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More Research and Writing in Science Education of Interest to Those New to the Profession

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Contents

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ASEJ publishes scholarly work and strictly follows the blind review procedures and many other editorial policies described in the *Publication Manual of the American Psychological Association*, 5th edition (Washington, DC: American Psychological Association, 2001). Thus *ASEJ* is a refereed journal similar to most other scholarly periodicals published in Canada and the United States.

Contributors

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Martina Metz is currently a doctoral student in mathematics education in the Department of Secondary Education at the University of Alberta. She has been a middle school teacher for 13 years, most recently serving at the Calgary Science Charter School.

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Kathryn O'Grady-Morris has just completed her doctoral studies in the Department of Secondary Education at the University of Alberta, and was recently seconded from Edmonton Catholic Schools to Alberta Education to develop the Grade 12 chemistry diploma examinations. Her research interests relate to student learning in science classrooms.

Bonnie Shapiro is a professor in the Faculty of Education at the University of Calgary, with joint appointments in the Division of Teacher Preparation and the Graduate Division of Educational Research. Her interests include learners' conceptions in science and environmental education; how learners organize their own efforts to learn; teacher thinking and professional development; interpretive studies in education; and the development of new ways to encourage teachers to engage in research, inquiry and writing to share their thinking and practices with colleagues.

Jessica Zimmer teaches Grade 8 humanities at the Calgary Girls' School (CGS) and is interested in learning environments. Her work at CGS is based on a collaborative planning model that allows her to work closely with colleagues to construct environments that invite rich cross-disciplinary inquiries.

Matt Zinken is a Grades 5 and 6 teacher who is interested in the development of literacy and in science learning. He teaches at Belfast School, an arts-centred school in Calgary with a focus on the fine arts and technology.

From the Guest Editor

Research That Studies Learners' Conceptions, Their Own Efforts to Learn and the Environments of Science Learning

This issue of the *Alberta Science Education Journal* is the second to present a selection of articles, refereed through blind review, of interest to those new to the profession or to practising educators who want to freshly consider current thinking about science learning and teaching. Our first refereed issue, published in December 2007, focused on research and writing in science education of interest to those new to the profession. That issue quite fortuitously had an emerging subtheme—its articles supported engagement with current ideas about the meaning and value of inquiry approaches in science teaching and learning. A subtheme has emerged in this issue, as well. This issue presents thoughtful efforts to study and report on research and thinking about learners' conceptions, their own efforts to learn and the environments of science learning that we create for them.

Kathryn O'Grady-Morris and *Norma Nocente* add a new dimension to the extensive literature on learners' ideas and representations in electrochemistry. Discussing their mixed-methods study, they introduce three important factors that freshly inform us about the development of students' conceptual knowledge: the decision routines that students use; students' alternative conceptions; and learners' ability to transfer between macroscopic, particulate and symbolic forms of representation in chemistry.

Martina Metz suggests ways teachers can help make children more aware of their own use of analogical reasoning as they strive to understand in a science learning context. She presents examples of classroom discussions that show children coming to know their own ideas in deeper ways as rich sources of insight.

Bonnie Shapiro and *Kamal Johal* provide resources for educators who want to consider new ways to practise multicultural approaches in science teaching and learning. This work honours the ways students from other cultures attempt to make connections in Western classrooms. Also, a model is suggested for analyzing educators' efforts to infuse and integrate cultural contributions in science education.

Jessica Zimmer shares her own developing philosophy on how the classroom environment influences science learning, as well as how learners' understandings and perspectives in science education are shaped by their personal experiences. She suggests some implications of this thinking for the development of a culture of science learning in the classroom.

Matt Zinken explores why children often find writing in science such a difficult mode for communicating their ideas. Through reflecting on research and thinking in the field, he examines how teachers can encourage children to make writing an important vehicle for thinking and learning in science.

It has been a pleasure to encourage colleagues, graduate students and teachers in the field to bring together these two refereed issues of the *Alberta Science Education Journal*. I know that these contributions will be useful in professional development work and will help teachers consider their practice in new and refreshing ways. I hope that through reading these articles developed by and in collaboration with practising educators, others in the field will be encouraged to contribute to specialist council journals and other publications. In this way, we will become a community of writers, researchers and thinkers who, through considering our own practices, are sharing what we find vital, informative and significant in current work in science teaching and learning.

—*Bonnie Shapiro*

Procedural Knowledge Versus Conceptual Knowledge: Exploring Student Understanding of Voltaic Cells

Kathryn O'Grady-Morris and Norma Nocente

Abstract

The literature on electrochemistry contains an extensive inventory of student alternative conceptions, but little research has explored student understanding in this field of study. A mixed-methods study was designed to uncover the types of knowledge students use when solving problems related to voltaic cells. Three factors that limited the development of students' conceptual knowledge in this study were the use of decision routines, alternative conceptions and a limited ability to transfer between the three levels of representation in chemistry: macroscopic, particulate and symbolic.

Types of Knowledge

Students who are highly successful on traditional paper-and-pencil tests may have developed a learning style that recognizes and uses memorized procedures without having the underlying conceptual understanding. Hiebert and Lefevre (1986) use the term *procedural knowledge* to denote superficial learning, including a grasp of the formal language (symbol representation), rules or algorithms, and the term *conceptual knowledge* to describe knowledge that is "rich in relationships." They assert that conceptual knowledge cannot be accomplished without meaningful learning; however, procedural knowledge may or may not be acquired meaningfully.

If procedures are learned meaningfully with appropriate connections, they are then linked to conceptual knowledge. This linkage between the two types of knowledge is necessary because procedural knowledge that is learned decontextualized from relationships is restricted to a specific context and is not easily transferred to other situations. Among the benefits of linking procedural knowledge with conceptual knowledge are better retention of information and easier transfer of procedures to new contexts. Although facts are important for thinking and problem solving, research on expertise in areas such as chess, history, science and mathematics (for example, Chase and Simon 1973; Chi, Feltovich and Glaser 1981) demonstrates that the ability of experts to think and to solve problems depends strongly on a rich body of knowledge that is structured to specify the contexts in which it is applicable and that supports understanding and transfer to other contexts, rather than only the ability to remember (Barnett and Koslowski 2002).

An important issue in science education is the understanding of how learners acquire knowledge. In the last three decades, a constructivist perspective on learning and teaching has been strongly advocated by science educators and researchers (Wu and Tsai 2005). Constructivism is a theory about knowing and learning (Bodner 1986) that asserts that knowledge cannot be directly transmitted but, rather, must be actively constructed by learners. This view of learning also highlights the significance of the individual learner's prior knowledge in subsequent learning. According to Simon (1996), the ever-increasing growth of easily accessible information has shifted the meaning of *knowing* from "being able to remember and repeat information to being able to find and use it" effectively and efficiently. The ability to use knowledge to solve new types of problems requires an understanding of that knowledge. Thus, teaching and learning practices should emphasize the development of conceptual knowledge: "learning with understanding" (Bransford, Brown and Cocking 1999).

Differentiating Between Procedural Knowledge and Conceptual Knowledge

This study explored the difference between procedural knowledge and conceptual knowledge in Alberta high school students learning electrochemistry. Electrochemistry has been identified as one of the most difficult topics in chemistry (De Jong, Acampo and Verdonk 1995; Finley, Stewart and Yarroch 1982; Sanger and Greenbowe 1997a, 1997b), and there is a rich body of literature that has identified the alternative conceptions students hold in this field (De Jong, Acampo and Verdonk 1995; Garnett and Treagust 1992a, 1992b; Ogude and Bradley 1994, 1996; Özkaya 2002; Sanger and Greenbowe 1997a, 1997b).

In order to select students for this study, a two-tiered multiple-choice diagnostic instrument was developed. The first tier of each pair of questions was used to assess students' procedural knowledge of a concept, and included facts, definitions, and the use of algorithms and procedures. The second tier was related to understanding the chemistry concept in the first-tier question. Electrochemical alternative conceptions that had been identified in the literature were used to develop distracters for these questions. The diagnostic instrument was administered to 87 student volunteers from six classes in two urban high schools.

Then, 19 students whose scores differed between procedural knowledge and conceptual knowledge were invited to participate in a semistructured, task-based interview (see Goldin 2000) in a laboratory setting, during which they set up a copper-zinc voltaic cell and discussed its operation. To explore students' ability to transfer their knowledge to novel situations, variations on the standard voltaic cell set-up were used; these were based on the protocol of Lin et al (2002), with modifications. In this article, only the eight students in the high group (those who scored above 80 per cent on the diagnostic instrument) are discussed. Student names have been replaced with pseudonyms.

The students were asked to select equipment and set up a standard copper-zinc voltaic cell, predict what they would be able to observe and explain how the cell operated. Each student assembled a voltaic cell with a solid copper electrode in a 0.10 mol/L copper(II) sulphate solution for the cathode half-cell, and a solid zinc electrode in a 0.10 mol/L zinc sulphate solution for the anode half-cell. The electrodes were connected with wires through a voltmeter, and a salt bridge containing potassium nitrate was used to connect the electrolytes.

The students identified that electrons would travel through the external wires and the voltmeter from the anode to the cathode, and that those electrons would be used to reduce copper(II) ions to solid copper. They also indicated that in order to keep the cell electrically neutral, cations would move through the electrolyte to the cathode and anions would move toward the anode. In other words, the students could correctly answer the types of questions typically used in paper-and-pencil tests to assess their knowledge of the operation of voltaic cells. This information led us to predict that the students had conceptual knowledge of the operation of the cells. Their explanations of how a voltaic cell operates, however, revealed some surprising ideas.

Students' Explanations of Voltaic Cells

When asked to predict what would happen as a copper-zinc voltaic cell operated, the students readily used their redox tables to write a reduction half-reaction for copper and an oxidation half-reaction for zinc. Using these equations, they were able to further explain that electrons from the oxidation of zinc combined with copper(II) ions to produce solid copper, which they were able to observe at the cathode during the operation of the cell. The information required to answer these questions, however, was procedural knowledge. The students had memorized a procedure that allowed them to successfully use a redox table to predict which chemical reactions would occur in a voltaic cell. The use of acronyms further allowed them to associate key vocabulary words with this procedure without understanding the underlying chemistry. This approach to solving problems—which involved the use of definitions, algorithms or procedures in a rigid manner—did not transfer to novel or more complex situations.

After setting up the copper-zinc voltaic cell, the students were asked to predict whether the cell would operate with only one of the two electrolytes present. Only four students predicted that the copper(II) sulphate solution would be essential for an operating cell, even after writing a half-reaction showing that the species undergoing reduction was the copper(II) ion. When asked to predict if one or both of the electrodes could be replaced with an inert carbon electrode, three students chose to replace either the zinc electrode or both electrodes, even though the oxidation half-reaction written at the beginning of the activity identified solid zinc as the source of electrons for the redox reaction in this voltaic cell.

Valerie explained her choice of an inert electrode at the anode: "Carbon is the weakest reducing agent. It is not going to be stronger than anything. It is so weak that they don't even put it on the table." When asked why the zinc was present in the cell, Ed and Fran both said, "I don't know," and they continued to search for carbon on the redox table. These students had successfully used a memorized procedure or decision routine to predict the reactions with the redox table, but they could not relate this knowledge to the underlying electrochemical concepts when confronted with a novel problem. Instead, they attempted to fit the new problem into their existing problem-solving pattern and were baffled when the strategy did not work.

According to Gabel (1998), conceptual knowledge in chemistry involves the ability to represent and translate chemical problems using three forms of representation:

- Macroscopic, which involves observation and tactile manipulations in science
- Particulate, which involves microscopic, atomic and subatomic entities
- Symbolic, which involves the use of chemical formulas and mathematical manipulation

In their comprehensive review of the research on problem solving in chemistry, Gabel and Bunce (1994) suggest that a main reason students have difficulty solving some chemical problems is that they lack understanding of the connectivity of the concepts needed to solve the problems. Bröder and Schiffer (2006) conclude that the use of decision routines limits flexibility in problem solving.

In this study, the students were successful with the three levels of representation when the levels were considered individually. At the macroscopic level, they could set up the copper-zinc voltaic cell and make correct observations while it operated. At the particulate level, they were able to discuss the movement of anions, cations and electrons. At the symbolic level, they used the pattern of the location of oxidizing and reducing agents on a redox table to predict and write reactions that would occur.

Difficulty arose, however, because the students could not connect the three levels of representation. Without this connectivity, they were able to demonstrate procedural knowledge when making predictions or observations, but they had little conceptual knowledge of the underlying processes that involved the movement of electrons and ions to generate electrical energy. In addition to the problems arising from students' limited ability to make connections between concepts in chemistry, research has found that students tend to ignore instruction that does not coexist well with their existing knowledge, or they reinterpret the information to match their expectations from previous exposure to the information (Driver and Easley 1978; Wandersee, Mintzes and Novak 1994). Thus, the students' successful prior use of a decision routine for a standard voltaic cell led to its rigid application in new, inappropriate contexts because of their failure to understand the relationships between pieces of information.

After assembling the copper-zinc voltaic cell and making observations, students were asked to talk about what happened to the electrons when they reached the cathode. According to the half-reactions written at the beginning of the interview, the electrons were consumed during the reduction of copper(II) ions. However, the students' explanations indicated that prior learning related to circuits and chemical bonding influenced the framework they constructed to understand the abstract nature of voltaic cells.

Dan recognized that a complete circuit was present because he could see a voltage on the voltmeter, and he explained how electrons were completing this circuit:

> It has to do with the transfer of electrons between ions in the solution because copper [ions] would still get the electrons from the copper electrode

> and [solid] zinc would steal electrons from the copper metal, creating more ions which steal more electrons through this circuit. The electrons piggyback across the ions between the electrodes to complete the circuit. The ions keep the electrons from each other.

Even though he had written a reduction half-reaction that represented electrons being removed from the system and had observed the production of solid copper, which verified that this reaction had occurred, Dan still believed that the electrons must be moving in a circle through the electrolyte and back to the zinc electrode for the circuit to be complete.

Another version of this electron movement was provided by Ed:

> Electrons are moving because it is part of a complete circuit. The sodium ions in the salt bridge are positive, and it allows the electrons to go from one sodium [ion] to the next through the solution.

Helen offered an alternative explanation, as she talked about the presence of electrons in the salt bridge:

> Negative ions have electrons. Everything has electrons, but negative ions have more than they need, so there is a negative charge there. Once they are in the salt bridge, they are not travelling freely, but they travel attached to other substances to the other side of the circuit. They are hitching a ride with the sulphate and nitrate to get over, so they still have to travel through, because they can't stop in a circuit.

The students' explanations about electron movement were based on their prior knowledge from lessons in junior high science courses. Dan indicated that he had learned in Grade 9 that electrons move in complete circuits, and both Helen and Ed referred to previous chemistry classes pertaining to ionic bonding when explaining how ions were attracted to each other in the salt bridge. Another explanation based on prior knowledge was given by Colleen, as she explained that the function of the inert electrolyte in the salt bridge was "to neutralize the charges on the moving ions," in the same way that a positive ion and a negative ion combine to form "a neutral compound like the potassium nitrate in the salt bridge."

Each of these students had actively constructed a logical framework for the functioning of a voltaic cell, using information from current lessons and prior knowledge. The task of educators, therefore, is to uncover the connections students have made and confront students' alternative conceptions so that they can construct scientifically accurate frameworks.

Imagine if an appreciation of the rational criteria for developing the tools used for decision making (for example, understanding the development of the redox table) were an epistemological goal of teaching electrochemistry. Students would then be able to contextualize their knowledge more coherently rather than relying on memorizing a decision routine, applying a formula or inappropriately incorporating prior knowledge. Indeed, Koslowski (1996) concluded that for students to achieve scientific understanding, both data and the theory of underlying mechanisms are needed for successful causal reasoning.

Understanding expertise can provide insights into the nature of thinking and problem solving. It is not simply general abilities (such as a good memory or intelligence) or the use of general strategies that differentiates experts from novices. Experts have acquired extensive conceptual knowledge that affects what they notice and how they organize, represent and interpret information in their environment (Barnett and Koslowski 2002; Bransford, Brown and Cocking 1999). This, in turn, affects their ability to remember, to reason and to solve problems. Experts' knowledge cannot be reduced to sets of isolated facts but, rather, reflects contexts in which those facts can be applied (Barnett and Koslowski 2002).

Conceptual knowledge is achieved by helping students construct relationships between pieces of information, by identifying students' relevant prior knowledge and by confronting students' alternative conceptions. Among the benefits of linking procedural knowledge with conceptual knowledge are better retention of information and easier transfer of decision routines to new contexts.

For example, students may be expected to remember that both cations and electrons move toward the cathode. A procedural knowledge test item for this information could contain a diagram of a voltaic cell with numbered arrows for students to identify. Students with conceptual knowledge of voltaic cells, however, would also understand why the particles have particular properties. They could start by knowing that a voltaic cell has two half-cells, each containing a solid and a solution, and that the substances in the half-cells must have different abilities to attract electrons. However, in understanding the relationships between the structure and the function of voltaic cells, students with conceptual knowledge would be better able to use what they had learned to solve novel problems—to show evidence of transfer.

Imagine being asked to design a voltaic cell from household substances. Would there have to be two chemical solutions? Why or why not? An understanding of the reasons for the properties of voltaic cells would reveal that solutions may not be necessary; perhaps sandwiching pieces of metal between damp paper towels would provide a conduit for particle movement and serve as the source of the electrolyte. An understanding of voltaic cells would not guarantee an answer to this design question, but it would support thinking about alternatives not readily available if students only memorized facts and procedures.

Promoting Conceptual Knowledge

Several students in this study who had conceptual knowledge of particle movement in voltaic cells attributed their ability to understand this abstract concept to the use of animations. Jayne explained that although demonstrations were useful, doing the animations was better because "when you are doing it on paper, it is very abstract. You don't actually see the ions, whereas when you are using the animation it forces you to think about what is happening as you are doing it." A wide variety of animations are available on the Web (use the search words *voltaic cell animations*).

It would be useful for students if lessons were sequenced to provide all three levels of representation, and if the levels were then collectively identified and their connectivity discussed. As became apparent in this study, students who can make predictions for an experiment do not intuitively make the connection to the abstract particle movement or laboratory observations.

When the students talked during their interviews about the operation of voltaic cells, several of them were able to recognize discrepancies between what they were saying and what they had observed, as shown by Gail's explanation of electron movement:

> The electrons are in the salt bridge, too. They should be there. Yes . . . they are there, because electrons can move in an electrolyte. No . . . they shouldn't be there, because you are using the electrons to make the copper solid. So the electrons only travel through the wire and not through the electrolyte because they are used up at the cathode.

By talking out loud about a process, either individually or in groups, students may be able to recognize and confront their alternative conceptions and reach a deeper understanding of the concepts.

Bransford, Brown and Cocking (1999) discuss Minstrell's (1992) *facets:* "Minstrell describes identifiable pieces of students' knowledge as 'facets,' a facet being a convenient unit of thought, a piece of knowledge, or a strategy seemingly used by the student in addressing a particular situation." A facet can relate to conceptual knowledge or to procedural knowledge, or it may be generic. By listening to students' explanations and identifying their facets, educators can determine what cues students use in different contexts and how they use those cues in reasoning; educators can then use that information to devise instructional strategies that increase conceptual understanding.

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“Jordan, Do You Know What an Analogy Is?”: Why Analogical Reasoning Deserves a Central Place in the Science Classroom and Beyond

Martina Metz

Abstract

The essential role of metaphor in both science and mathematics is being increasingly recognized. But what are the pedagogical implications of this recognition? This article summarizes a framework that describes various ways in which children use analogical reasoning to construct understanding in science, and considers how understanding this framework might more broadly inform pedagogy. Rather than viewing metaphor as a teaching tool or as an organizational framework for knowledge, the article considers how students might become more aware of their own use of analogical reasoning and how they might use it with greater awareness and intention, providing both a rich source of ideas and important considerations in the evaluation of those ideas.

Consider the following argument:

> Our perception of reality is mysterious.
> Quantum physics is mysterious.
> Perception is a quantum phenomenon.

Perhaps. Using metaphor without awareness or intention can lead to overgeneralization and assumption, and this lies at the heart of both prejudice and pseudoscience. When the final statement is rephrased, a very different message is presented:

> Is perception like quantum phenomena?

This raises further questions:

> Is there something in our perceptual process that behaves like subatomic particles?
> Are the similarities sufficient to assume that both are rooted in the same underlying phenomenon?

Used in this way, metaphor can be harnessed as a powerful tool for generating questions that open meaningful spaces for investigation.

The power of metaphor to bridge diverse disciplines and open creative avenues of thought has long been recognized as essential to science (Bronowski 1956; Kuhn 1970; Nersessian 1992). However, we hear little about the work that precedes these flashes of insight. In this article, I loosely define *analogical reasoning* as the identification, evaluation and application of metaphor (see “Differences That Make a Difference” later in this article for further clarification of the terminology). Most of the research on the use of analogical reasoning in the science classroom pertains to the use of analogy as a teaching tool to direct students toward predetermined conclusions, typically with the teacher being responsible for identifying where selected analogies break down (Dagher 1995; Duit 1991; Gentner and Gentner 1983; Glynn 1991, 1994; Mason 1994; Spiro et al 1989; Stavy and Tirosh 2000). Clement (1981, 1982, 1986, 1988, 1989a, 1989b, 1993, 1994, 1998) and Wong (1993a, 1993b) both emphasize the importance of learner-generated analogies in *expert* problem solving, and the limited research available on students’ use of learner-generated analogies (such as Cosgrove [1995] and Osborne [1996]) suggests that elementary science students’ strategies are similar to those used by Clement’s and Wong’s experts.

In this article, I briefly summarize a framework (which I have further developed in Schmidt [1999]) that describes how children become aware of their use of analogical reasoning. As its use becomes more intentional, analogical reasoning provides a rich source of ideas, important considerations in the evaluation of those ideas, and a means of interrupting deeply held assumptions that typically operate beneath the level of full consciousness.

Children's Use of Analogy in Science

The four levels of analogical reasoning discussed below were developed through interaction with a group of Grades 5 and 6 students attempting to explain the operation of various DC-powered electrical circuits. They are not developmental stages: students operate at different levels in different contexts. Also, advanced levels of reasoning often emerge as students converse about tentative ideas, making it impossible to attribute particular levels of awareness to individual students. (See Schmidt [1999] for additional examples.)

Level 1

In Level 1, analogy is used as a communication tool whereby the child describes or enacts new situations by subconscious reference to other, more-familiar situations. This type of assumption may be driven by an implicit recognition of similarity that makes certain beliefs "feel right," or it may involve interacting with objects to see what happens. Either can be a fruitful starting place for new ideas and hypotheses. However, when a gut feeling is accepted as unevaluated truth, it can become a source of overgeneralization.

In the following dialogue, Robert used his belief in clashing positive and negative currents (from the two ends of a battery) to explain why a wire connected to the positive and the negative terminals of a battery got hot:

> Robert. And to get a hot wire, then your energy would mix together, and then it would [*motioning*] try to, like, on a plus and a minus . . . on the . . . pretty much on the plus and minus side of a battery, er, of a magnet. They would push each other back [*motioning with his hands*].
>
> Ms S. So, one side is a positive, and one side is a negative, so when they come together . . .
>
> Robert. Then they . . . like . . . shake. Almost. Yeah. Pretty sure. And the reason it doesn't do that in the bulb is because it's separated from . . . it never has to meet. (Schmidt 1999, 238)

Robert was convinced that his explanation was right because it "felt right." He did not seem to realize that his prior experience with magnets was colouring his understanding of the circuit. To him, the magnet was a tool to explain something that he was already "pretty sure" of. Clement (1994) refers to such generalized, bodily and unjustified statements of intuitive plausibility as "elemental physical intuitions."

The students in this study often developed complicated descriptions of moving particles with no apparent consideration of what caused them to move; it seems that they deemed possible (and often plausible) anything that they could visualize. When questioned regarding causation, they often either didn't see the point of the question or invoked animistic explanations.

Effective analogical reasoning can occur subconsciously. The students frequently challenged each other's understanding of source analogues, and even the applicability of the relationships in question, without realizing that analogical reasoning was taking place. Recently, my five-year-old niece was surprised to discover that her new baby brother had a penis and testicles. She asked my sister if they were like the umbilical cord stub that she remembered from the arrival of her now two-year-old sister and wanted to know if they would eventually fall off. When my sister told her that, no, all boys have them and keep them for life, she immediately made another connection: "Does *Daddy* have them, too?!" Note that she was both mapping analogical relationships and questioning whether transfer was appropriate—a very effective use of analogical reasoning essential to learning about the world. However, this use was unconscious and automatic. In a situation that didn't already strike her as surprising, she would not think to question the transfer of meaning.

Level 2

In Level 2, the child is explicitly aware of his or her use of analogy in formulating ideas and explanations, and actively seeks out useful analogies. However, the child explains away the parts that don't work with the rationale that the idea is "just an analogy." Students at this level realize that it is not necessary for all components of identified analogues to correspond, but they do not realize that such correspondence is necessary if the explanation depends on that part of the analogy. This lack of awareness is commonly seen in statements such as "It acts like [a living thing], but it's not really alive." If the object is not alive, an anthropomorphic rationale for its behaviour is not plausible.

Level 3

In Level 3, the child is aware of the need to evaluate the applicability of selected analogues: just because you can relate two things doesn't mean that an analogy based on them will make sense. Students often challenge the applicability of an analogy if it conflicts with their prior knowledge; however, it is important that they learn to question applicability intentionally in less-familiar contexts where conflicts do not alert them to potential trouble.

As the students in the following dialogue wrestled with the inconsistencies in their "clashing current" model, the role of analogy was brought to the foreground:

> SAMANTHA. It's like a highway. If you have a car coming this way and a car coming this way, and they go, "BOOM," well, they're going to crash, aren't they? Well, if he doesn't want the wires to mix, well then, that's sort of like two sides of a highway. One goes this way and the one goes the other way.
>
> ROBERT. But then shouldn't you have two roads? But he only has one road.
>
> CARL. We've only got one road out here, and we can still pass, right?
>
> SAMANTHA. Maybe there's two sides in the wire. Like, there's two different parts in the wire. Like, you have one going one way and one going the other way, so then it can go like Frank says. And it can go through.
>
> JORDAN. But, still, the wire. How can there be two highways? There would have to be people driving these electric things.
>
> CARL. Jordan, do you know what an analogy is? It's something that's different, but it . . . (Schmidt 1999, 272–73)

Jordan did know what an analogy was, but he didn't accept Carl's use of it. The tension evident in their differing views helped push them toward greater awareness of the way they used analogy.

Level 4

Level 4 was not observed in this study, and therefore the following discussion is hypothetical. In Level 4, we seek awareness of previously unconscious constraints on our thinking and make conscious attempts to break free from those bindings. Although it is impossible to identify all metaphorical blinders, awareness of how they operate can remind us to seek out the source of gut feelings that may be convincing but are wrong, and to attend more consciously to the beliefs and actions they influence.

Differences That Make a Difference

Without getting too mired in terminology, I hope this is an appropriate juncture to elaborate on my use of the term *analogical reasoning* (that is, the intentional, and often recursive, transfer of meaning between two or more ideas). Analogical reasoning involves the identification, evaluation and application of metaphor, which I describe in the introduction to this article. This broad definition intentionally collapses a number of categories commonly identified in the literature.

For example, Sfard (1997, 345) distinguishes between analogy and metaphor as follows: "Analogy enters the scene when we become aware of a similarity between two concepts that have already been created; the act of creation itself is a matter of metaphor." However, recognizing similarity may itself be seen as an act of creation that has an impact on both concepts, and therefore I prefer to use the terms *analogy* and *metaphor* interchangeably. However, while the use of metaphor can be (and often is) implicit, analogical *reasoning* is an intentional thought process. The distinction between within-domain and between-domain analogies (Vosniadou 1989) is necessarily arbitrary: once a connection is perceived, the distance between domains is reduced to zero. Before a connection is perceived, a distance that some might see as insignificant is in fact large enough to prevent a transfer of meaning.

According to Clement (1988) and Gentner (1983), base and target analogues must be at the same level of abstraction, thereby helping to eliminate confusion between examples and analogies. Clement uses what he describes as a nonanalogous relationship between a bird and a robin to illustrate this idea (p 569). However, a robin is an example of a bird only because we choose to define it that way. A young child could easily overgeneralize a butterfly as an example of a bird, depending on the child's perception of what makes a bird a bird. Clement also excludes extreme-case reasoning from his definition of *analogy,* claiming that it often relies on manipulating a problem variable. However, once we manipulate a problem variable, we must confirm whether the modified situation still applies to the target we are considering; perhaps new variables enter into play at the extremities being considered. He similarly excludes parts of the original system as potential bases for understanding the whole, which ignores the possibility of properties that emerge through the interaction of the parts. Finally, he excludes connections that depend only on surface similarity; however, surface similarity is often confused for deeper conceptual similarity.

By considering examples, extreme cases, part-to-whole relationships and surface similarities as instances of analogy, we require of them the logic of confirmation necessary for effective analogical reasoning. It is often precisely these cases in which we assume connections that are in fact overgeneralizations, or in which we assume that connections obvious to us will be obvious to others. When classroom events are recognized as potential instances for nurturing analogical reasoning, then *analogic* may be consciously applied:

1. *Identification.* Recognize similarity.
2. *Evaluation.* Question that similarity: How is A like B? How are they different?
3. *Application.* Decide whether (and how) transfer of meaning between A and B is appropriate.

The students in this study debated whether circuits powered by a wet cell, a dry C cell and a flashlight battery would behave differently. According to many of the definitional limitations discussed here, a different power source would not be a sufficient difference to classify the circuits as analogous. Yet many of the students demonstrated an unwillingness to transfer explanatory structure between otherwise identical circuits until they had (appropriately) spent a considerable amount of time exploring the nature of differences that might seem trivial to a casual observer.

Different representations may also be treated as analogous rather than identical, especially when their equivalence is not obvious to students. Again, this sometimes means allowing significant chunks of time for students to explore relationships that might seem obvious to the teacher. The students in this study explored many different circuit arrangements, and they often diagrammed these in their journals in complex jumbles. One student suggested drawing little bumps to distinguish between wires that cross and wires that connect, and soon there was frequent reference to "wire jumps" in the students' discussions. At one point, a student noticed that the diagrams could be "untangled" and drawn in a way that did not require wire jumps, and that doing so made two of the main circuits the students were exploring (and arguing over) appear the same:

> JORDAN. Take this wire and go over here and touch this wire [*referring to a tangled circuit diagram drawn on the board during class discussion*].
>
> MS S. So, instead of crossing here, *would that still be the same thing*? [emphasis added] He wants to take this wire right off, and instead of connecting to this part of the negative wire, go around and connect to this part of the negative wire. Anybody else disagree?
>
> CARL. I don't disagree, but then you could take this wire off, and then bring it around to here.
>
> MS S. And then . . . So we don't have any overlap? Okay. That is interesting how you changed . . . You know what, let's even try to straighten this out a little bit. Let's start with the battery [*drawing on the board*] and from the negative end, where do we go first?
>
> JORDAN. You go down to the first . . .
>
> MS S. To the sides of the bulb? Okay, let's put a bulb in here. And does this bulb also connect to the positive end of the battery?
>
> SEVERAL VOICES. Yes.
>
> MS S. Right away? Or does it have to go through another bulb?
>
> JORDAN. It needs to go through another bulb. (Schmidt 1999, 226)

This continued for some time.

> ROBERT. This one looks exactly like Carl's.
> JORDAN. Just the extra bulb.
> CARL. Hey, you connected that to the positive one.
> JORDAN. Hey! That's drawn like Carl's. (p 227)

For several days, untangling circuit diagrams and testing hypothesized equivalences became the centre of activity, and the students began to perceive a number of previously unique circuits as being identical. Taking perceived differences seriously prompted students to look closer at their circuits and to consider which differences in arrangement made a difference to the performance of the circuits.

As Pimm (1995, 185) notes, "Metaphors express particular stressings and ignorings"; they prompt attention to "differences that make a difference" (Bateson 2002, 92). Clearly, we often fail to adequately consider whether situations are similar enough to justify transfer of meaning. Awareness has the potential to interrupt our unconscious biases, allowing us to ask questions instead of making assumptions.

Closing Thoughts

Whether or not we are aware of it, metaphor is essential to human thought (see Lakoff and Johnson [1980]). In fact, our very language is metaphorical. The EcoJustice Dictionary (www.ecojusticeeducation.org), in its definition of *root metaphors,* states that "languaging processes carry forward past ways of thinking that are based on assumptions unique to the culture." It points out our own culture's use of root metaphors such as mechanism, individualism, patriarchy, progress, anthropocentrism and evolution, and seeks to preserve root metaphors inherent in diverse linguistic traditions that honour more ecological world views. Helping children become aware of their use (and misuse) of metaphor could ultimately have a tremendous impact on the way we individually and collectively think about and interact with our worlds.

The other day I received an e-mail forward falsely attributed to commentator Andy Rooney.[1] It had the subject heading "CBS Didn't Stop Him: This Is Great!!" and included the following statement:

> The only things I can think of that are truly discriminatory are things like the United Negro College Fund, *Jet* magazine, Black Entertainment Television, and Miss Black America. Try to have things like the United Caucasian College Fund, *Cloud* magazine, White Entertainment Television, or Miss White America and see what happens. . . . Jesse Jackson will be knocking down your door.

The language used in this message assumes a similarity between organizations that privilege blacks and those that privilege whites. While some may still take this position even after closer examination of the arguments, statements that assume equivalence as self-evident might come to act as triggers to seek out potentially significant sources of difference. Is a college fund that privileges blacks the same thing as a college fund that privileges whites? To use (and question) another metaphor, Is a college fund provided for blacks significantly different from the multitude of other organizations that provide eligibility criteria for the scholarships they fund? Is Miss Black America the same as Miss White America? Have black contestants in the mainstream Miss America pageant been routinely overlooked because of different standards of beauty? If so, could the problem be better addressed by attending to judging biases? On the other hand, if difficulty breaking into the ranks of traditionally white organizations is grounds for separate competitions (and to introduce yet another potential metaphor), would it be acceptable to have a National White Basketball Association? The arguments are far from simple. Analogical reasoning does not provide answers or proof, but by directing attention to differences and asking whether those differences make a difference, it helps to open conversations that honour the complexity of difficult issues.

It may seem that I have strayed far from the science classroom. As I have emphasized throughout, however, metaphor is essential to human thought, and attending to its use in a variety of contexts could allow for the development of greater awareness of that use. Within the science classroom, analogical reasoning provides a much-needed strategy for helping students develop and test their own hypotheses; science requires creative ideas and testable implications before the logic of the experimental method can be applied.

Note

1. See www.snopes.com/politics/soapbox/rooney4.asp (accessed February 9, 2009).

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Research and Resources to Support Leadership and Reflection on Multicultural Approaches in Science Education

Bonnie Shapiro and Kamal Johal

Abstract

This article serves as a resource for teachers, student teachers and leaders in science education. It reviews research, resources and questions related to multicultural approaches in science teaching and learning, builds on work in professional development education and is designed to help educators move more deeply into discussions about multicultural engagement in science. The authors explore what it means to take up a multicultural approach in practice by (1) summarizing research that helps develop a basic understanding of the issues, (2) describing inspiring efforts from educators and teacher educators whose writing about their work in multicultural science education suggests new approaches to practice and (3) describing a model created by James Banks and reflecting on its implications for science education reform.

In this article, we review some of the research, resources and questions we have found of value as we have engaged in reading and research about the meaning of and possibilities for multicultural approaches in science teaching and learning. Written as a resource for teachers, student teachers and leaders in science education, the article builds on work in professional development education (Shapiro 1994; Shapiro and Kirby 1998; Shapiro et al 1999; Shapiro and Last 2002) and is designed to help educators reflect more deeply on multicultural engagements in science (Johal 2003).

The article is constructed around several questions about what it means to take up this approach in practice. We organize the discussion by (1) summarizing research in the field that is useful in developing a basic understanding of the issues, (2) describing inspiring efforts from educators and teacher educators whose writing about their work in this field suggests new approaches to practice and (3) describing a model created by James Banks and reflecting on its implications for analysis and critique in efforts to reform practice in science education. It is our hope that this article will serve as a useful starting point for discussion and sharing for those who want to move more fully into crafting philosophies and practices in multicultural approaches to science education.

What Is Meant by a Multicultural Approach to Science Education?

How we conceptualize multicultural approaches to science education will influence how we organize, structure and live our work in practice. As Hodson (1993, 688) notes, "Multicultural science education can mean many things to many people." Some regard the use of a multicultural approach as a way to address the needs of students who are not part of the dominant cultural group of the classroom. Others consider the approach a way to include the contributions of scientists outside of Western science traditions. Hodson (1999) describes multicultural science education in an inclusive way, as (1) a set of teaching and learning strategies to help teachers cope with cultural and ethnic diversity within the classroom, (2) a set of curriculum proposals aimed at raising the self-esteem of members of ethnic minority groups who feel excluded or alienated from science and (3) an approach for raising group consciousness about racism in science and science education. Luft (1998) describes a multicultural approach in science education as an attempt to resolve the inequities that exist in the science classroom and to create a more holistic view of science that is more accessible to all students. According to Atwater (1993, 34), "Multicultural science education is a field of inquiry with constructs, methodologies, and processes aimed at providing equitable opportunities for all students to learn quality science in schools."

These positions support the value of multicultural knowledge in increasing students' self-worth and their view of themselves as successful learners, and in laying the foundation for developing understanding of other cultures to promote intergroup harmony and the ability to think, work and live with a multicultural perspective. Carson (1997, 109) states that such "reform needs to be systemic throughout the entire K–12 curriculum and across all subject areas."

The Need for a Multicultural Perspective in Science Teaching

It is important to teach science from a multicultural perspective in Canada for many reasons.

First, we must recognize that Canada's demographic landscape has changed significantly (Roessingh 1995), and the number of immigrant students in Canada is rising. Between 1991 and 2001, approximately 1.9 million immigrants came to Canada (Statistics Canada 2004a). The total population of visible minorities aged 0–14 is almost 1 million (Statistics Canada 2004b). In 2002, Alberta welcomed 14,682 immigrants; of those immigrants, 22 per cent were 19 years of age or younger (Alberta Learning 2003). The escalating diversity of learners in the mainstream classroom will have a profound effect on how teachers teach and how they work with their colleagues (Roessingh 1995). Locke (1988) asserts that teachers need to develop certain levels of cross-cultural awareness to be effective in teaching culturally different students.

Ethnic minority students may benefit from an acknowledgement of the contributions of different cultural groups to current understandings in science. Pomeroy (1994, 56) asserts that "students of diverse backgrounds will be able to relate more easily and proudly to science and scientists if they are able to study the contributions of people of diverse cultures." Recognizing the contributions made to science by other cultures can enhance and build positive self-concept in ethnic minority students. According to Bryant (1996), multicultural education fosters increased self-respect, increased self-confidence and an appreciation of one's culture seen in context with other cultures. Hodson (1993, 687) writes that, currently, "the science curriculum does little to raise the self-esteem of children from some ethnic minority groups and is seen by many as irrelevant to their experiences, needs, interests, and aspirations." Johal (2003) notes the need to recognize that ethnic minority students bring many talents and much knowledge with them into the classroom. Through her own experiences as an immigrant child and now as an educator, she has come to believe that the challenge for teachers is to find ways to make science learning interesting and attainable so that immigrant students can overcome barriers and succeed in science-related careers.

In addition to changing demographics, there are many other reasons for multiculturalizing the nation's science classrooms, particularly the need for "a more scientifically literate populace for the 21st century and the demand for more scientists and engineers" (Atwater 1995a, 21). It may be argued that because of the homogeneous populations of some schools, teachers do not need to emphasize multicultural education. However, Atwater (1995b, 45) asserts that even monoethnic classrooms need to be multiculturalized: "Even though all the students in a class might have the same skin color, they will still differ in world experiences to some degree." This leads to one of the most important reasons for multicultural science education. By using examples of multicultural contributions to science and by teaching all students about ethnic diversity, teachers can try to address the problems of racism and discrimination (Ghosh 2002). Hodson (1993, 692) asserts that a teacher's

> Willingness to utilize children's knowledge and experiences of other cultural practices may benefit other children; such practices could be expected to have value in raising self-esteem and in combating racism because all racial, cultural and religious groups are seen to possess important knowledge and have had significant experiences.

How Might We Consider the Goals and Approaches of Multicultural Science Education?

A scant but growing literature describes the goals of multicultural science education. A major goal is to present science to students as a global body of knowledge, not one created solely by Western civilizations (Abdi 1997). According to Brophy (1991), the contributions of world scientists and their cultures can be recognized by more fully integrating them into the development of science knowledge, skills, attitudes and practices. A second goal of the multicultural approach is to increase the academic success of all students. This means not underestimating the ability of ethnic minority students to succeed (Henson 1975). A third goal of multicultural science education is to reduce prejudice, stereotyping and racism. Lang (1995, 172) believes that multicultural science education can serve to "reduce prejudice and enhance cultural appreciation in the service of improved academic achievement of all students."

Instead of focusing on only one form of knowledge taught in the classroom, Aikenhead (2000, 246) suggests considering the ways that particular approaches to science teaching come "each with an ideological agenda and each with a stake in what counts as knowledge in school science."

Krugly-Smolska (1992) agrees that multicultural education can no longer be a topic isolated to areas such as history. Instead, it should be integrated into all subject areas. To meet the needs of all students, teachers need to teach within a curriculum that recognizes, promotes and enhances diversity. This implies that the curriculum, methods of teaching, evaluation, norms and standards of excellence must incorporate the world views, histories and experiences of all children rather than only those in the dominant culture (Ghosh 2002).

There is a great need for support, through professional development and resources, for changes in curriculum development and implementation to promote scientific literacy for all. In the pursuit of scientific literacy, Hodson (1998, 5) suggests

> Addressing the inherent biases in science and science education, creating a more authentic, culturally sensitive and inclusive image of science, scientists and scientific practice, showing science being used and developed by diverse people in diverse situations and maintaining a school science environment in which all students feel a sense of comfort and belonging.

According to Cobern and Aikenhead (1998), we need to develop teaching methods that allow the incorporation of content and aspects of other cultures into students' everyday lives and enable students from other cultures to enjoy and construct meaning from Western science without the need to assimilate.

Multicultural science education can provide opportunities for immigrant youths to achieve their fullest potential and make positive contributions to the fields of science and technology. According to Rosenthal (1996), limited English proficiency (LEP) students represent a large pool of yet unrecognized talent; they could be "tomorrow's university and industry researchers, high school and college science instructors, technicians and/or technologically and scientifically literate members of the public" (p 25).

Educators Share Ways to Implement Multicultural Approaches in Science Education

Many teachers and teacher educators have been reflecting on how to implement multicultural science education, and have suggested approaches and shared resources. It is useful here to look at a couple of examples.

In "A Cultural Classroom Library," Maria Lawrence (2007), a Native American classroom teacher and now teacher educator, describes her efforts to select children's literature by diverse authors to integrate with inquiry-based science units. She strives to select cultural literature that is "authentic, respectful, and culturally accurate," with the help of good reference resources, such as *A Broken Flute: The Native Experience in Books for Children* (Seale and Slapin 2005), a compilation of reviews of literature about Native Americans. Lawrence also suggests that teachers carefully consider the terms and language used in a piece of literature to ensure that the diversity, complexity and contributions of specific Native American nations are represented. She looks for cultural books that clearly "reflect an appreciation of the natural world" and "describe science wonderings drawn from close observation of the world and are a creative telling of that knowledge" (p 35). This rich literature can be used by teachers to "enrich children's interactions with science concepts and processes by integrating cultural stories about animals and environments" (p 35).

In his article "Roots of Diversity: Growing Culturally Significant Plants in the Classroom," Allan Foster (2007) suggests that plants grown in classrooms are educational resources, considering the many roles plants play in important cultural traditions and rituals around the world. Foster, a botanist, believes that growing culturally significant plants is a way to meet one of the most important goals of public education: "to develop in students esteem for the customs, cultures and beliefs of a wide variety of societal groups."

A Model for Reflecting on Multicultural Practice

The research of scholar James Banks (1991, 1994, 1995, 1997, 2001), who works extensively in the field of multicultural education and curriculum reform, is a powerful resource for the critique of practice. Banks (1995) suggests the following five dimensions of multicultural education as a useful model for analyzing multicultural commitments and practices in schools:

1. Content integration
2. Consideration of the knowledge construction process
3. Prejudice reduction
4. Equity pedagogy
5. Empowering school culture and social structure

Content integration deals with the extent to which examples and content from a variety of cultures and groups are used to illustrate key concepts, generalizations and issues.

Consideration of the knowledge construction process involves gaining deeper awareness of the ways students understand, investigate and assess how biases, frames of reference and perspectives in a discipline influence how knowledge is constructed within the discipline.

Prejudice reduction refers to the generation of lessons and activities used by teachers to help students develop positive attitudes toward different racial, ethnic and cultural groups.

Equity pedagogy exists in a classroom when educators modify their teaching to enable students from diverse groups and of both genders to achieve academically. Banks asserts that when teachers use strategies and approaches consistent with the wide range of learning styles in various cultural and ethnic groups (such as role play or cooperative learning), students have a better chance of academic success.

The fifth dimension, *empowering school culture and social structure,* focuses on improving equitable operations and opportunities in the total school culture. Implementing this dimension requires that educational environments be reformed with careful consideration of the attitudes, beliefs and actions of teachers and administrators; the curriculum and courses of study; assessment and testing procedures; and the strategies used by teachers.

Banks's model is useful not only in the review and analysis of individual classroom teacher practice, but also as a tool for rethinking and re-imagining school culture and ways to employ resources. Banks (1997) believes that integrating the curriculum with culturally sensitive content is an essential step toward curriculum reform. He suggests that "during this process the entire curriculum is transformed to enable students to view events, concepts, and issues from diverse ethnic and cultural perspectives" (p 52). He also urges educators to embrace multicultural education throughout the entire curriculum, not merely focusing on cultural holidays and events, and he emphasizes that using pictures of ethnic minority students or gender-balancing photographs does not address "the issue of diversity."

Using the Banks Approaches to Multicultural Curriculum Reform to Analyze Current Practice

Banks (2001) also outlines four levels of approach to multicultural curriculum reform (see Figure 1). These approaches are useful in reflecting on current practices in science education and reconceptualizing the curriculum.

Level 1: The Contributions Approach

The contributions approach to multicultural integration simply points to such things as cultural heroes, holidays and foods. In science education, students might read stories about or write reports on scientists from other cultures. Learning experiences might incorporate examples of scientific phenomena in the context of nondominant cultures or explanations.

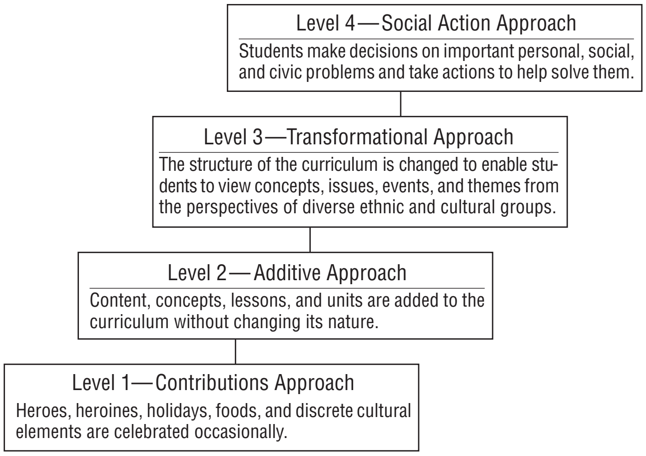
Level 2: The Additive Approach

The additive approach expands the focus on multicultural connections by adding on full units dealing specifically with content, concepts, themes and perspectives related to a particular cultural group. This approach does not significantly change curriculum content and methods of teaching but, rather, adds to the curriculum. While a Level 1 approach might involve reading about an individual's contributions to science, in Level 2 a block of time might be devoted to studying individuals representing the same cultural perspective (for example, the contributions of Hispanic, Aboriginal or black scientists). The additive approach adds to or extends ethnic content, while approaches to curriculum content remain the same.

Level 3: The Transformational Approach

The transformational approach involves altering the structure of the curriculum to allow students to see concepts, issues, events and themes from a variety of ethnic and cultural perspectives. How is this approach different from the contributions and additive approaches to multicultural education? This approach creates ethnic and diverse cultural content anew. Teachers and students may even be involved in activities that require curriculum redevelopment or redesign. For example, students might be involved in understanding how cultural experiences are lived by the ethnic or cultural groups they might access first-hand. Curriculum strategies, materials and forms of engagement are transformed. Old materials may be thrown out, and the multiple and diverse perspectives of a variety of ethnic groups may become the content for study. One approach is to draw on the ideas, understandings and cultural connections to science learning of the variety of cultures that exist within a school or school district.

Figure 1.
Banks's Approaches to Multicultural Curriculum Reform



Level 4—Social Action Approach
Students make decisions on important personal, social, and civic problems and take actions to help solve them.

Level 3—Transformational Approach
The structure of the curriculum is changed to enable students to view concepts, issues, events, and themes from the perspectives of diverse ethnic and cultural groups.

Level 2—Additive Approach
Content, concepts, lessons, and units are added to the curriculum without changing its nature.

Level 1—Contributions Approach
Heroes, heroines, holidays, foods, and discrete cultural elements are celebrated occasionally.

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Level 4: The Social Action Approach

The social action approach involves students in identifying important social problems and issues, gathering data to inform reflection on and discussion about those issues, and taking action supported by the information and evidence gathered. An example of an action study in science education is the gathering of information on pine beetle infestation in the forests of western Canada to understand the issues and controversy that can arise when making decisions that include multiple perspectives from a variety of interest groups. Learners will understand what has been done to address the issue, the possibilities for dealing with the problem and what actions some say should not be done. In gathering information, students will become sensitive to issues in which there may be multiple perspectives and trends in thinking about those issues from wider ethnic and cultural groups. This approach allows students to see the social impacts and issues relating to the application of science knowledge informed through their own personal experience in gathering information and hearing about those views first-hand.

We have provided here (1) a consideration of some of the research in the field of multicultural science education to help develop a basic understanding of the issues, (2) descriptions of inspiring efforts from educators and teacher educators whose writing about their work suggests new approaches to practice, and (3) features of Banks's frameworks for analysis. It is our hope that these resources will be useful tools to help educators become serious students of multicultural approaches in science curriculum reform and will serve to build strength in the reflection on and critique of practice to build new approaches in science teaching and learning.

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The Science of Space: Creating a Classroom Culture for Science Learning

Jessica Zimmer

Abstract

Author Jessica Zimmer's own memories of elementary classrooms are as places of colour, with bright posters on walls framed with patterned borders. As a new teacher, she is questioning the impact of commercialized images and materials and of the physical arrangement of the classroom on science learning. In this article, she examines her developing philosophy of how the classroom environment affects science learning in the elementary setting. She explores how learners' understandings and perspectives in science education are shaped by personal experiences, and how the physical arrangement of space shapes relationships and learning within the space. Finally, she suggests avenues that others might pursue to develop a culture of science learning within the classroom.

Schools are settings that convey the cultural norms and values of society. It is within the walls of educational settings that children learn, through exploring the curriculum, what society deems to be of value and importance. The physical arrangement of the classroom communicates what is expected from students, relationship norms and pedagogical principles (Tarr 2004). As a result, the physical construction of the classroom has a strong impact on how teaching and learning take place.

A web of interdependence exists between the members of a classroom community; the actions and interactions of individual members affect the entire community. The interdependence of the teacher, the students and individual experiences is also affected by the curriculum and the environment where learning occurs (Raider-Roth 2005, 163–66). We are all part of our surroundings, and as a result, learning experiences are shaped by the physical arrangement of the classroom. A classroom is not merely a place where learning takes place; rather, it is woven tightly into the fabric of teaching and learning. With careful consideration, it is possible to construct a classroom environment that reflects a culture of science learners.

Science in Elementary School Classrooms

Elementary school science can be surrounded by an atmosphere of apprehension and anxiety for both students and teachers. Studies have found that elementary science is often taught sporadically or, in extreme cases, omitted entirely because of the teacher's discomfort with the subject matter. Teacher self-efficacy has an impact on how science learning occurs in the classroom. A study conducted on teacher self-efficacy in science (Finson, Riggs and Jesunathadas 1999) found that teachers with high self-efficacy were more willing to implement inquiry-based, student-centred activities. These teachers were also more willing to implement collaborative learning opportunities and to move outside of the classroom for science learning experiences. On the other hand, teachers with low self-efficacy tended to initiate science learning from a teacher-centred, direct-instruction approach. Therefore, teachers' positive self-concept and familiarity with science concepts affect how they approach science learning in the classroom.

Personal pedagogy about the nature of science also plays a role in elementary science learning. On one hand, science can be perceived as a series of facts, with the objective of conforming to the scientific method. On the other hand, science can be viewed as a continuing process of discovery experienced by teachers and students together (Victor and Kellough 2000, 23).

Science values and beliefs are based on teachers' self-efficacy and personal pedagogical principles about the nature of science. These values and beliefs influence teaching strategies, the time allotted to science and the nature of the classroom environment.

Science in Alberta

The curriculum is a central actor to consider when examining the role of the classroom environment in science learning. The philosophy of Alberta's science curriculum is based on the principles of inquiry-based, child-centred, collaborative learning. These principles are dependent on creating a challenging environment and encouraging active student involvement (Alberta Education 1996, A.2). Science education extends beyond subject matter and the scientific method; it depends on complex notions of who children are as learners and how they negotiate the subject matter.

Teachers' perceptions about science shape how they interpret the curriculum. Additionally, external issues have an impact on science teaching and learning in the elementary classroom. Alberta Education's (2006) *Elementary Science: Program and Resource Review* indicates that Alberta teachers support the principles of the program of study; however, it identifies key issues that affect how science is approached in the elementary classroom, including the appropriateness of and access to resources. For example, many of the resources employed in teaching science are single-topic books that support a portion of the subject matter. Teachers argue that there is a lack of access to hands-on learning materials and that crafting inquiry-based lessons consumes too much time (Alberta Education 2006, 2–3). Incorporating authentic inquiry-based learning requires multiple forms of engagement and resources with a wide scope of information, as opposed to isolated materials that present concepts in a fragmented way. How can a teacher with limited access to appropriate science resources create a classroom environment that communicates a culture of science learners?

Semiotics

Semiotics is the study of how signs and symbols communicate direct and indirect messages about the values and beliefs of a culture. In the context of the elementary classroom, semiotics considers how these messages are communicated and their impact on the teacher–student relationship and on the individual learner. There are multiple forms of communication in the elementary classroom, including spoken and body language, audio and visual, and subject matter and architecture (Shapiro 1998, 609–11). Children negotiate multiple messages and meanings in their daily reality. Semiotics deconstructs the ideas and images transmitted through physical space and the exchanges that occur within the space (Shapiro and Kirby 1998, 227). The classroom environment is not merely a setting where students learn but, rather, a venue that influences what and how students learn.

The Commodification of Education

Aesthetic codes are the ways in which the classroom reflects the culture's image of the child, values and educational goals (Tarr 2001, 33). There are enduring themes in elementary classrooms that shape the reality of the school experience. Images that convey these codes include scalloped boards, brightly coloured paper covering bulletin boards, alphabets, numbers, calendars, thematic mobiles, and posters with cartoon-like people and animals (Tarr 2004). These images cover the walls, hang from the ceilings, crowd the doorways, creep onto students' desks, and line the windows and blackboards. They are part of the daily experience of many elementary school students and contribute to the classroom culture.

Such images are often taken for granted as part of the elementary school educational experience. They are said to create a warm and caring environment or to provide decoration. Elementary teachers who fail to conform to this aesthetic standard have been pressured to do so by colleagues and parents (Tarr 2004). Analyzing these images from a semiotic perspective challenges tradition and habit and questions the messages these images convey about teaching and learning in the classroom (Shapiro and Kirby 1998, 225).

Commercially produced images and resources, with their tacit messages for learners, are becoming more prevalent. These materials underestimate the intellectual capacity of children. They construct the learner as a receiver of information and knowledge, rather than as an agent who constructs meaning and understanding. The messages conveyed through these products are indicative of the learning that occurs in the classroom. These materials convey the message that learning should be artificially fun and amusing rather than complex and engaging, and suggest that items external to the teacher, the children and the curriculum are required in order to captivate students' attention (Tarr 2001, 2004). They suggest that children are not capable of engaging in their learning but, rather, need to be guided or coerced into a relationship with the subject matter through artificial materials. The individual student is perceived as the receiver of information rather than a co-constructor of meaning.

In addition to underestimating the capabilities of children, the commercialized products placed in elementary classrooms reduce learning opportunities. The cartoon-like images convey stereotypical assumptions of how children experience the world around them (Tarr 2004).

Such stereotypical assumptions are present in the calendars displayed in many elementary school classrooms. These calendars depict the four seasons: the autumn months are decorated with fall colours and blowing leaves, the winter months are framed with snowflakes and snowmen, and the spring months portray rain and budding flowers. The seasons are portrayed as simple, distinct phenomena, while the reality is that not everybody experiences the four seasons, nor do the seasons always conform to rigid guidelines. In Calgary, for example, the climate is complex: a chinook (a warm, dry wind) can roll in during winter and a snowstorm can occur in the spring.

Therefore, adorning classroom walls with commercially produced images and implementing those images as learning tools does not encourage student-centred, active engagement with the science curriculum, because such images fail to account for the complexities of daily human experience.

Accessibility to Science Learning Materials

The materials in the classroom should be rich enough to engage children in learning activities; therefore, materials should be evaluated based on whether they encourage active participation or passive reception. It is equally important to consider if and how the materials in the classroom invite children to engage in their learning. For example, who has access to the materials? Access can be viewed in terms of the classroom community as a whole or individuals within the community.

There are a number of ways in which children are granted or denied access to science materials in the classroom. Often students are denied access to science learning through its approach. Traditionally, science has been approached as a discipline in which teachers hold the knowledge and the answers, ignoring the current understandings of students. This perspective is embodied in a teacher who conducts a science experiment while students observe. This sort of arrangement denies students access to learning on a couple of levels. To centre the activity on the teacher suggests that the teacher holds the knowledge and that the only way to learn science is to conform to the teacher's methods. Also, the activity physically situates students on the periphery of the learning. They can only observe the lesson and receive information rather than actively engage in their learning.

Access is also denied or granted through the materials themselves. The quality of all science materials, whether commercial or not, should be analyzed before they are incorporated into the classroom. For example, resources should represent the diversity in the classroom; issues such as gender, ethnicity, ability and socioeconomic status intersect the learning environment. Materials must reflect the reality of the Canadian identity in order to invite all learners to engage in science learning (Shapiro and Kirby 1998, 232–33). When diversity is not represented, the realities of many students go unacknowledged. Materials that depict science as a discipline for white, middle-class men deny access to many students by reinforcing stereotypical cultural norms and assumptions.

Children should be allowed to work with real scientific materials (Shapiro and Kirby 1998, 232). Making science materials readily available to students invites them to engage in scientific inquiry. Classrooms where materials are kept out of sight or on out-of-reach shelves do not invite student investigation (Tarr 2004).

Creating a science corner is one method of inviting students to access learning in the classroom community. Designating a specific space for science materials and resources incorporates science into the daily life of the classroom. However, simply placing science materials in a designated area does not fully promote a climate of science learning. A strong science corner will include resources appropriate for the learning that is to occur, such as relevant literature, measurement objects and science tools. The science corner should not be a place for merely displaying work but, rather, should provide an interactive experience for students to work and think about the unit of study. Students should be involved in the creation and maintenance of the science corner, and it should be in a constant state of transition. As students negotiate their learning, the space should reflect their thinking processes and understandings (Koch 2002, 118–20). Therefore, providing students with continuous access to science materials and the agency to use those materials to pursue their learning grants them access to science learning in the classroom.

Reggio Emilia

The Reggio Emilia educational philosophy can be incorporated into the classroom in a practical way to create a complex learning environment. The crux of the philosophy is that teaching, learning and space are not isolated elements in the classroom but, rather, are interwoven and interdependent in the culture of the classroom.

Documentation is an aspect of the Reggio Emilia approach that can alleviate the desire or pressure to blanket walls and ceilings with commercially produced images. Observing and recording student work allows for sharing, reflection and interpretation; provides insight into students' thinking; and, as a result, enables teachers to plan future learning endeavours. The principle of documentation suggests that students' engagement and experience with their learning should be documented and displayed in multiple ways to create a record of their learning. Documentation can be used as an assessment tool, as it represents a child's thinking and learning processes. It can take various forms (photographs, transcriptions of discussions, audiovisual and so on), it promotes discussion and further inquiry, and it involves parents and the school community (Shireen Desousz 1999). Therefore, documentation helps to create a community of science learners because it demonstrates the value of student thinking and learning. Displaying students' work shows respect for their efforts and invites others into the learning process by making learning and knowledge public.

Conclusion

To create a classroom culture of science learning, it is imperative that we understand and deconstruct the role of the classroom environment in teaching and learning. Commercialized images have an enduring presence in elementary education, and discretion must be employed when incorporating them into the classroom. The purpose and impact of such materials should be closely considered. I believe that materials and the physical arrangement of space need to be carefully analyzed to ensure that learning activities encourage active engagement in science learning.

Issues such as a teacher's lack of self-efficacy, a lack of appropriate resources and a lack of time affect how science learning transpires in the classroom. However, a teacher's values and beliefs about the discipline of science may have a far greater impact on how the subject is approached within the classroom walls. To create a culture of science learning, teachers must value the importance of science and place the student at the centre of the learning process. In my own practice, I strive to actively weave science into the daily fabric of the classroom experience through the physical environment, the teaching strategies I employ and the resources I make available to students.

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Tell Me What You Know: Learning to Write in Science

Matt Zinken

Abstract

Children often have difficulty expressing in writing their understanding of scientific concepts, even if they can successfully communicate ideas in other subject areas. This article considers common areas of difficulty among students. It is written using Amy Jent's ideas about organizing an inquiry as an I-Search paper (an approach developed by Ken Macrorie). The author informally interviewed children and talked with teachers to engage with the question, What makes writing in science more difficult than writing in other subjects? His explorations are also framed within the context of research literature in the field and, through this reflection and reading, he has attempted to focus on new practices to help build literacy skills into science learning and teaching.

Inspiration

During my first year of student teaching, a young boy named David asked me why he had to write the prediction and conclusion for his science experiment in complete sentences. I knew that it was difficult for many of the Grade 2 students to remember to write in full sentences, and I often reminded them to use sentences to describe their ideas in science. I believed that this was important practice, and I knew that they were capable of writing the three sentences required. Yet David had the courage to ask *why* complete sentences were necessary when he could more easily explain his thoughts using a couple of sentence fragments. Looking at his worksheet with him, I asked David, "Why do you *think* I want you to write in complete sentences?" His response was not at all what I expected: "Is it because I hit you with the ball in dodge ball?" His answer, and my observations of many other children's resistance to writing, made me want to research the topic and to build into my own practice more insight into children's ideas about writing in science.

David had no idea why a teacher would ask students to write in full sentences. I realized that in science no link had been made between writing and communicating one's ideas. That type of thinking seemed reserved for English language arts. My students thought that science was simply about following the steps of an experiment, drawing a picture and then moving on to the next experiment. Continuity between topics did not exist.

I believe that science writing should be made explicitly relevant as a skill associated with skills in math, language arts and social studies. David's question made me want to learn more about how to do so.

Writing in Elementary Science

In many elementary classrooms, science is taught as a discipline that requires a specific set of skills that are often not explicitly made relevant to other fields of study. Many teachers easily integrate art activities into science and language arts, but there is often little planning for the development of a language arts program explicitly tied to science.

In fact, the culture of science requires one to have a specially developed set of literacy skills in order to be considered scientifically literate. To explain even the most basic scientific concepts, one must use a wide variety of communicative tools, or languages. Science learning requires that students communicate using all of the literacy tools normally developed in the language arts classroom. Listening, speaking, viewing, thinking, reading and writing are as much a part of the science learning experience as they are of language arts. But in addition to these literacy skills, students of science are expected to learn and communicate using skills associated with the language of mathematics, with specific scientific vocabulary and with contextual language. While the person who explains a scientific idea must understand these language forms and how they work together to describe a scientific phenomenon, the person who receives the message must also be able to link language forms together to develop a coherent representation of his or her understanding.

It is no wonder that children have difficulty understanding how to verbally describe their sensory perceptions using these many language forms. If it is difficult for students to verbalize their understanding of a scientific concept, what can we expect when we tell them to put their understanding in writing?

Documenting Inquiry Using I-Search

I wanted to document some of my thinking to share with fellow teachers. Early in my research and thinking about this topic, I found an article written by Amy Jent (2004) that detailed her experience writing an I-Search paper. The I-Search approach was developed by Ken Macrorie (1988), an English professor. Jent's ideas about organizing to investigate using I-Search have been very helpful. She describes the I-Search paper as an opportunity to "scratch a genuine itch until you've quieted it" (p 33).

What sets the I-Search process apart from a traditional research paper is that the audience changes as the narrative unfolds. Initially, during the research phase of the process, you (the researcher) are the audience. By developing and researching the topic with your own interests in mind, you can better make personal decisions about the direction in which the research is taking you based on your developing understanding of the issue and the topic. When you begin an I-Search paper, you are the only audience. Once the actual writing of the paper begins, the audience shifts from you (the researcher) to a more general audience, such as the general public, a class or an instructor. The resulting paper describes your developing understanding of the topic through your research.

I have found that this type of thinking is well suited to my effort to share what I am learning with colleagues. It allows me, as a teacher-researcher, to develop new ideas about the topic in a way that documents the ongoing nature and understanding of the topic throughout the research process. Jent (2004, 33) compares the I-Search process to writing a travelogue about a trip. What results is a research paper that documents the development of the inquirer's understanding of the topic over time. It is helpful to show how scientists communicate their findings to colleagues and the rest of the world through writing. This communication between scientists involves the same process as writing "in the sense that it involves thinking, feeling, talking, reading—and writing" (Turbill 1983, 9).

A Beginning: Conversations with Children About Writing in Science

To address the challenges associated with scientific writing and to develop a method for integrating a writing program into my science curriculum, I began to speak with teachers and students, and to consider how scientists view the importance of writing in science. I wanted to find out why so many students find it difficult to explain scientific concepts in writing. Over an extended period, I spoke informally to almost 50 students in Grades 3–6 from several different schools. I expected to find that writing was simply not emphasized in their science classes and that adding elements of the writing process to the scientific process would help children develop a deeper understanding of science.

All of the students were quite willing to share their knowledge of science and their ideas about writing, and to show me the work they had done in their science classes. The interviews quickly took on a conversational tone that was often directed by the students. I found that the children's responses were quite similar.

The first question I asked each group of children was, "Why is science important?" Responses ranged from skill-related learning (such as measuring things or building models) to learning about the history of science. Almost all of the children came to the conclusion that science helps to explain things we encounter in the world. Interestingly, most of the students who enjoyed science were intrigued by the fact that science helps to develop products we will use in the future. All of the students agreed that science is a very important topic of study.

During every conversation, I asked the students to show me their best work, the work they were most proud of. Most of the products the kids showed me were observational pictures or notes, along with posters, lab reports and a book made through the collaborative efforts of an entire class. The work I saw contained little writing. A few lab reports showed some detail, but the focus tended to be on the pictorial representation of the students' knowledge.

After taking a look at the students' work, I asked them to tell me if they thought that writing is important in science. Everyone responded that writing is very important in science. Most of the students told me that writing helps you explain what you have learned to other people. They also commented that writing is important for students when making observations and notes so they can remember new concepts.

Until this point I had thought that children placed little value on writing in science. My initial belief was that students tended to focus on the hands-on aspects presented in the science classroom rather than on communicating their ideas. The students I spoke with all understood that writing is an important science skill, but most of them admitted to avoiding writing in science, instead opting to draw pictures of their observations whenever possible.

When I asked students what they found difficult about writing in science, they usually said that writing hurts their hand or that it is too slow and boring. Assuming that by *boring* they meant *difficult,* I asked the students what in particular makes writing in science boring? Most of them said that it is hard to explain things in science. Some explained that what they know about a new scientific concept requires them to use words they may have learned only that day. Reflecting on this, I can see that it takes time for students to learn a new word, understand its meaning and then apply the word in their own written work. One child put it very well when he said that it is harder to know a word than it is to know a picture.

I asked many of the children, "What would make writing in science easier?" Most of the responses were suggestions for how to present new vocabulary in a functional way so that students would have plenty of opportunities to work with new words. They shared several great ideas about how to introduce new science words. Many of the students said that they would like to spend more time learning the words they would need to describe things in science. It is difficult to use new words in context while writing, so providing students with more opportunities to use new words would give them the practice they need.

Giving Students Writing Opportunities

When faced with new vocabulary, students need time to work with the words before putting them to use. Implementing the writing process in science can get students involved in constructing drafts of their work. In this way, they can experiment with using new words until they can find a context that fits their understanding. When the time comes for students to use a new word in the final draft of their work, they should have already had opportunities to hear the word used several times and to apply the word during an inquiry or experiment. Kydd, Jones and MacAlister (1989, 4) show how this process works by explaining that "what you have observed, you can think about, what you think about, you can talk about, what you can talk about can be written and read about." Using new words in a variety of contexts will provide students with several chances to add these words to their vocabulary in speech, writing and understanding.

By using a writing process in conjunction with the process of engaging in inquiry in science, teachers can give students a framework that allows them to think about what they have learned before they are required to respond. Through engaging with a specific writing process in this way, students may be able to write a number of drafts using their new vocabulary. It is not necessary to have students simply edit misconceptions out of their drafts until they have their "final draft" or "good copy." A student's initial draft may be a journal sketch that shows various instruments for measuring wind. The second draft could be a simple write-up of an experiment in which the student used each instrument. If students are demonstrating their learning well, there may be no need for a transactional (formal) write-up. The final draft may be a photo journal showing how the instruments can be used and how they have informed the student's learning.

Writing in science requires a set of skills that draw from observations and personal experience, theories, analytical thought and the ability to integrate new language into a description of one's own understanding. Students need time to work through new discoveries, and even more time to communicate what they have found. Teachers must realize that the end of the experiment doesn't mean the end of the learning experience. Students should be encouraged to demonstrate the things they have discovered in a way that allows them to properly develop and fully display their understanding.

By examining the language of science in the context of an elementary learning environment, teachers can easily integrate science with their literacy programs to foster a deep scientific and literary understanding in their students. Certainly, "the ability to read and write the language of science is central to scientific literacy" (Fang 2006, 491). This specialized form of literacy is not contained to the realm of a single field of study. Casteel and Isom (1994, 541) see a student's developing understanding of science and literacy as a reciprocal process: the successful communication of scientific findings will inevitably lead to new, engaging questions for the student. Doris (1991, 10) supports this view: "When we do science we search for answers, but we seldom stop in any particular place for long. Ideas are formed, reviewed, and revisited. Interpretations vary. Questions sometimes lead to answers, and invariably lead to other questions." As students develop their skills while working through the scientific process, it is important to draw their attention to the similarities between the scientific process and the writing process.

Starting with What Students Know About Reading and Writing

Casteel and Isom (1994, 538) suggest that "one way to ensure improved science learning is to begin with what students know about the reading and writing processes." This statement sets up an incredibly useful constructivist scaffold that can be used to develop and integrate any science writing program.

Students often need assistance in making a meaningful connection between the steps they use to solve problems in science and the steps they use in writing. Teachers can present the two frameworks for solving problems and communicating understanding through a simple comparison. In science, one follows a simple procedure to define the problem, make a prediction, develop a procedure and determine the materials needed to carry out the procedure, make observations and communicate findings (which often lead to new questions). The writing process answers the question, How can I best convey what I know? In the context of the field of science, the writing process should be used to organize the data collected, interpret results, think about the findings in light of the question being asked and communicate any new understandings about the topic. There is, of course, always room for new questions. All of these steps draw from the writing process; however, students who successfully follow the writing process in language arts often have a difficult time communicating their scientific understandings in a coherent manner.

According to Kydd, Jones and MacAlister (1989, 3), many "teachers think of science notes in terms of lab write-ups, diagrams and graphs, and specialized vocabulary." This type of writing represents only one among several stylistic options for communicating scientific concepts. James Britton's (1975) sliding scale, which categorizes the writing done in schools, is useful in designing learning experiences. At one end of the spectrum is formal, or transactional, writing, which includes lab reports, research papers and other formal reports. Expressive writing allows for a more informal or personal style and includes journals, diaries and friendly letters. (This article may be considered an example of expressive writing.) The third category of writing is poetic writing, in which a formalized style is used along with the most expressive writing styles. Poems, stories and plays would fall into this category (Kydd, Jones and MacAlister 1989). In science, all of these types of writing have a place as children discover, develop and communicate their understanding of science concepts.

Britton has suggested that "because expressive writing most closely resembles how we think and talk about experiences . . . perhaps it might be the most useful form of writing for learning purposes, especially when grappling with new concepts" (Kydd, Jones and MacAlister 1989, 5). This experience with concepts allows children to come up with their own explanations for how things work, which can be translated into scientific language as the student becomes comfortable with new concepts and new vocabulary. Using a wide variety of writing strategies gives children experience in working with new concepts in meaningful ways. When children experience concepts in several different ways, they are able to make connections that allow them to develop metacognitive skills useful in a wide variety of learning situations (Casteel and Isom 1994, 544). By simply offering a variety of written assignments, teachers can allow children to express their understanding of concepts as it develops.

When using a variety of writing formats, it is important to maintain the validity of transactional writing assignments. In lab reports, research cannot be discarded entirely in favour of more expressive forms. Kydd, Jones and MacAlister (1989, 28) point out that

> One of the goals of teaching the process skill of communicating in science is the increasing confidence and facility of students with the transactional type of writing characteristic of our subject area. In other words, all students should eventually be able to write a lab report, a research study paper, or keep accurate observations using correct scientific terms.

Students need to learn how to express their ideas in a variety of ways that lead to their understanding of a topic. Transactional writing is intended to present concepts and ideas in a form that is relevant and standard in the field of science. While it is initially difficult for children to express their ideas through this form, the skills they will develop through thinking and writing in a variety of forms will give them the tools to begin communicating their ideas in a formal context.

The Importance of Time in the Development of Communication Skills

The greatest factor in developing any set of communication skills is time. Students need time to develop their understanding of a concept before being asked to communicate what they have learned. Using expressive or poetic forms of writing to show their previous conceptions of a concept allows students to address their feelings, thoughts and beliefs. Providing options for depicting these ideas in the form of sketch journals, poetry assignments, photographic journals and creative writing allows students to develop an understanding of the topic while experimenting with new words in several written forms. This practice with new vocabulary will help to improve student writing in science as students' confidence with the vocabulary improves and as they work toward the transactional forms.

Helping Students Move Toward the Development of a Conclusion

To show students how the frameworks of thinking go together, I suggest working with a simple set of writing steps that can be used to develop a conclusion. This type of explicit teaching will work well in an elementary classroom if it is introduced after the students have collected data from their observations but before they are able to write their concluding statements.

Step 1: Pre-Writing

- Gather and interpret the information collected in the observations.
- Organize your findings.

Step 2: Writing

- The written part should answer the following questions: What did you find out? Was your prediction right? Why do you think your prediction was right (or wrong)?

Step 3: Post-Writing

- Read your conclusion out loud. Does it make sense?
- Did you answer your question?
- Is there anything you may be able to add to your explanation?

This simple exercise helps students think about what they have found and express their understanding in a clear way. By following the steps of the writing process at the end of the experiment, students can work through their answer several times, reinforcing the concepts they have learned. Once students have written down their understandings, a simple editing process can often reveal overlooked data that may have otherwise led to misconceptions.

If teachers want to adapt this process to work within their science experiments, it is important to remember that "adequate time is essential to have kids write well" (Turbill 1983, 11). It is impossible to expect students to conduct an experiment, interpret their data and construct an answer all in one half-hour science class. Experimental observations cannot be viewed as the conclusion of a topic. Discussion of the findings developed through the course of an experiment leads to a deeper understanding of a scientific concept than simply tacking an answer to the bottom of a page.

Conclusion

I have found it important to use several tools to encourage students in science writing. Science requires critical thinking, and students must draw information from a variety of sources, organize their thoughts and understanding, and develop their ideas. An I-Search paper is one form of written work that allows students to show their understanding of a topic as it develops. Children's success in communicating their understanding depends on their ability to bring together the six literacy skills: listening, speaking, viewing, thinking, reading and writing.

Science learning requires these literacy skills, in addition to the practical skills built through physical experiments. Casteel and Isom (1994, 540) quote Postman's (1979) eloquent definition of the sciences, stressing the importance of literacy in the field: "Biology is not plants and animals. It is language about plants and animals. . . . Astronomy is not planets and stars. It is a way of talking about planets and stars."

It is my hope that my search to gain insight into students' views on science writing will help teachers see literacy skills in science in new ways. Writing in science is a way to show what we know. I hope that this investigation helps students and teachers see writing in science as a powerful way of learning and as a way of engaging with the world through the enjoyment of writing.

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