the arguments. Students used these reactions and suggestions to inform the first draft of the newspaper article. They were provided with an opportunity to redraft their first drafts after they had been assessed by the teacher for science content and by the editor for writing style and balance of arguments.

This task addresses the students' developing reasoning in relation to their understanding of the public discourse. The structure of the task acknowledges the need for students to blend their general reasoning with those associated with the forms of warrants, evidence, and claims valued in scientific inquiry. The reasoning and epistemological demands of the task encouraged students procedurally to display in a balanced fashion the traditional scientific, rational, practical, interpretative, and socially critical argumentation found in most environmental debates. Furthermore, the task also enabled students to understand the reasoning appropriate for presenting a scientific issue for public debate. The structure of the newspaper task required students to judge the relative merits of different arguments and assumptions in developing their own scientifically justifiable position.

In attempting to meet the requirements of this task, the students found the demand for impartiality in presenting both sides of the argument difficult. This was partly a matter of their initial understanding of the topic, and their preference for one side of the case. They could not easily identify and elaborate counter-
arguments to their own viewpoint and this resulted in a tendency to understate possible alternative perspectives. However, by the completion of the task they recognized that their understanding of the issue was enhanced by the process of considering and giving adequate emphasis to alternative perspectives.

The audience, purpose, type of writing, and method of production of this writing task are all important elements in developing students' reasoning skills in science. Each provides specific contextual requirements that need to be addressed for the writing to be considered successful in achieving its purpose. For example, students will need to make judicious choices of evidence and explanatory language if they are to produce an accessible, informative and balanced report for a general readership. The method of production, in this case, the use of a prewriting activity, written feedback on content and writing style of first drafts, and opportunities to redraft, encourages students to refine the expression and selection of arguments to support their position. This method of production also provides a practical way to develop students' skills in, and understanding of, science literacy.

Class concept map

The dominant focus of this task was the nature of science, in particular, the conception of shared public meaning involved in revealing alternative interpretations or constructing consensus. The teacher's initial focus was to broaden and develop students' reasoning and epistemological techniques in justifying knowledge claims included on the group-constructed maps, and then to encourage students to utilize these techniques when constructing their individual concept maps. Students listened to a passage from Michener's *Alaska* describing the life cycle of a salmon. The students were then asked, in groups, to develop a detailed map of a section of the life cycle incorporating the associated ecosystem. The integration of the small-group maps into a single complex map was done as a whole-class discussion. This required that the students explain their reasoning and justify their sense of knowing to the class in order to clarify alternative concepts or negotiate consensus on the final concept map. Students were required to analyse the integrated map to define the essential components of an ecosystem and to negotiate an understanding of the scientific terms used to describe these components. Each group was then asked to construct its own concept map of a different ecosystem of their choice using these negotiated ideas. The group-maps were presented to the class for discussion and feedback from the teacher and peers.

In responding to this task students recognized and appreciated that points raised in their own concept maps could be incorporated into a larger class-generated concept map. They understood that this activity was a valuable exercise in developing an expanded view of the larger issues of the topic, and that a more comprehensive view could be developed by this process of negotiation.

While the structure of this task focused on various aspects of science literacy, including the development of reasoning and the refinement of epistemological beliefs, the primary purpose centred on the nature of science. Students were expected to arrive at a consensual, justified understanding or clearly defined different interpretations of the topic in a way that parallels the generation of knowledge in the scientific community. The task invites the students to understand
science as a continuing process of debate, knowledge construction and modification.

**Group or individual report writing for peers**

The dominant foci of this task were epistemological understandings and reasoning. Students were required to concentrate on particular scientific knowledge and to create generic criteria for judging diverse presentations and written handouts prepared for them by their peers. These criteria addressed communicative effectiveness and scientific content. In this way the task addressed the cognitive abilities, content, and communication aspects of science literacy. Small groups or individual students were given freedom to investigate a particular aspect of an ecosystem revealed in the previous task in greater detail. The students were required to present their information to their peers in oral and written forms. Emphasis was placed on ensuring that they clearly articulated their epistemological claims and the reasoning used to justify their knowledge claims. An essential component of this task was translating scientific terminology from the resource materials into language that their peers would be able to understand. This requirement engaged the students in crossing the boundaries of the science community and the student community to experience the difficulties related with dissemination of knowledge and the development of scientific knowledge as interconnected components of science literacy. Students presented their report formally to the class, thus representing an authentic expert-non-expert audience interaction.

The report-writing task promoted various aspects of science literacy. Students developed knowledge of the scientific topic and an awareness of their personal way of knowing. They also experienced factors that are important in the public debate of scientific issues, such as the requirements of balanced, accurate presentation of issues.

In responding to this task students said that they found balancing the demands for appropriate scientific vocabulary with the need for accessible language for their peers a major challenge. They recognized that successful communication of their ideas was based on meeting both these requirements. Students who responded most effectively to this challenge often incorporated labelled diagrams in their explanations as an additional resource for clarifying their meaning.

**Discussion**

Contemporary science literacy entails several interdependent dimensions including understanding of the nature of science and scientific inquiry, the role of reasoning, and the influence of epistemological beliefs central to the construction, dissemination and application of science knowledge. This article has argued that each dimension needs to be understood and addressed explicitly in a global context of teaching and learning science. Science literacy cannot be viewed as stacked facts, skills and attitudes but rather as interacting related dimensions of abilities, habits of mind, knowledge and communication.

This enlarged view of the nature of science literacy has several implications for the role and value of student writing within the development of scientifically literate habits of thinking. Rather than serving only as work tasks or traditional evaluation assignments, writing is a crucial problem-solving tool in the develop-
ment of lifelong learning about science and in the participation in public debate on scientific issues. As such, writing is not only evidence of student learning, knowledge, and engagement with scientific inquiry but also represents the means through which students communicate with diverse readerships their understanding of and commitment to this form of inquiry.

The article has also highlighted conditions for success in using writing to develop science literacy. These conditions include teacher knowledge of the interconnected dimensions of literacy and classroom strategies to focus explicitly on and to link each dimension. Teachers' confidence and comfort with writing frequently surface as issues as they try to establish scoring rubrics for written products (Lawrence, et al. 1998). The outlined classroom examples indicate that a sequence of different writing tasks, with contrasting contexts, purposes and readerships, is needed to develop the cluster of attitudes, knowledge, epistemological commitments and reasoning capacities needed to achieve science literacy (Hand and Prain 1995; Prain and Hand 1996b). A critical feature of these series of tasks is that students are required to transform the form of the writing, consider different audiences and attend to multiple purposes. A further condition of success is that students understand the nature and purposes of writing in science. These incorporate both opportunities and requirements for developing reasoning skills, understandings, and dispositions in acquiring science literacy.

This article has identified areas for potential classroom-based research on the role of writing in learning to enhance science literacy. These include analyses of the effects of different tasks and the identification of particular classroom strategies to enhance literacy. There is a need to identify which tasks are most effective in promoting particular skills, knowledge and attitudes that comprise the interdependent aspects of science literacy. In analysing the effects of these tasks there is a need to distinguish between tasks that develop students' reasoning skills and science knowledge, and tasks that enable students to understand the rationale and bases for scientific habits of mind and methods of inquiry. Further, there is a need to investigate the effects of particular sequences of writing activities within and across topics in strengthening both kinds of learning. Research is also needed on students' responses to these tasks. Such research will analyse students' performance in, and understanding the purpose of, various linked writing tasks that seek to develop students' knowledge of, and capacity to demonstrate, scientifically literate perspectives. Within this focus on students' perceptions, strategies, understandings and capacities, there is a need to identify what might count as satisfactory student progress in learning to become a writer in science subjects. Furthermore, inquiries are needed to explore the effects of student differences in cultural background, cognitive attributes, and epistemological beliefs on the effectiveness of writing to learn science generally and on using specific series of writing tasks.

References


