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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.

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From the Editor

Wytze Brouwer

In this special peer-reviewed issue of the *Alberta Science Education Journal,* we once again highlight the work of the Centre for Research in Youth, Science Teaching and Learning (CRYSTAL-Alberta). CRYSTAL-Alberta, which is funded by the Natural Sciences and Engineering Research Council of Canada (NSERC), aims to promote science and engineering in schools and in the broader community. The research projects described in this issue were carried out under the leadership of research director and principal investigator Stephen Norris, of the Faculty of Education, University of Alberta. (For more CRYSTAL-Alberta research reports, see Volume 40, Number 1, September 2009.)

In "From Indigenous Science Examples to Indigenous Science Perspectives," Frank Elliott points the way for Alberta science teachers to respectfully and inclusively incorporate Aboriginal perspectives into their ongoing science teaching practice.

Nathan Stelnicki, John Braga, Gerda de Vries and Stephen Norris, in "Using Adapted Primary Literature to Teach High School Science," show how primary scientific papers can be adapted for use in high school science classes and how they can enhance students' critical thinking.

Hagop Yacoubian, Sun Joo Hur, Yu Lei, Carolyn Freed, Linda Phillips and Stephen Norris, in "Teaching Scientific Inquiry Using Science Trade Books," review a number of trade books in order to evaluate their capacity to change student attitudes toward science learning and to develop students' inquiry skills.

In "Visualization in Science Education," Karen Vavra, Vera Janjic-Watrich, Karen Loerke, Linda Phillips, Stephen Norris and John Macnab review the research on visualization in science education and present recommendations on the use and effectiveness of various forms of animation and visualization in the science classroom.

Yu Lei, Hagop Yacoubian, Sun Joo Hur, Carolyn Freed, Stephen Norris and Linda Phillips, in "Fostering Scientific Vocabulary Learning: A Close Look at Science Trade Books in K–6 Classrooms," investigate how the use of trade books in the science classroom influences the learning of scientific vocabulary. The authors conclude that the development of scientific vocabulary has not been sufficiently emphasized in most trade books but that teachers can supplement the use of trade books to develop proper vocabulary and learning skills.

Elizabeth Vergis, in "Concepts of Evidence in High School Chemistry Textbooks," examines the three chemistry textbooks most widely used in Canada for their emphasis on concepts of evidence in establishing hypotheses and conclusions. The author found great variation in the treatment of concepts of evidence across the textbooks.

From Indigenous Science Examples to Indigenous Science Perspectives

Frank Elliott

Recent developments in science education have identified scientific knowledge within a larger context. Some refer to this context as *multicultural.* An Internet search for recent multicultural science research brings up over 1,000 results, yet little of this research seems to have found its way into teacher practice in the science classroom. Even for teachers who are familiar with Glen Aikenhead's (2006) humanistic approach (discussed below), this "conceptual understanding does not necessarily influence classroom practice" (p 67).

In addition to overloaded classrooms and curriculum issues, one reason for teachers' hesitation is that the topic of multicultural science education is too broad, unreferenced, undefined and too theoretical. In the hope of alleviating the summary dismissal of the topic of multiculturalism by experienced science educators, this article focuses on the inclusion of First Nations, Métis and Inuit (FNMI) scientific perspectives.

FNMI Perspectives in Alberta's Science Curriculum

Aikenhead's (2006) book *Science Education for Everyday Life* provides a solid starting point for addressing the question of why FNMI perspectives are now included in Alberta's science curriculum.[1] One of Aikenhead's key concepts—that teaching science is a cultural activity and that the belief structures of the science teacher affect the knowledge transmitted in the classroom (p 108)—should provoke a response in science teachers who are unfamiliar with or resistant to this idea. Aikenhead proposes a humanistic perspective in school science that includes a "multiscience approach reflecting international perspectives (including indigenous science)" rather than a "mono-science approach founded on universalism (Western science)" (p 3).

In adopting a humanistic perspective, science teachers acknowledge the cultural bias found in Western scientific teaching practice. Western science is one way of knowing the world, but other ways can be taught in the classroom under the general category of theories of knowledge. The unquestioned promotion of Eurocentric concepts in science education (such as universalism, the fragmentation of natural events into decreasingly smaller conceptual parts and the increasing acquisition of detailed factual knowledge) as representative of "knowing science" has come under closer scrutiny. In Alberta, FNMI ways of knowing have emerged in response to this inquiry.

Could a knowledge system describing and explaining natural events based on experimental evidence have existed in what is now Alberta before the presence of Europeans? There is evidence that what we call scientific knowledge did exist in the Americas before colonization as part of a sophisticated Indigenous knowledge system (Peat 2002; Aikenhead 2006; Dickason 1992). In fact, Indigenous scientific knowledge predates the Western term *science.*[2]

The fact that other knowledge systems are now receiving prominent attention in science education leads to another question: "Whose culture is being transmitted in school science?" (Aikenhead 2006, 108).[3] There are many recent studies on why multicultural initiatives (such as Alberta Education's infusion of Indigenous science into the science curriculum) are now being addressed (Aikenhead 2006), and they describe the Eurocentric attempt to eradicate Indigenous knowledge through such educational institutions as residential schools. I will not examine the long, dark shadow of Alberta's educational history here, except to point out that many Aboriginal people remember the genocidal effects of those institutionally imposed and culturally defined educational policies, which were meant to assimilate Aboriginal ways of knowing the world into "Western civilization." This history still casts a shadow on people in affected communities and on some of the students in our science classrooms.

To help heal the effects of this cultural educational bias, science teachers need to begin to acknowledge and address other ways of knowing the natural world, as an avenue to meaningfully understanding natural events holistically, in contrast to the Western cultural practices now affecting global warming, biodiversity, overpopulation and potential pandemics (such as swine flu, avian flu, SARS and Ebola). David Suzuki, speaking of the Haida, puts it succinctly: "Their sensitivity to human interconnection with all life on their homeland, I believe, can give us an alternative to Western culture's narcissistic self-preoccupation coupled with an ecologically destructive worldview" (Knudtson and Suzuki 1992, xxv).

In response to this emerging epistemological support for other ways of knowing,[4] Alberta Education has mandated the inclusion of FNMI perspectives in Science 10, 20 and 30; Biology 20 and 30; Chemistry 20 and 30; and Physics 20 and 30. Many University of Alberta secondary education students in their final student teaching practicum react to this inclusion by saying "I don't know this material." Two pragmatic questions have emerged from further discussions with student teachers: "Where are the resources?" and "How can I teach this material respectfully?" These questions indicate beginning science teachers' desire for classroom approaches to FNMI perspectives that are informative, respectful and inclusive.

Resourceful teachers are now developing their own curricular materials, often in isolation. The University of Alberta's Centre for Mathematics, Science and Technology Education (CMASTE) is involved in a research initiative through the Centre for Research in Youth, Science Teaching and Learning (CRYSTAL-Alberta) that intends to locate and provide access to resources, websites and people under the general heading Aboriginal Science Resources. CMASTE will then evaluate the use of these resources in science classrooms. This beginning step will provide science teachers with more access to FNMI resources.

Teaching this material respectfully begins, I believe, with an understanding of FNMI concepts (or Indigenous knowledge). Blue Quills First Nations College, in St Paul, Alberta, differentiates between white academic thought (*moniyaw mamtonecihkan*) and Indigenous thought (*Nehiyaw mamtonecihkan*) and is structuring many of its courses, including science, around an Aboriginal perspective. Living within these two world views is often a difficult daily experience for Aboriginal students.

Before science teachers examine other ways of knowing (or, to use the Western term, multicultural perspectives), it might be helpful to identify which elements of our Western scientific perspective either add clarity to or cloud the understanding of other perspectives. In her book *Science as Salvation,* English science philosopher Mary Midgley (1992) identifies the four philosophical pillars on which today's Western scientific enterprise rests:

- There exists an external reality, separate from the observer.
- The senses are accurate informants.
- Memory is reliable and accurate.
- Logic provides a valid construct of natural events or reality.[5]

Midgley points out the difficulty of these basic constructs: none of them can be proved using the Western scientific model of reproducible proof obtained from experimental evidence. We can argue over Midgley's definition of terms, such as *reality;* however, such arguments often end in a solidification of our existing personal belief structure. Debating these issues may expose the presence of scientism, which is the belief that only science (particularly Western science) can describe or explain natural events. For some science teachers, this belief prevents an open-minded approach to Indigenous science, and the teacher's beliefs are thus often passed on to students through classroom instruction.

Aikenhead (2006) argues that adherence to scientism is one element that clouds understanding and prevents the introduction or acceptance of multifaceted theories of scientific knowledge, specifically Indigenous knowledge, in the science classroom. Even though Midgley's (1992) four principles of Western science cannot be scientifically proved, they do exist. Indigenous science also exists and, as Aikenhead points out, for similar reasons has been culturally demoted:

> Now, as then, indigenous knowledge, and subsequently indigenous science, is seen by most members of the public as something quaint and interesting, but certainly not something that is going to help you get ahead in this world, make money or build a respectable career in a contemporary labour market. (p 122)

The Voices of Teachers

The table "Pre-Service and Serving Teachers' Themes" in the report *Learning Indigenous Science from Place* (Michell et al 2008, 120) lists areas of concern that emerged from interviews with preservice and practising teachers. Two of these areas also repeatedly came up in our own discussions with student teachers: a lack of resources and materials, and a lack of experiential strategies for teaching FNMI concepts:

> Resources and materials emerged as a critical need expressed by educators for use in guiding the integration of Indigenous knowledge in science curriculum. (p 128)
>
> One of the most important things that a teacher will need to include in achieving meaningful inclusion of traditional knowledge in science education is to provide land-based experiences together with Aboriginal traditional land users and Elders. (p 127)

As noted earlier, CMASTE has begun to develop an information bank to help teachers approach FNMI science content. The CMASTE approach offers a cautionary note, echoed by Michell et al (2008): research should not "produce *recipe* formulas for inclusion of Indigenous science concepts" (p 117) or a "*one size fits all* approach to incorporating First Nations culture content" (p 121), as efforts in that direction often perpetuate a hegemonic colonial approach that promotes Western science ideology over Indigenous science. Thus, our conceptual understanding of Western scientific epistemological approaches (such as reductionism) should also include holistic Indigenous science approaches to describing or explaining natural events. This recommendation to avoid a "one size fits all" approach should come as no surprise to those who teach differing student demographics.

The University of Alberta is addressing these concerns through including FNMI perspectives in science education courses. Student teachers are first presented with Indigenous science concepts and then asked to develop lessons that include Indigenous, process-oriented, affective methods of science instruction. Michell et al (2008, 123) suggest,

> These [courses] would include such things as inclusion of holistic views of education and the natural world, the understanding that we are an integral part of the natural world, non-coercive education, opportunities for learning through observation, teaching by example, non-interference in the learning process, learning in natural settings, and non-regimented/institutionalized programming. Concepts such as bravery, courage, kindness, sharing, survival, knowing animal behaviour, moral lessons and values constitute important qualities learned through traditional forms of Aboriginal education.

Indigenous scientific thought acknowledges affective areas of understanding (including community, relationship, the oral tradition and narrative, the wisdom of the elders, and metaphor) and promotes the process of "coming-to-know" science (Elliott 2008; Cajete 1999, 2000).

Incorporating these concepts in science classes is not solely for the benefit of Aboriginal students. Research indicates that acknowledging and incorporating other ways of knowing can benefit all students, both Aboriginal and non-Aboriginal (Aikenhead 2006, 84–105). Giving meaning to the whole person (mental, physical, spiritual and emotional) is one interpretation of Indigenous science praxis. Philosopher Walter Benjamin identifies *corporeal knowledge* as a type of knowledge obtained from experience that resides in the whole being of the learner (Beasley-Murray 2008). Michael Polanyi discusses *tacit knowledge,* which is knowing "learned by direct experience through the whole of one's being" (Peat 2002, 66). Peat likens the acquisition of this type of knowledge to Aboriginal coming-to-know: both are gained through experience and relationship with the thing to be known, and both include the whole person. One elder quoted in Michell et al (2008, 78) identifies experiential knowledge passed on by elders as a critical aspect of learning Indigenous science:

> Science teachers should be approaching those people within the community that have expertise or knowledge about something whether this is about trapping, food gathering, and somebody who is a good hunter. All of these people have knowledge within that area in which they live, and how they connect with it, how they live in harmony within that area and recognize that parts of that area are sacred for that particular productivity for different items or reasons, and bear in mind that these people live within that land as their Mother and they know. And there is a particular feeling that happens when you look at the land as your Mother. You have this view in your mind as you are walking

> in the bush or sitting on a hill and just feeling that energy that comes with that. So there is that kind of interaction that science teachers should know about and incorporate. This will not take anything away from Western science, it is going to increase and improve the ability of those young people who live in and appreciate why they live in that area of the world.

Student teachers in their final practicum are presented with the process of integrating cognitive learning with affective learning in science classes. Not surprisingly, this often occurs on field trips. Elders have also suggested field trips as a way to teach corporeal or tacit knowledge:

> Going on a nature walk just kind of slowed down life for a moment and we just stopped and listened to the different sounds of nature and smelled all the different smells. All your senses just got wrapped up in it. And so I think it is important to do that with your students because they learn to develop a relationship with nature. They develop a respect for nature. I think this is key because of all the pollution. We have a big job ahead of us in fixing our environment with what we have done to it. (Michell et al 2008, 109)

What Does Nature Have to Do with Teaching Science?

The suggestion to expand our world views as science teachers is not new. In fact, teachers often ask the same of their students. When a science teacher begins an explanation of atomic structure by indicating that the desks students are sitting in are composed of mostly empty space, the teacher is beginning a journey in which the students' common sense must be set aside and replaced by trust in the teacher and belief in the content being taught. This also applies to scientists themselves:

> Scientists realize that their own fundamental presuppositions about the world must change dramatically before they can work through the complexity of a new paradigm replete with counterintuitive ideas. For example, physicist Greene (1999) concluded, in the context of explaining Einstein's special theory of relativity, "Understanding and accepting [counterintuitive ideas] requires that we subject our worldview to a thorough makeover" (p. 27). Because most students hold worldviews dissimilar to a scientific type of worldview (Cobern, 1996, 2000), meaningful learning of science content requires students to undertake a thorough makeover of their worldviews. How many students will actually do this . . .? (Aikenhead 2006, 86)

Science teachers expect students to suspend their existing world views in the science classroom. Aikenhead's question may also apply to teachers: Can science teachers suspend their existing world views when faced with Indigenous knowledge concepts?

Elements from the Western scientific world view can add clarity to this dilemma of conflicting belief structures. For those science teachers who possess only one way of knowing the world, Peat (2002) outlines some commonalities between Western science and Indigenous knowledge. In physics, Western scientists have identified quantum physics, the existence and importance of the dual nature of light, and Heisenberg's uncertainty principle, and Pauli and Jung described the existence of acausal synchronicity. Indigenous scientists have similarly described natural events as being "in a state of flux" (Little Bear 1994), which Western scientists describe as being *indeterminate* (Greene 2004). Braden (2007, 3) addresses the question of Western scientific objectivity by quoting Max Planck: "Science cannot solve the ultimate mystery of nature. And that is because in the last analysis, we ourselves are . . . part of the mystery that we are trying to solve." As one student teacher we talked to put it, "A role or prominence of Aboriginal perspectives is to open students' minds to different ways of thinking, not to show that stable, long-standing ideas still necessarily have an exclusive place." While many science teachers know and understand concepts such as these, they may experience difficulties when incorporating them in praxis, where the educational focus is on presenting detailed factual knowledge and assessing student retention of that knowledge. Yet indeterminacy stands as an underlying explanation or description of natural events in both world views.

The convergence of Western science and Indigenous knowledge can also be found in biology. The Western Gaia hypothesis (Lovelock 1991) and the Indigenous metaphor of Mother Earth are similar in that both describe natural phenomena as an interrelated, holistic concept. Natural cycles, such as the water cycle, are presented to students in elementary science, and recycling is a common theme in examining environmental sustainability. Indigenous thought often relates natural events to a circle, as in the medicine wheel, the cycles of nature, and the shape and movement of the sun and moon (Brown 1953). The Nehiyaw (Cree) depict human beings symbolically as a circle divided into four balanced sections containing intellectual, spiritual, physical and emotional elements (Elliott 2008, 20). However, divergent concepts also exist: Western scientific thought is often characterized as linear, logical, rational and fragmented, in contrast with the more circular, intuitive, holistic Indigenous thought (Peat 2002, 249).

In Biology 20 classes in Alberta, the ecological concept of maintaining biodiversity within a biome is presented. This concept can be taught from the perspective of restricted mono-science pipeline ideology (Aikenhead 2006). However, when different ways of knowing are examined in the science classroom, a new and more inclusive understanding of scientific knowledge can emerge that will allow the topic of biodiversity to be presented holistically. Science teachers can introduce FNMI scientific perspectives (Cajete's [2000] native science) as one way of describing or explaining natural events in the world as an initial framework to depart from a Eurocentric, mono-scientific perspective. This approach allows for the inclusion of examples of Aboriginal science perspectives.

> Participants commented that it is important to have many different forms of life and to understand biodiversity and knowledge diversity. Being too reliant upon one type of knowledge is similar to not honouring the diversity within ecosystems. (Michell et al 2008, 101)

What Does Community Have to Do with Teaching Science?

Community has a specific biological definition. When *community* is defined holistically as a group of individuals with a common goal, then each school can be seen as a community (or a series of communities), which in turn comprises communities of students and communities of teachers (Alsop and Ibrahim 2007). Many science teachers have the ability to bridge the gap between the lived-in-reality or community of the teacher and the lived-in-reality or community of the students.

Acknowledging the role of community in the science classroom marks a shift from *teaching science to students* to *teaching students science*. Among other things, this shift in perspective moves teaching beyond a strictly content orientation to include a process orientation where the relationship between the teacher and the student becomes an acknowledged part of the enacted teaching event. Alsop and Ibrahim (2007) point to the shift from a triad of teacher, curriculum and school to a triad of learner, community and place/location. They use motivation as a context for this shift from product to process.

Davis (2004) points out that it is difficult to separate process from content in interactive classroom-teaching events. To aid their understanding of this theoretical concept, secondary science education students at the University of Alberta learn the meaning of *praxis*—theory into practice—by actually going into a classroom and teaching students. That should not surprise us, but practising science teachers, in their attempts to get through the course content, often forget the importance of this experiential element of their own students' learning.

Aikenhead's (2006, 3) humanistic science approach shows one way to incorporate experiential learning in the science classroom. The inclusion of experiential learning as an example of an FNMI perspective can be enacted by overtly acknowledging the importance of relationship and community in the science classroom. In acknowledging community, science teachers respectfully enact and acknowledge other ways of knowing the world—such as Indigenous scientific thought:

> Participants spoke about experiential learning that provided opportunities to learn practical skills, developing personal relationships and spiritual understanding, carrying out of protocols as a measure of respect, caring for others and functioning as a part of cultural community. (Michell et al 2008, 91)

Michell et al (2008) further describe participant response to the perceived goals of science. For Aboriginal learners, experiencing only a Western scientific perspective in the science classroom is described as having detrimental consequences and as being a cultural reflection of hegemonic economic determinism. Participants in this study described one goal of science being addressed when teachers acknowledge the role of community in the classroom:

> Some participants suggested we need to ask *what the goals of science are* and *whose science has what goals*. They believe that since the word science is a

> western word, it drags you in that direction. Further, it was felt that key goals of western science are military application, commercialization, profit generation, industry, consumerism, capitalism. Some participants described the goals of an Indigenous science as about connecting the generations and learning your culture and history. . . . Another participant described science as the family, a sense of belonging, survival, knowing who you are, what you are, where you come from. (p 106)

For these participants, community is an integral part of teaching science.

Conclusion

An expanded conception of the term *science* has been presented here, and including FNMI perspectives has been suggested as one way to address this expanded conception in science classes.

Western science provides a powerful way of describing and explaining the natural world; however, there are other ways of knowing the world. Teaching science, as an activity carried out by humans, is a cultural activity (Aikenhead 2001, 2002, 2006). Thus, scientific knowledge presented from a Eurocentric, monoscientific perspective reflects that culturally derived belief structure. The inclusion of theories of knowledge—different ways of knowing—in the science classroom facilitates a more holistic description or explanation of the natural world, exposes residual scientism and can aid student motivation (Aikenhead 2006).

One way of knowing—Indigenous science—acknowledges affective areas of understanding (including community, relationship, the oral tradition and narrative, the wisdom of the elders, and metaphor) and includes the process of coming-to-know. Thus, one way to infuse Indigenous science into the curriculum is highlighting the role of community and relationship in the science classroom.

Alberta Education has begun the process of infusing FNMI knowledge into its science curriculum. University of Alberta student teachers' response to the inclusion of FNMI perspectives resulted in two suggestions: increased access to adequate resources, and an examination of the epistemological meaning of science. Comments from Aboriginal elders support moving from simply describing examples of Indigenous science to including Indigenous science perspectives in the classroom, and they have offered suggestions for accomplishing this.[6] This points the way for science teachers to respectfully and inclusively incorporate FNMI perspectives in their ongoing science teaching practice through acknowledging the importance of community and relationship and enacting experiential learning activities beyond the laboratory.

Notes

1. For Alberta Education's science programs of study, go to http://education.alberta.ca/teachers/program/science.aspx.

2. The term *science* itself is a relatively recent term replacing the term *natural philosophy,* a political move made by the British Association for the Advancement of Science (BAAS) in 1831 (Yeo 1981, 69).

3. This is a reframing of the question posed by philosopher Herbert Spencer (1859): "What knowledge is of most worth?"

4. Epistemology is the study of how we know reality.

5. These principles have been more recently reiterated by Battiste and Henderson (2000, 24–27).

6. In this study, the Aboriginal elders have specifically requested anonymity in order to serve as nonpersonal sources of knowledge.

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Using Adapted Primary Literature to Teach High School Science

Nathan Stelnicki, John Braga, Gerda de Vries and Stephen P Norris

It is widely recognized that fostering a scientifically literate citizenry is an important goal of an education system (Baram-Tsabari and Yarden 2005, 403). This goal makes sense when one considers the pervasiveness of science in our daily lives. However, there is an active debate about what constitutes scientific literacy, how it should be conceptualized and how it should be taught (Baram-Tsabari and Yarden 2005). Many science educators would agree with DeBoer's (2000, 598) declaration: "Ultimately what we want is a public that finds science interesting and important, who can apply science to their own lives, and who can take part in the conversations regarding science that take place in society."

Norris and Phillips (2003, 226) argue that literacy is of vital importance in the development of scientific literacy: "Reading and writing are inextricably linked to the very nature and fabric of science, and, by extension, to learning science." For instance, Tenopir and King (2004) surveyed 1,780 scientists, engineers and medical professionals and found that, on average, 58 per cent of their time was spent in some form of communication activity. Of these communication activities, the vast majority involved communicating their own scientific ideas or reading those of their peers. With reading and writing being such an integral part of what it means to be a scientist, it follows that these activities should be part of a curriculum that aims to promote scientific literacy in an authentic manner.

We can distinguish between primary scientific literature and secondary scientific literature. Primary scientific literature (PSL) represents communication among scientists and, thus, is rich in jargon and argumentative in the sense that it provides reasons and evidence to support conclusions. An article in a science journal is an example of PSL. Secondary literature (SL) is communication from scientists to nonscientists and is typically written by an intermediary (such as a reporter), who conveys the information in lay terms and in narrative or expository genres that largely dispense with argumentative structure. Newspaper and magazine articles on scientific topics are examples of SL.

Brill, Falk and Yarden (2004) were motivated to explore the use of PSL in one area of science education—biology—"because learning through research articles can serve as a means of bringing the practice of knowing biology in school closer to what it means to know biology within the discipline" (p 499). However, the direct use of PSL in high school science education can be prohibitive because of its ubiquitous use of jargon and technical detail.

Adapted primary literature (APL) is created by adapting PSL in such a way that it "is distinguished from secondary literature . . . by maintaining the structure of the primary article upon which [the APL] is based, even though it uses simplified language and may omit technical details" (Norris et al 2009, 322). Because of its design, APL is closer to the authentic way in which scientists communicate than are other genres of scientific text used in science education.

The origins of APL can be traced back to Baram-Tsabari and Yarden (2005), although the concept is foreshadowed in Yarden, Brill and Falk (2001). We and our associates have continued to investigate the use of APL in high school science education, specifically in biology courses. The main findings of Baram-Tsabari and Yarden's study, in which they compared the use of APL and SL in biology education, were as follows:

> Although there was no significant difference in the students' ability to summarize the main ideas of each text, indicating no eminent distinction in their content, we found that students who read adapted primary literature demonstrated better inquiry skills, whereas secondary literature readers performed

> better on the comprehension section of the test. (p 418)

Furthermore, they found that "APL creates a better understanding of the nature of scientific inquiry, while secondary literature permits better comprehension of the content and creates less negative attitudes among the students" (p 422). These findings suggest that APL may be an effective new tool for science educators in both teaching scientific content and teaching about the nature of science, with the caution that students may find the genre more difficult to understand and less interesting.

In May 2009, *Research in Science Education* published a special issue, "Adapting Primary Literature for Promoting Scientific Literacy." In the guest editorial, Yarden (2009) writes that the articles represent "the current state of the art with regards to the use of APL for science learning" (p 310), and explains that the special issue "focuses on the reading of scientific texts in general, and on the adaptation of primary scientific literature for promoting scientific literacy among high-school science students in particular" (p 307). Thus, the issue presents a holistic look at the possibilities and the pitfalls of APL. It shows a tempered optimism that through critical analysis of the capabilities of APL in relation to SL, the set of resources available to science educators will be enriched.

While there are currently few published empirical studies on APL, more are in the publication process or are being planned. The rest of this article focuses on two such studies conducted through the University of Alberta's Centre for Research in Youth, Science Teaching and Learning (CRYSTAL-Alberta). The first APL study used an article on the West Nile virus to test the scientific inquiry results of the Baram-Tsabari and Yarden (2005) study in the Albertan context. The second APL study is in the planning stages and will use an article on the coronal heating paradox to explore the impact of APL on scientific reasoning skills.

APL and the West Nile Virus

The West Nile virus arrived on the east coast of North America in 1999 and has since spread westward across the continent. The virus is transmitted back and forth between mosquitoes and birds, and occasionally from mosquitoes to mammals, including humans. Since some people suffer severe symptoms and even death, the West Nile virus is a health concern. Public health agencies are interested in finding out which control strategies are most effective: spraying adult and larval mosquitoes, removing larval mosquito habitat or keeping bird populations small. Mathematical modelling can be used to help find solutions to these unknowns.

The direction we took with this work reflected the composition of our group: a biologist, a mathematician with special expertise in mathematical biology, a university science educator, a high school mathematics teacher and an undergraduate science student. Departing from the context of biotechnology used in the Israel study by Baram-Tsabari and Yarden (2005), we decided to demonstrate to students the integral role that mathematical techniques and mathematical thinking play in the development of science. We adapted an article published by our biologist in the *Proceedings of the Royal Society of London* (Wonham, de-Camino-Beck and Lewis 2004), which describes a mathematical model of West Nile virus transmission. The Alberta curriculum for Math 31 includes an optional unit in mathematical biology, which has often been undersubscribed because of a lack of suitable materials. With the original author serving as our science writer, we proceeded to adapt this article and study its effectiveness with high school students.

This particular application of APL was motivated primarily by results out of Israel showing that students using APL demonstrated increased scientific inquiry skills. These results indicate an opportunity for improvement in critical areas of science education through the use of literature and a minds-on approach to science that is in line with current curricular goals in Alberta that focus on teaching students the process by which science is developed (Alberta Education 2006). In making this claim, we do not wish to take away from the important hands-on training received in the school lab. Rather, we seek to align the experience of the student more fully with that of the scientist. It was with this rationale that we decided to determine if the positive results obtained in Israeli classrooms would also be evident among students in Alberta, despite the language and cultural differences.

Materials

Two members of our group (the mathematical biologist and the high school math teacher) developed four preparatory units. The units were designed for teachers to introduce students to the background knowledge needed to understand the adapted article: the concept of rate of change, exponential growth and decay models, the logistic equation, and a two-compartment model for disease transmission. Teachers were introduced to the material during a 180-minute session at the University of Alberta wherein any questions or concerns about the units could be discussed with the authors.

We created two adaptations of the article by Wonham, de-Camino-Beck and Lewis (2004): an APL version and an SL version. The SL version had already been published in a magazine targeting nonscientists (Wonham 2004). The APL version was created by maintaining the structure of the original article as closely as possible and clarifying complicated concepts.

We also developed a booklet consisting of four questionnaires. The first two questionnaires tested comprehension by asking students to summarize important points in the article and to answer 11 true-or-false questions. The third questionnaire measured scientific inquiry by asking students to describe (based on what they had read) the implications for future research, to think critically about how the research might have been improved, and to suggest additional applications for the research methods used. Students' attitudes toward the literature were measured by a fourth questionnaire that contained 11 statements to which students responded on a scale of 1 (strongly disagree) to 6 (strongly agree).

Participants and Method

Our participants were 211 Math 31 students from four high schools in Edmonton, Alberta. To participate in the study, students under the age of 18 were required to have written parental consent.

The background topics were presented to the students by their regular classroom teachers in two 90-minute classes. A third 90-minute class was used for reading the adapted articles (APL or SL) and completing the corresponding questionnaire packet. Students were randomly assigned to read either the APL or the SL article.

Results

In this article we describe only some of the results of our experiment. Although we did not find a difference between readers of APL and readers of SL in the three combined parts of the scientific inquiry questionnaire, we did find differences in the critical-thinking aspect, on which the APL readers scored significantly higher than those who had read the SL. Students who had read the APL were more likely to provide suggestions for how the research might be improved.

Other studies have shown that using primary literature has positive effects on critical thinking (Hoskins, Stevens and Nehm 2007; Kozeracki et al 2006; Russell et al 2004). Unique to our study, however, is the absence of any scaffolding mechanism. Most of the research into the use of primary literature has taken place in the undergraduate classroom, where the literature was used as part of a teacher-directed program or group project in which directed questions or group discussion was used to help students understand the articles. These aids make it difficult to separate the effect of the literature from that of the instruction. In our study, we attempted to isolate this effect by removing those aids.

The magnitude of the observed difference is encouraging because it is in line with other investigations into APL, including that of Baram-Tsabari and Yarden (2005). The increase in critical thinking found in our study is attributable to the structure and language of the literature students were asked to read. This shows that the genre and structure of the materials presented to students can lead to different educational outcomes. Some genres and structures are better aids for conveying content; others are better aids for developing scientific reasoning.

Science and Mathematics Background

To our surprise, the students' backgrounds in science and mathematics courses did not contribute significantly to their scores. One explanation for this result may be the interdisciplinary nature of the text. Yu (2009) found that familiarity with specific topics, not general topics, is what facilitated understanding. The specific topic in our article was mathematical biology and the West Nile virus; thus, general courses would not have aided student understanding.

APL and the Coronal Heating Paradox

The *coronal heating paradox* refers to the odd situation in which the sun's corona (the uppermost layer of the sun's atmosphere) is much hotter than the photosphere (the lowermost layer). We would be shocked if we found that as we moved away from a campfire, the air became many times hotter than the fire itself, but this is similar to what happens with the sun. Despite six decades of debate among scientists, and hundreds of theoretical models, there is still no obvious or generally accepted explanation for the corona's high temperature. This is due, in part, to the many difficulties that arise in seeking to understand why the corona is so hot, not the least of which are the financial and technical difficulties involved in observations of the corona by space-based instruments. We hope to capitalize on this paradoxical phenomenon and the rigorous debate it has engendered in order to help students understand the role of controversy, debate and uncertainty in scientific reasoning.

Being able to reason scientifically is an essential component of understanding the nature of science and, thus, of developing scientific literacy. Yet the current high school curriculum does not "treat systematically and comprehensively the nature of scientific reasoning and argument and how they are connected to scientific conclusions" (Norris et al 2009, 322). As we discussed in the West Nile virus example, APL may help address this shortcoming. Baram-Tsabari and Yarden (2005, 419) postulate that "APL's structure, due to the similarity in the structure of scientific writing and scientific method, might serve as an organizer for students' scientific thinking." Furthermore, with regard to the use of APL to develop better understanding of scientific reasoning, Phillips and Norris (2009, 316) speculate that "the specifics of scientific justifications were going to be beyond the grasp of most non-scientists. Nonetheless, they could be taught to grasp the general nature of scientific justifications so that the source of scientific findings would seem less of a mystery." According to Giere, Bickle and Mauldin (2006, 5), "learning to understand scientific reasoning is a matter of learning how to understand and evaluate *reports* of scientific findings" in various examples of SL and PSL. The current research on APL points to the possibility of its use in developing scientific reasoning skills, but there has not yet been a study conducted that explores the limits of this specific possibility.

We are currently creating a case of APL based on the coronal heating paradox to test the efficacy of APL in fostering scientific reasoning skills. The adaptation we are creating is based on "The Coronal Heating Paradox," by Markus Aschwanden, Amy Winebarger, David Tsiklauri and Hardi Peter, published in the *Astrophysical Journal* in 2007.

Many aspects of the coronal heating paradox are conducive to revealing several elements of scientific reasoning:

- It illustrates that science involves controversial and unresolved questions, with scientists exploring alternative hypotheses.
- It shows how scientists may enter into debate, arguing for or against a hypothesis in seeking to resolve the controversy.
- It demonstrates how scientists use different kinds of evidence, including counterevidence, in formulating and supporting their arguments.
- It illustrates that questions can remain unsettled for an extended period of time.

Our question is whether an APL about the coronal heating paradox can be used to help high school students realize all of this.

Conclusion

Our ultimate aim is to improve the quality of science education. We have demonstrated that one application of APL in the context of mathematical biology resulted in an increase in critical thinking by students. The effect of genre on the critical-thinking measure serves to strengthen our hypothesis that the nature of APL is what facilitated this increase in both our study and in Israel. It is promising that these results were obtained in two different cultures and languages and with different science topics.

In our forthcoming work with APL and the coronal heating paradox, we will endeavour to teach students important components of scientific reasoning. These studies will also be independent of any scaffolding techniques, making application in the classroom relatively straightforward should the results be positive. Our first investigations into the use of APL suggest that it can be a useful tool for teachers as they guide students toward an understanding of the nature of science.

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Teaching Scientific Inquiry Using Science Trade Books

Hagop Yacoubian, Sun Joo Hur, Yu Lei, Carolyn Freed, Linda M Phillips and Stephen P Norris

Ford (2004a) and Schroeder et al (2009) report an increasing use of science trade books by elementary teachers in teaching science. Science trade books contain science content and are intended for the general public. They are often used to introduce children to science and to serve as a source of scientific information outside the school. These books could serve the dual role of promoting both literacy and science (Ford 2004a; Madrazo 1997). Because inquiry is a major theme in science curricula worldwide, including in Alberta, it is essential to describe the potential of science trade books in supporting inquiry teaching and learning.

Text constitutes a major means of communication in scientific communities. Ford (2004a, 2004b) argues that text should serve a similar function in the science classroom. Fang et al (2008) and Morrison and Young (2008) highlight the importance of reading as an essential tool in doing science. Norris and Phillips (2003) argue that text and reading are features that define science. If reading scientific texts is so important to scientific inquiry, then science trade books also should have an inquiry focus.

Ford (2004a) and Schroeder et al (2009) report that most science trade books present factual, descriptive information, with no reference to how scientific knowledge is constructed. Ford (2004a) has also determined that science trade books often present a distorted view of science, portraying it as limited to making observations, and observation itself is oversimplified as merely looking at nature. She concludes that "most of these books are not . . . useful for modeling or supporting inquiry" (p 288). Schroeder et al (2009, 246) conclude that "there is a danger that trade books . . . could influence children to view science as merely a collection of facts, as opposed to a process of inquiry, discovery, and experimentation."

Building on previous research, we attempted to evaluate the potential for science trade books to support inquiry by documenting more precisely the aspects of inquiry that trade books do and do not support. An evaluation of science trade books from an inquiry perspective should be based on a comprehensive array of characteristics of inquiry found in the literature.

A Comprehensive Analytic Framework for Scientific Inquiry

Considering the extent to which science trade books promote inquiry immediately raises the question of what inquiry is. There is no single definition of *scientific inquiry* that all science educators and policy documents endorse. Moreover, there are diverse viewpoints about how science teaching can foster inquiry.

Definitions of *scientific inquiry* can be as general as what Schwartz, Lederman and Crawford (2004, 611) propose when they consider scientific inquiry to include "characteristics of the scientific enterprise and processes through which scientific knowledge is acquired, including the conventions and ethics involved in the development, acceptance, and utility of scientific knowledge." Other definitions, such as the one proposed in the US *National Science Education Standards,* are more specific and include several components of scientific inquiry:

> [Inquiry] involves making observations; posing questions; examining books and other sources of information to see what is already known; planning

> investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. (US National Research Council 1996, 23)

Science educators and science education policy documents portray inquiry teaching and learning from two additional perspectives: (1) what happens during the process of inquiry teaching and learning, and (2) what happens as a result of inquiry teaching and learning. The first focus is on teacher and student behaviour, classroom interactions and the context in which learning occurs. For example, Keys and Kennedy (1999) identify major processes associated with inquiry teaching and learning, such as the planning of instruction based on questions that arise from students, and the outcomes of student learning.

We based our evaluation of the extent to which science trade books promote inquiry on the second process, because we examined the trade books themselves rather than how they are used by teachers and students in the classroom. However, we recognize that a trade book that seems poor may work wonderfully when used creatively by a science teacher, and a book that seems very good may engage students in no more than superficial reading and rote memorization when the teacher's guidance does not foster inquiry.

Welch et al (1981) divide the domain of inquiry into three parts: science process skills (observing, measuring, interpreting data); the nature of scientific inquiry (understanding that scientific knowledge is tentative, viewing science as the product of human efforts); and general inquiry processes (decision making, logical and analogical reasoning, problem solving). Welch et al focus on *inquiry as an end,* which must be differentiated from *inquiry as a means.* Both are essential outcomes of inquiry-based teaching and learning (Rutherford 1964; Tamir 1983). Lederman (2004, 308–9) says that scientific inquiry "includes the traditional science processes, but also refers to the combining of these processes with scientific knowledge, scientific reasoning, and critical thinking to develop scientific knowledge." He argues that "students' understandings of NOS [the nature of science] are best facilitated if situated within a context of inquiry" (p 308). Schwartz, Lederman and Crawford (2004) also consider inquiry a suitable context for teaching and learning the nature of science.

We have developed a comprehensive framework for scientific inquiry that includes four categories of student learning:

- Scientific content knowledge
- Nature of science and nature of scientific inquiry
- Scientific inquiry skills
- Attitudes toward science, and scientific attitudes

Each category includes subcategories, as displayed in Appendix A. Our list of subcategories is long (but not exhaustive), and is meant to provide a sense of the complexity of the goal of scientific inquiry.

Scientific inquiry skills include scientific process skills (such as observing and hypothesizing), general inquiry skills (such as thinking critically and solving problems) and practical how-to skills (such as reducing error as much as possible). We have included procedural knowledge as a subcategory of scientific content knowledge. Gott, Duggan and Roberts (2002) claim that to be able to understand scientific evidence, one needs to understand an underlying body of knowledge, termed *concepts of evidence,* about how that evidence is obtained. We consider this body of knowledge an essential learning outcome for inquiry in the science classroom. Technical knowledge (such as how to use a thermometer) is important for carrying out scientific inquiry in particular settings. The ideas underlying thermometer use, such as the fact that the thermometer must be calibrated to reduce uncertainties in readings, are concepts of evidence.

Method

We selected a random sample of 60 science trade books from the library of an elementary science alternative school that houses approximately 1,000 such books. The trade books were of various genres and suitable for various grade levels.

We used the framework in Appendix A to develop five criteria for evaluating the books from an inquiry perspective:

- Promotes the development of students' scientific content knowledge
- Presents aspects of procedural knowledge[1]
- Helps students develop an understanding of the nature of science and scientific inquiry
- Encourages students to sharpen their scientific inquiry skills
- Helps develop students' attitudes toward science and their scientific attitudes

The trade books were rated on a scale of 1 to 4 for each criterion. They were evaluated separately by two researchers, using the same rubric. The researchers then met and discussed their evaluations. Disagreements were either resolved or referred to a third researcher, whose view was taken into consideration in making the final judgment.

The following is a profile of a science trade book that would be rated 4 for each criterion:

- The scientific content knowledge presented in the trade book is substantial.
- Aspects of procedural knowledge are substantially presented.
- Three or more aspects of the nature of science and the nature of scientific inquiry are evident consistently in the book.
- Three or more scientific inquiry skills are evident consistently in the book.
- The book consistently fosters the development of positive attitudes toward science and scientific attitudes.

Results

Scientific Content Knowledge

The scientific content knowledge presented by most (85 per cent) of the science trade books in our sample was either acceptable (rating of 3) or substantial (rating of 4), though some books contained misconceptions. Only 15 per cent of the books poorly presented scientific content knowledge (rating of 2). None of the books contained no scientific content knowledge at all (rating of 1).

For example, Stephen Kramer's (2001) *Hidden Worlds: Looking Through a Scientist's Microscope* (rated 4) tells the story of a microscopist and provides a wealth of scientific information, including microscopic images of everyday objects:

> Dennis spent six years doing research on South African clawed frogs to learn about muscle cells.
>
> Muscle cells are different from other cells in your body because they can contract, or become shorter. When you decide to wiggle your finger, your brain sends a message through your nerves to the muscles that control your fingers. The nerve cells release a chemical that causes the muscle cells to contract. (p 22)

Nancy Luenn's (1994) *Squish! A Wetland Walk* (rated 2) guides young readers to appreciate that animals and plants, no matter how small or how large, have important roles in a wetland. However, the book presents a limited amount of scientific content knowledge, and the illustrations are an artist's renderings:

> A wetland is a place to listen
> to a choir of frogs
> A blackbird's spring song
> the slap of a beaver's tail
> It smells like mud
> and rotting plants
> and young leaves in a sudden rain

Procedural Knowledge

Most of the trade books (85 per cent) did not present procedural knowledge at all (rating of 1). A few books (3.3 per cent) presented procedural knowledge but did so poorly (rating of 2). We did not find any books in which certain aspects of procedural knowledge were substantially presented (rating of 4), but we found them acceptably presented in 11.7 per cent of the books (rating of 3).

The following excerpts illustrate how science trade books present procedural knowledge. Both books received a rating of 3; the procedural knowledge presented was not substantial enough for a rating of 4.

Sharon McCormick's (1992) *Weather Projects* discusses how thermometers work:

> Most thermometers consist of a fine glass tube filled with mercury. Mercury is a liquid metal that expands when it is heated. As the mercury expands and contracts, it moves up and down the tube. The tube is marked with a scale. (p 36)

Douglas McTavish's (1990) *Isaac Newton* discusses the telescope:

> The first telescope was invented in 1608 by a Dutch instrument maker, Hans Lippershey. His type of telescope—called a refracting telescope—uses a lens to collect light rays and bring them together at the eyepiece, where they are magnified. Newton designed a new type of telescope which used mirrors to collect the light and then redirect it to the eyepiece at the side of the tube. Newton's telescope is called a reflecting telescope. (p 21)

The following excerpt from Donna Jackson's (2002) *The Bug Scientists* illustrates poor presentation of procedural knowledge (rated 2). The author makes an explicit link to the design of the investigation in question, without providing further details regarding the dependent and independent variables:

> After the specimens are collected, Cervenka gathers temperature data from the weather station nearest the death scene. "Once I determine how the temperature and other variables would have affected the flies' growth cycle, I can calculate how many days it has taken for the immature flies to develop into their present stage." (p 30)

Gott, Duggan and Roberts (2002) argue that while many students will acquire concepts of evidence during normal study of science, many others will not learn them without explicit instruction. Even if we are optimistic and believe that students can formulate on their own the understanding that, say, most instruments rely on a linear relationship between two variables, students still might have difficulty appreciating this understanding in the broader context of scientific inquiry. Hence, we urge that procedural knowledge be an explicit part of both trade books and instruction, whenever possible and applicable.

Nature of Science and Nature of Scientific Inquiry

Most of the books (85 per cent) did not present any aspects of the nature of science or scientific inquiry, and hence received a rating of 1. Three or more aspects were consistently evident in only 3.3 per cent of the books (rating of 4), while fewer than three aspects were consistently evident in 5 per cent of the books (rating of 3). In 6.7 per cent of the books, only one or two aspects were presented (rating of 2).

Isaac Newton (McTavish 1990) received a rating of 4 on this criterion because multiple aspects of the nature of science were consistently evident. The following excerpt shows quite well the interplay between the tentative, social and subjective aspects of the nature of science:

> A few weeks later Newton sent the Society a short paper describing his experiments and putting forward his conclusion that white light was actually a mixture of colours. This idea was totally against the teachings of the Ancients and even the theories of Descartes. None of his contemporaries would accept it and Newton found himself drawn into a series of bitter arguments. (p 24)

Most of the science trade books failed to present the nature of science and scientific inquiry as an explicit part of the text. This finding is consistent with the findings of Ford (2004a) and Schroeder et al (2009), who argue that science trade books often present factual information without reference to the construction of scientific knowledge.

Scientific Inquiry Skills

Only 20 per cent of the science trade books treated scientific inquiry skills fairly consistently (rating of 3 or 4). One or two instances of the skills were evident in 35 per cent of the books (rating of 2). Almost half of the books (45 per cent) included no scientific inquiry skills at all (rating of 1).

The following excerpt is from *Weather Projects* (McCormick 1992), which fosters well the development of scientific inquiry skills. The book received a rating of 4 on this criterion because multiple skills were consistently evident throughout:

> You can stop water from flowing using air pressure too.
>
> 1. Position a funnel in the neck of the jar. Seal it tightly with plasticine.
> 2. Fill the funnel with water. What happens? Why do you think the water won't run through?
> 3. Now make a hole in the plasticine. What happens now? (p 15)

Our study focused on the extent to which the trade books encouraged students to sharpen various scientific inquiry skills. The trade books were inconsistent in creating opportunities for students to practise such skills. Most of them either lacked reference to those skills or treated them inconsistently by limiting them to one or two instances in the book. Moreover, most of these skills were limited to asking the reader to perform direct observations of nature or a second-hand investigation (such as observing the photos in the book). Although Cervetti et al (2006, 230) claim that second-hand investigations can help students "investigate phenomena that are not easily modeled in classrooms," we think that students need to be given opportunities to develop skills in first-hand investigations as well.

Attitudes Toward Science, and Scientific Attitudes

All of the trade books we looked at fostered the development of students' positive attitudes toward science and their scientific attitudes: 15 per cent of the books fostered the development of these attitudes consistently and explicitly (rating of 4), and 85 per cent did so rather implicitly (rating of 3). This result is not surprising: it is difficult to imagine a science trade book that did not foster the development of such attitudes, either implicitly or explicitly.

Conclusion

In this article, we presented the results and conclusions of our evaluation of science trade books from an inquiry perspective. We plan to evaluate more science trade books and to make those evaluations available to teachers.

It is important to interpret the results of our study separately for each domain of scientific inquiry. No book received a rating of 4 on all aspects of scientific inquiry; thus, we were not able to make general claims, such as a claim that a particular book promoted or did not promote inquiry. Different books have different objectives and are of different genres. Therefore, it is wise to use a variety of science trade books to support inquiry teaching, carefully selecting the books so that there is good representation of all aspects of scientific inquiry. In this way, teachers can ensure that the trade book collection they use has a high potential of engaging students in scientific inquiry.

However, as we mentioned previously, the teacher's role is central in fostering scientific inquiry in students through explicit teaching of how scientific knowledge is constructed and tested. A science trade book can only support a good teacher in attaining this objective.

Appendix A

A Comprehensive Framework for Scientific Inquiry

Scientific Content Knowledge

Students will be able to develop the following:

- Scientific content knowledge
  - Scientific laws
  - Scientific theories
  - Scientific conceptual understanding
- Scientific vocabulary
- Procedural knowledge

Nature of Science and Nature of Scientific Inquiry

Students will be able to develop an understanding and appreciation of the following:

- Tentative nature of science (NOS) (subject to change)
- Empirical NOS (empirical-based)
- Subjective NOS (theory-laden)
- Invention of explanations (by using creativity and imagination)
- Human inference, imagination and creativity
- Sociocultural embeddedness
- Distinction between observations and inferences
- Different scientific methods

Scientific Process Skills

Students will be able to do the following:

- Define a problem
- Ask questions
- Predict
- Observe
- Compare
- Classify
- Plan investigations
- Develop a hypothesis
- Test a hypothesis
- Collect data
- Analyze and interpret data
- Draw conclusions
- Use evidence
- Develop explanations based on evidence

General Inquiry Skills

Students will be able to do the following:

- Think critically and logically
- Solve problems
- Build, test and revise models
- Make decisions
- Communicate results through speaking, reading, writing, negotiating and arguing
- Reflect on the process of inquiry

How-To Skills

Students will be able to do the following:

- Use tools to gather, analyze and interpret data
- Use different modes of presenting data (graph, table, chart)
- Use controls

- Perform fair tests
- Measure
- Reduce error as much as possible
- Sample populations

Attitudes Toward Science

Students will internalize the following attitudes:

- Positive attitudes toward science
- Interest toward scientific inquiry
- Motivation to learn more

Scientific Attitudes

Students will internalize the following attitudes:

- Disciplined habit of mind
- Perseverance
- Risk taking
- Curiosity
- Inventiveness
- Skepticism
- Open-mindedness
- Ability to deal with doubts
- Positive approach to failure
- Flexibility (willingness to modify ideas)
- Respect for evidence
- Reflectiveness

Notes

We are grateful to the principal and staff of Elmwood School, Edmonton Public Schools, for their support and for granting us access to their library collection.

1. Procedural knowledge was singled out from scientific content knowledge because of its importance.

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Visualization in Science Education

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There is general agreement in the educational community that visualization is an effective teaching tool. Current applications of visualization are found in many teaching contexts, including mathematics, reading, science and technology. In this article, we review key studies in science education that show that visualizations are effective to the extent that they meet relevant instructional goals and objectives and that students have the necessary background knowledge and skills to understand and interpret the information represented in them. We report select findings from a review of 65 empirical studies of visualization in science education, and address the following four questions:

- How is visualization defined and conceptualized?
- What theoretical perspectives inform the application of visualization in science?
- What is the research evidence on visualization in science education?
- What are some recommendations for the most effective development and use of visualizations in science?

Defining Visualization

There is a pervasive lack of clarity about precisely what constitutes visualization. Several terms related to visualization are found in the research literature: *visual representation, visual media, media literacy, visual communication skills, visual literacy, illustrations* and *media illustrations.*

The term *visualization* can be used to name a representation, to refer to the process of creating a graphical representation or as a synonym for *visual imagery.* Bishop (1989) explains that *visualization* can refer to the *what* of visualization (the product, object or visual image) or the *how* of visualizing (the process, activity or skill).

The most common terms in the research literature—*visualization, image, visual aid* and *visual literacy*—often are used interchangeably and remain imprecise. Merriam-Webster Online defines *visualization* as the "formation of mental images" or "the act or process of interpreting in visual terms or of putting into visible form." It defines *image* (noun) as "a mental picture or impression of something" or "a vivid or graphic representation or description," and *image* (verb) as "to create a representation of," "to form an image of" or "to represent symbolically." A *visual aid* is "an instructional device (as a chart, map, or model) that appeals chiefly to vision." Finally, *visual literacy* refers to "the ability to recognize and understand ideas conveyed through visible actions or images (as pictures)."

We identified three important distinctions in the conceptualization of visualization:

- *Visualization objects* can be pictures, three-dimensional models, schematic diagrams, geometrical illustrations, computer-generated displays, simulations, animations, videos and so on. Objects can be displayed in a variety of media formats, including paper, slides, computer screens, interactive whiteboards or videos, and may be accompanied by sound and other sensory data.
- *Introspective visualizations* are mental objects pictured by the mind. They can be thought of as imagined visualization objects.
- *Interpretive visualization* involves making meaning from visualization objects or introspective visualizations in relation to one's existing network of beliefs, experiences and understandings. An interpretive visualization involves a *cognitive action*—a change in thinking as a result of interaction with a visualization object or an introspective visualization (Phillips, Norris and Macnab 2010).

Thus, visualizations are differentiated in terms of *physical objects* (geometrical illustrations, animations, computer-generated displays, picture-like representations); *mental objects* pictured by the mind (mental scheme, mental imagery, mental construction, mental representation); and *cognitive processes* that involve the interpretation of physical or mental visualizations (cognitive functions in visual perception, manipulation, and transformation of visual representations by the mind; concrete to abstract modes of thinking; picturing facts). These distinctions are important for understanding the demands and contexts of visualization use and for determining the most effective application of visualization in the science classroom.

Theoretical Perspectives on Visualization in Science

Visualization in science education can be explained by two theoretical perspectives: (1) dual-coding theory (DCT) and (2) visual imagery hypothesis (VIH). The main difference between these two perspectives lies in the function of or purpose for visualization.

DCT (Paivio 1986; Sadoski and Paivio 2001) focuses on visualization as a means for understanding how linguistic information (words and sentences) and visual information (images) are encoded by two independent mental systems, a verbal one and a nonverbal one. The information stored in each system can be accessed independently of the other. However, the combination of linguistic information and visual information provides dual support for learning and knowledge acquisition. DCT provides important insights into how visual perception affects memory and how visualization can be used to enhance learning and understanding.

VIH (Johnson-Laird 1998; Pylyshyn 2003) focuses on visualization objects. According to Vekiri (2002), graphical representations allow one to process information more efficiently than do verbal ones, ultimately reducing the demand on working memory. VIH underscores several important functions of visualization objects, such as organizing and highlighting key concepts, making information accessible for manipulation and comparison in order to generate inferences to solve problems, and identifying logical and complex interconnections and relationships (Tversky 2001). The basic premise of VIH is that visualization objects and activities provide the necessary information and concepts to facilitate the application of knowledge and skills for problem solving.

Empirical Research on Visualization in Science Education

During the past 20 years, the consensus in the research has been that "visualization objects assist in explaining, developing, and learning concepts in the field of science" (Phillips, Norris and Macnab 2010, 63). Different types of visualization in science can serve different purposes. For example, realistic diagrams (such as an anatomical diagram) highlight the salient features of an object. Schematic diagrams (such as an electrical circuit diagram) illustrate relationships, assist in calculations, or provide descriptions of a phenomenon or process. Other visualizations in science education include photographs, simulations, astrophotographs and scale drawings of equipment. Scientific visualizations can offer a means for imagining the unseen (such as the molecular, atomic and subatomic worlds).

We analyzed 65 research articles on the application of visualization in a number of science subjects. Most of the studies were in chemistry and general science. Our discussion focuses on research involving K–12 students. However, we refer to studies with postsecondary students when the results are pertinent to the application of visualization in elementary, junior high and senior high school. The research review is organized into three parts: (1) visual representations, diagrams and animations; (2) dynamic media and learning performance; and (3) animations, visualizations and conceptual change.

Visual Representations, Diagrams and Animations

We started with studies focusing on how visual representations, diagrams and animations have been used to communicate the essential features and functions of important scientific concepts. These provided an indication of the application of visualization in science, including the merits of various types of visualization for representing scientific content, the contexts and conditions that promote the most effective use of particular visualizations in science, the characteristics of students who benefit most from specific visualizations, and the effect of visualization on student performance.

Some research suggests that certain types of visualization can enhance or even replace verbal or textual explanations of particular scientific concepts. For example, Gilmartin (1982) studied the effect of maps on learning with 133 postsecondary geography students. The students were assigned one of three readings: a text-only passage, the same passage accompanied by a reference map, or the passage accompanied by maps with some of the textual material placed in the map captions. After reading, the students answered a series of questions. Gilmartin found that "maps provided with a passage of regional geography text helped students learn the content of the text, both for immediate testing and for delayed testing" (p 149). These results suggest that maps have the potential to represent spatial relationships more effectively than verbal descriptions do.

Another study showed that the most effective applications of visualization in science are supplemented by textual or verbal information. Mayer and Anderson (1991) found that the combination of visualization (in this case, animation) and verbal or textual information enhanced understanding of scientific explanations and concepts. They conducted an experiment in which 30 undergraduate students viewed an animation of a bicycle tire pump. The students who were presented with both words and pictures performed better in problem-solving activities than the students who were presented with words only or pictures only to clarify the concept. The researchers concluded that "effective understanding of scientific explanations requires a mapping between words and pictures" (p 484).

Visualization has numerous applications in chemistry. Comprehension of chemistry concepts requires highly developed visuospatial skills. Wu and Shah (2004) highlight the importance of learner differences and the role of visualization in reducing how much students have to remember in chemistry. They claim that visualizations provide multiple representations and descriptions of the same information, which enables "students to visualize the connections between representations and relevant concepts" (p 483). In chemistry, visual representations have several important functions: to make connections visible, to present the dynamic and interactive nature of chemistry, to promote the transformation between two-dimensional and three-dimensional thinking, and to reduce how much students need to remember by making information explicit (p 485).

Some research highlights the specific contexts and conditions for visualization in science. Lee, Plass and Homer (2006) studied the most effective conditions for using simulations with 257 Grade 7 Korean students. All the students benefited when a computer simulation of the ideal gas law was separated into two screens showing smaller segments of information. The amount of information contained in the visual simulation, as well as students' prior knowledge, was important for reducing the load on memory. Thus, the more information students already know, the more effective the simulation.

Some studies provide further insight into the characteristics of students who benefit most from specific visualizations and the effect of visualization on student performance in science. For example, Huk (2006) studied the educational value of three-dimensional visualizations in cell biology using a CD-ROM (*The Cell II: The Power Plant: Mitochondrion and Energy Metabolism*) with 106 German biology students in high school and college. The inclusion of complex 3-D models of plant and animal cells most benefited students with high spatial visualization ability by supporting the recall of auditory and visually presented information. However, the addition of the 3-D model resulted in cognitive overload for students with low spatial visualization ability. This finding was similar to that of Wu and Shah (2004), who showed that highly developed visuospatial ability is a prerequisite for understanding visualizations in chemistry.

Other studies provide evidence of particular attributes and benefits of using visualization in science. Winn (1988) maintains that the effectiveness of diagrams in high school science instruction is contingent on a student's ability to focus on and learn the relevant information from a diagram in order to accomplish specific tasks. Wilder and Brinkerhoff (2007) found with 69 Grade 9 students that performance was better on questions that included visualizations on the computer-based biomolecular instructional program Chemscape Chime. Results showed that "computer-based biomolecular visualization instruction was an effective curriculum component supporting the development of representational competence" (p 5).

Dynamic Media and Learning Performance

We found only a few studies that focused on the effects of dynamic media (animations) on student engagement and learning performance. Three recent studies found that animations increased student engagement and interest level, but questions linger about whether the visualizations had any effect on learning and understanding (Annetta et al 2009; Korakakis et al 2009; Limniou, Roberts and Papadopoulos 2008).

Korakakis et al (2009) studied 212 Grade 8 Greek students to determine whether the use of specific types of visualization (3-D illustration, 3-D animation and interactive 3-D animation), when combined with verbal narration and text, enhanced students' learning of methods for separating mixtures (including distillation, factional distillation, pouring, centrifugation, filtering, evaporation, paper chromatography, sieving and magnetic separation). They found that the students assigned to 3-D animations and interactive 3-D animations required more time to learn the task than did the students in the 3-D illustrations group. Those students also experienced more difficulties in constructing relevant information from the dynamic visuals because the information was unfolding too quickly. Similar to two other studies (Gilbert 2005; Gilbert, Reiner and Nakhleh 2008), the study by Korakakis et al (2009) showed that the interactive controls produced an extra cognitive load for students, and they seemed to lack the spatial ability to conceive the visualizations completely. Although students' interest and attraction increased in response to the interactive 3-D animation and the 3-D animation, their understanding of the concept did not improve. Ultimately, the more dynamic animations enhanced student engagement but also placed more demands on their memory.

In another study, Limniou, Roberts and Papadopoulos (2008) investigated how 2-D and 3-D chemical animations designed for a fully immersive virtual reality environment affected students' interest in and motivation for learning. The 14 postsecondary students showed more enthusiasm for and better comprehension of molecular structure and change during a chemical reaction after engaging with 3-D animations than after engaging with 2-D animations. However, it was less clear whether the students truly understood the concepts, given that "they had the feeling that they were inside the chemical reactions and they were facing the 3D molecules as if a real object was in front of them trying to grab them" (p 592).

Annetta et al (2009) made a similar discovery in their investigation of the impact of teacher-created video games on the engagement and learning of 129 high school biology students. A key finding was that students in the gaming group were more engaged than students in the control group (who used paper-and-pencil practice and discussion to review a genetics unit). Interestingly, results from the cognitive assessment showed no difference in student performance. The researchers cautioned that games are not a panacea and called for the development of specific design and evolution criteria that focus more on instructional content and less on animation, text and audio.

These studies show that a significant attribute of dynamic media is its ability to stimulate student interest and engagement. However, it remains unclear whether dynamic media enhances the learning and understanding of science concepts.

Animations, Visualizations and Conceptual Change

Another body of research examines the influence of specific animations and visualizations on understanding and conceptual change for students of varying ages in various science subjects. The studies provide information about specific types of visualization, purposes for and methods of application, and the contexts and conditions in which visualizations have been used successfully to support conceptual understanding.

Although some studies have found that animations do not make a significant difference in student learning and conceptual change, others have shown that under certain circumstances animations can be a useful learning resource.

Özmen, Demircioğlu and Demircioğlu (2009) investigated the effects of animations on overcoming alternative conceptions of chemical bonding. The study included 28 students who received conceptual change texts coupled with computer animation instruction, and a comparison group of 30 students who received regular instruction with a teacher who used lots of examples and illustrations in a "chalk and talk" approach. The computer animation instruction, which involved active engagement and interaction, did not significantly change students' alternative conceptions of chemical bonding. These results suggest that it may be necessary to consider other ways of enhancing the learning of particular chemistry concepts.

In contrast, Yarden and Yarden (2010) compared the comprehension of the polymerase chain reaction (PCR) by Grade 12 students using animations as an aid with that of students using still images. The most salient finding was that PCR animations showed a distinct advantage over still images for student learning. However, the researchers caution that although animation was effective for demonstrations of molecular phenomena, the results may not generalize to other physical phenomena, such as motion.

Similarly, Holzinger, Kickmeier-Rust and Albert (2008) found discernible differences in learning performance between students who were exposed to dynamic media and those who were exposed to static media. Their study of 129 undergraduate computer science students indicated that the more complex the learning material, the greater the advantages of the dynamic media compared with the static. However, the researchers caution that "dynamic media are only appropriate and facilitate learning when they represent a meaningful model of a process or a system. This representation must also be within the limits of the cognitive system, and it must build upon learners' previous knowledge and expertise" (p 287).

Rieber (1990) compared the effects of using static graphics, animated computer visualizations and no graphics in elementary physics lessons. Results showed that "animated presentations of the lesson content influenced student performance when practice was provided; however, this effect was eliminated without practice" (pp 138–39). Rieber concluded that animations can be useful in science when lessons are adequately challenging and when an animation cues students' attention to the detail in the graphic. He suggests the following practices for the most effective application of animations in elementary science: (1) use lessons that require visualizing motion; (2) use material that is adequately, but not unreasonably, challenging; (3) cue students' attention to the detail of the graphic; and (4) use other instructional activities in conjunction with animations.

Computer visualization programs have been developed to supplement traditional textbooks in chemistry. Wu, Krajcik and Soloway (2001) report that a computer program called eChem was an effective visualization tool for helping Grade 11 chemistry students visualize, understand, and mentally manipulate interactions between and among chemical molecules. They found that using a combination of computational and concrete models helped students to acquire conceptual knowledge at the microscopic and macroscopic levels and to gain a more accurate understanding of properties, structures and underlying concepts.

The influence of diagrams on conceptual learning and understanding in science is another area that has been explored. Mathai and Ramadas (2009) studied the role of diagrams and text with 87 Grade 8 students learning about the digestive and respiratory systems. They found that the students experienced "difficulties in comprehending diagrams related to understanding of cross-sections, microscopic or chemical processes, and structure–function relationships" (p 449) and that the students showed more competence with and a preference for text over diagrams. This finding is not surprising, given that diagrams often cannot stand alone—they must be explained.

In contrast, Dechsri, Jones and Heikkinen (1997) examined whether illustrations and diagrams would improve the recall and comprehension of 83 undergraduate chemistry lab students. Their findings revealed that the students in the experimental group (who used a lab manual with accompanying pictures and diagrams) were better at interpreting data, better comprehended reaction rates and equilibrium, and demonstrated a more positive attitude toward laboratory work than the students in the control group (who used a lab manual with no pictures or diagrams). The study showed that "students perform better in the cognitive, affective and psychomotor domains" (p 901) when visual aids are accompanied by text in chemistry manuals.

By and large, the research on animations, visualizations and conceptual change indicates that visualizations are not effective in isolation. The application of scientific visualizations requires specific conditions. If visualizations are to support knowledge acquisition and conceptual change in science, they must take into account the levels and abilities of students and provide opportunities for explicit instruction on how to use visualizations. In addition, students must have the visual and spatial skills to understand and interpret the visualizations.

One study in particular underscores the importance of explicit instruction to ensure effective use of visualizations in science. Linn (2003) found that visualizations are useful for interpreting ideas. However, without instruction in visualization techniques, students often experience difficulty interpreting three-dimensional information. She discovered that learners may be confused by scientific visualizations because they do not have the same background knowledge as the people who created the visualizations. Although she recognizes the role of technology in science, Linn concludes that "the appeal of visualizations overshadows the challenges of designing effective material" (p 746). Linn's concerns draw attention to the importance of planning when and how to use different types of visualization in order to maximize their usefulness.

Visualization in science serves many purposes across a variety of disciplines. They provide a means for transforming, representing and communicating the essential functions and features of complex scientific concepts. Hall and Obregon (2002, 8) state that "images and graphics can be easily used to relay information over any distance, and in almost any discipline." Thus, visualizations have a wide range of possibilities and potential applications for those who understand how to read them and when to use them.

This review of visualization in science provides important insights into the application of various types of visualization in various science contexts. The research offers instructive guidelines and principles for making the most of scientific visualization.

Recommendations for the Development and Use of Visualization in Science

The effectiveness of visual representations is related to the contexts in which they are used; there is no direct path from visualization to understanding. Visualizations serve two primary functions: (1) to promote learning and understanding, and (2) to aid in analysis and problem solving. It is important to note that the purpose of an educational activity should have a bearing on the type of visualization chosen and on how it is used. The following recommendations are applicable to both static visualizations (drawings, graphs, diagrams) and dynamic media (animations, computer-based visualizations).

Recommendations for Visualization Objects

Visualization objects are used in science as an aid for both understanding and analysis. The dual-coding theory provides guiding principles for how visualizations can be used to help build understanding. From the DCT perspective, the fundamental premise is that visualizations must be accompanied by language-rich instruction. Based on our research and that of Vekiri (2002), we offer the following suggestions:

- Visual aids must be relevant to the lesson objectives. Expectations must be clearly articulated, and the type of visualization must be relevant to and appropriate for the particular task, the scientific concept, and the students' background knowledge and skills.
- The content of the visual aid is more important than the presence of colour or the depth of realism in drawings.
- Students require a repertoire of knowledge and skills to use visualization objects effectively. Visuospatial abilities are crucial to understanding and interpreting visualization objects in relation to space and time. Encourage students to construct their own visualization objects when it seems appropriate for specific learning outcomes.
- Visual aids should be combined with verbal or textual information for conceptual understanding. The visualization object should be coordinated with the verbal or print text so that students can see how the two fit together.
- Provide explicit explanations or guidance about the most relevant features and the application of the display. To avoid confusion or informational overload, there should be a match between the visualization object and the key components of the corresponding linguistic instruction (Vekiri 2002). Thus, the words and the visualization object should be presented in close proximity and simultaneously.
- Use visual aids as a supplement to text, not a replacement for text. Using a combination of visuals and printed information enables students to access information through the text, the visual or both.

The visual imagery hypothesis outlines how visualization objects are used as computational aids; thus, in this perspective, the most important aspect of visual images is to support thinking rather than to serve as an aid to encode nonvisual information. The interaction between the visual image and language is not important; rather, the main function of the image is to help students process and analyze information more efficiently, thus reducing the load on working memory. Information based on the image may allow learners to order, compare and manipulate the information. In turn, if students are to learn from a visualization, they must be able to discern which features are fixed, variable or irrelevant to the problem.

Pylyshyn (2003) outlines five ways in which visualization objects may help thinking:

- Visualization objects that show logical systems of visual operations (for example, a Venn diagram) can help students see logical relationships efficiently.
- Visualization objects can depict larger concepts broken down into smaller concepts.
- Visualization objects can depict the overall relationship between concepts in order to facilitate generalizations (for example, in diagrams and charts).
- Visualization objects can be used to track relationships and seek alternative solutions (for example, a graph that shows a relationship between two variables, which allows students to extrapolate or formulate a new hypothesis).
- Visualization objects provide a picture of the data that students can refer to and review in order to assist during recall of information.

Recommendations for Introspective Visualization

The idea of introspective visualization is prevalent in the popular literature, but there are few empirical studies on its effectiveness. Therefore, the potential benefits have not yet been determined, and this area requires additional research.

Recommendations for Interpretive Visualization

There is much to be learned about the comparative merits of teacher-produced visualization objects and those produced by students. However, there is some evidence to suggest that student-generated visuals are a viable form of interpretive visualization because they are personally meaningful and relevant to students' prior knowledge and the construction of meaning and understanding (Cifuentes and Hsieh 2003; Levie and Lentz 1982). In order to maximize the benefits of visualization, it is advisable to select visualization objects that are appropriate for the level of the students. Teach students how to work with visualization objects, and monitor and assess the appropriateness and effectiveness of visualizations.

Recommendations for Animations and Computer-Based Visualizations

Animations and computer-based visualizations are popular in science classes, and studies have shown a dramatic increase in their use since the 1980s. Like static visualizations, animations and computer-based visualizations can be divided according to function, either as an aid for understanding or for computational purposes. When the purpose of the visualization is to promote understanding, the animation should be supplemented with text or narration. Animations and computer-based visualizations can facilitate student interest and engagement, and provide opportunities for extra practice. However, further research is needed to assess whether and how they improve learning.

Research indicates that students of all ages are highly interested in and engaged with lessons that involve animations and computer-based visualizations. However, interest and engagement are not sufficient. Milheim (1993) acknowledges the powerful learning potential of using animations, but he also recognizes that an animation "will not necessarily be effective whenever it is used simply because it provides information in a somewhat motivating format" (p 173).

We have compiled the following recommendations to guide the development and use of animations in science:

- Animations and other computer-based visualizations are useful for getting students' attention and increasing their motivation and engagement in a lesson.
- Effective animations and other computer-based visualizations focus on the specific and important learning objectives.
- Use animations only when the knowledge to be gained is related to movement or if a concept can be better understood through a 3-D visual.
- Animations are useful for instruction that requires visualization (especially spatially oriented information).
- Use animations that are short, simple and obvious in terms of what is being demonstrated or represented. Avoid including distractions, and guard against visual overload.
- Provide immediate and continuous reinforcement and feedback to students when animations and other interactive or dynamic visualizations are used.
- Ensure that the speed of presentation and the zoom capabilities of animations can be controlled so that particularities can be emphasized when needed.
- Use animations and computer-based visualizations in conjunction with other instruction, not as a replacement for good teaching.

- Choose animations and other computer-based visualizations at a level appropriate to students' abilities and prior knowledge.
- Avoid using animations with novices who are unable to differentiate between the relevant details and cues of the animation. Not all students are prepared to make full use of visualizations.
- Use animations that have the potential to explain concepts that can't be seen (for example, subatomic collisions of particles).

Ultimately, the success of educational visualization, regardless of the form, depends on what learners bring to the task in terms of background knowledge, visuospatial skills and interpretive ability. Thus, "a thorough understanding of the nature of visualization objects, their functions . . ., and the interpretive skills essential to assess the plausibility, validity, and value of visual images is critically important" (Phillips, Norris and Macnab 2010, 27–28).

Conclusion

The use of visualization in teaching is advocated far and wide. Moreover, there is a widespread and unchallenged belief that visualization is useful in both teaching and learning. However, research shows that not all visualizations are created equal. The extant research provides evidence that visualization has an important place in science teaching and learning. Nonetheless, science teachers must be vigilant in order to ensure that visualization objects and activities are appropriate for each particular context, for each instructional purpose and, ultimately, for each student in the learning of science.

Note

This article is based on several chapters in Phillips, Norris and Macnab (2010).

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Fostering Scientific Vocabulary Learning: A Close Look at Science Trade Books in K–6 Classrooms

Yu Lei, Hagop Yacoubian, Sun Joo Hur, Carolyn Freed, Stephen P Norris and Linda M Phillips

Unlike inquiry-based instruction and hands-on scientific activities, which are generally recommended in teaching science, scientific vocabulary instruction has played a subordinate role in teaching scientific concepts. The reason for this might be that science learning historically has been seen as an active meaning-making process, while language acquisition has been viewed as a passive meaning-taking process (Yore, Craig and Maguire 1998). Underestimating the role of scientific vocabulary in science learning has led to less than optimum use of science books in the classroom (DiGisi 1993; Gottfried and Kyle 1992).

A number of studies have demonstrated that providing definitions for new vocabulary, exposing children to new vocabulary in a variety of contexts, using appropriate illustrations to support print, and relating new vocabulary to children's life experiences can significantly increase children's learning of new word meanings and concepts (Biemiller 2006; Hart and Risley 1995; McKeown 1993; Miller and Gildea 1987; Pressley, Levin and McDaniel 1987). These findings are frequently put into practice by teachers in the science classroom. However, print-based resources may contain features that inhibit the teaching of new vocabulary. Unfortunately, little research has closely studied the nature of books used for science teaching and how they support children's vocabulary learning and development; thus, we know little about how well these resources function. This area deserves a more complete investigation, because teachers need guidance on how to select books that best foster children's learning of new scientific vocabulary.

The study we report on in this article focused on whether and how science trade books support children's acquisition of scientific vocabulary. The purpose of our study was to examine features of science trade books and to determine whether those features conform to what the research suggests best supports scientific vocabulary learning.

We first provide a brief summary of important research on vocabulary learning. Second, we describe the creation of our book evaluation model based on this research. Third, we present the results of our evaluation of science trade books selected from a school library in Edmonton, Alberta. Fourth, we discuss the challenges faced by teachers when selecting teaching resources, and the practical implications of our study. Finally, we describe a promising database we are developing to help teachers select trade books that have the desirable features for fostering vocabulary learning.

Vocabulary Learning

Much research has been devoted to investigating vocabulary development in children from kindergarten to the upper elementary grades, but we found no study that focused on the development of scientific vocabulary. Our review of the literature thus focused on the extensive research examining children's learning of vocabulary from a broader perspective.

A common idea found in the literature is that word learning is a combination of learning both word form and word meaning. *Word form* is the spoken or written word, or the word that is heard or read. *Word meaning* is the sense of the word or the word's referent (Biemiller 2006; Bloom 1998; Woodward and Markman 1998).

For example, Carey (1978) observed that young children usually acquired a new word form quickly, but it took them longer to fully understand and use the word.

In this article, we use the term *vocabulary development* to refer to learning new word meanings or concepts. For the purpose of examining to what extent science trade books support children's vocabulary development, our review focuses on the circumstances under which word meanings are acquired.

Use of Children's Literature

Reading is widely viewed as an important way to expose children to new vocabulary and as a factor in vocabulary development (Nagy and Scott 2000; Tabors, Beals and Weizman 2001). Beck, McKeown and Kucan (2002) suggest that the more variety in children's reading, the more new vocabulary children will encounter. They further argue that rich explanations of word meanings and opportunities for children to play word games during reading will help them develop deep knowledge of words. In addition, using children's literature helps promote children's interest in learning vocabulary and helps them develop a positive attitude toward reading (Atwell 1987; Baumann, Kame'enui and Ash 2003; Bridge, Winograd and Haley 1983).

Language Interaction with Children

Dickinson, Cote and Smith's (1993) study on teacher–child interaction shows that properly structured interaction promotes children's language and literacy skills. The researchers suggest that teachers' use of new vocabulary, cognitively challenging talk, explanation and idea sharing contribute positively to children's vocabulary growth. Tizard and Tizard (1974) studied the language development of children in an orphanage. They found that the level of language development highly correlated with the language the nurses used with the children. Children in the care of nurses who "offered more informative talk, spoke in longer sentences, gave fewer negative commands, and were more likely to explain themselves when they told the child to do something" (p 143) learned dramatically more vocabulary than those in the care of nurses who were less responsive to children and who merely followed procedures.

Similar findings exist for interactions within families. Hart and Risley (1995, 1999), for example, found that children's vocabulary positively correlated with the number and types of words parents used with them, and with suggestive rather than directive language. In general, research has demonstrated that interactions between children and adults who actively engage in dialogue help create a comfortable and positive language environment for children to build vocabulary.

A recent review by Phillips, Norris and Anderson (2008) concluded that it is not only the quantity of interaction with parents and teachers that affects children's vocabulary learning. In addition to merely reading to children, adults should point to pictures to explain vocabulary, introduce word meanings to children while they are focusing on the word forms (Baumann, Kame'enui and Ash 2003), ask questions (Blewitt et al 2009) and encourage children to read themselves (Whitehurst et al 1994). Blewitt and her colleagues found that not only children's vocabulary learning but also their comprehension of stories improved when they were asked questions and received explanations of target words during shared reading. In addition, children's comprehension was enhanced when simple rather than high-demand questions were asked at a word's first appearance. Specific questions (such as "Is the dog barking?") are more beneficial to vocabulary growth at the beginning of reading than are general statements (such as "Tell me something about the dog"). As children get better at the task of shared reading, the questions can become more demanding.

Bus, van IJzendoorn and Pellegrini (1995) studied the relationship between reading books to children and children's vocabulary development. They concluded that the frequency of parents' reading to children explains only 8 per cent of children's vocabulary learning. Simply reading to children does not help much with vocabulary growth. Sénéchal and Cornell (1993) had similar findings. They assessed preschool children's vocabulary learning after storybook reading by parents. They found that reading to children without asking questions and discussing the story was not sufficient to enhance vocabulary development.

Effective Methods for Reading to Children

Jenkins, Stein and Wysocki (1984) have demonstrated that the more frequently a word appears in text, the more likely that it will be learned. Similar findings are reported in other studies (Finn 1977/78; Hoffman 1980; Robbins and Ehri 1994; Sénéchal 1997).

Robbins and Ehri (1994) found that kindergarten children learned more new words when a story was read to them at least four times. In addition, reading storybooks to children is beneficial for their acquisition of novel words. More specifically, Sénéchal (1997) found that repeated reading with questioning was the most effective way to increase vocabulary.

Providing clear and concise definitions using language familiar to children is more effective in teaching new vocabulary than asking children to look up new words in the dictionary (McKeown 1993). Several studies have concluded that helping children focus on word meaning and applying new words in meaningful contexts is preferable to having them use a dictionary (Beck, McKeown and Kucan 2002; Stahl and Fairbanks 1986).

Snow (1983) suggests that adults continue discussion on the story topic after reading to children. This active participation and structured dialogue will help children learn vocabulary. This claim has been supported by subsequent research. Dickinson and Smith (1994) found that discussions and explanations during reading did not have a significant effect on children's vocabulary learning; however, discussions before and after reading were helpful, with after-reading discussion being the most beneficial.

Providing context clues is often viewed as an important method to help children learn vocabulary. Sénéchal and Cornell (1993) pointed out in their study that children may be able to learn new words just by listening to or looking at the context of sentences and the accompanying illustrations. Written sentences and illustrations can convey the association between a word form and the word meaning. Biemiller (2006) showed that embedding new words in meaningful contexts is helpful for increasing children's vocabulary. Earlier studies focusing on the role of context clues in vocabulary learning include McKeown (1993), Shefelbine (1983) and Jenkins, Matlock and Slocum (1989).

Method and the Evaluation Model

In evaluating science trade books, we used a model based on the major findings in the literature on vocabulary learning. For example, considering the beneficial features of adult–child interactions during or after reading, we looked at whether a book contained open-ended questions, whether it included projects requiring children to experiment and discuss, and whether it provided any guidance for teachers or parents on creating fruitful interactions with children.

We defined six categories of criteria for our model:

- Defining key vocabulary
- Repeating key vocabulary
- Relating to readers' life experiences
- Providing examples or context for key vocabulary
- Using illustrations
- Including activities or open-ended questions relating to the book topic

Each category was assessed by answering one to three questions. In total, 13 questions were developed across the six categories (see Appendix A). We used scores ranging from 0 to 2 to determine to what extent a book met the standard in each question (0 = not often or never; 1 = sometimes; 2 = always or most times). The highest possible score for a book was 26.

We randomly selected 203 science trade books from an elementary school library that housed approximately 1,000 such books. The topics of the books related to Alberta's K–6 science curriculum. The school was an elementary science alternative school with Edmonton Public Schools.

Based on the evaluations, we determined the percentage of books obtaining scores of 0, 1 or 2 for each of the 13 questions. We also determined the range of total scores for books to allow teachers to compare the books based on their potential to foster children's vocabulary development.

Results and Discussion

In terms of percentile rank, 20 per cent of the science trade books received a total score of 8 or lower, and the top 20 per cent scored 19 or higher. Also, 40 per cent of the books scored lower than 13, which means that on average they scored lower than 1 on each question. A score of 1 means that a feature appeared only sometimes in a book, so we deemed any score lower than 13 to be mediocre. Thus, 40 per cent of the books lacked adequate text, organization and illustration features for supporting the teaching of scientific vocabulary.

The books in the 41st to 60th percentile range scored on average 1 or slightly higher than 1 on each question. Before teachers could effectively use these books to teach vocabulary, they would need extensive preparation, such as locating the new words in the book, developing a glossary for the new words, developing discussion questions and providing examples. For any teacher these books might prove useful, but considerable effort would be needed to develop supplementary material. Only 20 per cent of the books (those in the 81st percentile and above) had an average score per question of 1.5 or higher. Such books displayed the desired features all or most of the time.

To investigate in more detail how the science trade books supported vocabulary learning, we examined the percentage of books scoring 0, 1 or 2 for each evaluation question:

- Less than half of the books provided a glossary for new scientific words.
- More than 70 per cent of the books that did provide definitions defined the words in language suitable for children.
- Even though most books did not highlight key scientific vocabulary, the words were usually repeated throughout the books.
- Only 30 per cent of the books regularly related children's life experiences to scientific topics or concepts.
- More than half of the books provided examples to explain key scientific words and used the words in context.
- Illustrations were frequently used, and they were used to present realistically the objects or phenomena described in the books.
- About 90 per cent of the books did not provide a guide for teachers. This finding is not surprising; trade books are not necessarily written to serve as curriculum materials. However, because teachers' guides provide a general idea of how books are organized, what features teachers can use to help them teach and what cautions need to be taken (particularly with books containing experiments), their scarcity is to be regretted.
- Discussion questions and hands-on experiments or activities were not promoted by most of the books.
- As indicated in the research literature, adult–child interaction during and after reading is crucial for children to fully understand the meanings of new words. However, this interaction was not realized in a large portion of the trade books.

Here are two examples to illustrate the importance of including open-ended questions or activities in science trade books. *Tigers: Striped Stalkers* (Richardson 2002) introduces young readers to tigers and their habitat. Some science topics are difficult to relate to children's life experiences, and consequently are more difficult for children to understand. Although the book uses photographs of tigers in a variety of postures (roaring, scratching a tree trunk, mating) to give readers a concrete idea of tigers, the attempt is limited by the fact that tigers are not like dogs or cats, which children see and touch in ordinary life. At the end of the book, children are instructed to use pencils and a yardstick to measure a distance of about nine feet, which is approximately the size of a tiger. This activity helps children build knowledge of how big a tiger is compared with their own size. It also allows them to reflect on and discuss what they have learned in the process of doing the activity.

Matter, Matter Everywhere (Pan-Canadian Science Place Team 2000) uses simple language to introduce the concept of matter to young children. After a brief description of the scientific facts, each small section of the book usually includes a hands-on activity and open-ended questions to encourage children to relate what they have read to their own experiences. For example, in the section on introducing solids, children are asked to look at a piece of chocolate and discuss its shape and size. Then they are asked to break the chocolate into smaller pieces and discuss whether the size and shape have changed and whether the pieces are still chocolate. This activity uses a familiar material (chocolate) to convey the information that a solid has a definite shape, that it will not change shape by itself, and that its substance remains the same even when its shape has been changed. Open-ended questions such as "How are solids like each other?" and "How are they different?" also offer children opportunities to use the new words they have learned.

Discussion and Conclusion

During our research project, we held a workshop with teachers in the school to introduce them to the study and invite them to reflect on their selection of science trade books. The teachers reported selecting books according to their own criteria but thought that the 13 questions we were using to evaluate the books would be useful to them.

Even though the results from our analysis indicate that science trade books have shortcomings in supporting children's learning of science vocabulary, the books can be carefully selected and used for other teaching purposes. For example, the books that scored poorly on our scale do not have the distinctive features to assist in vocabulary teaching, but they still may be useful for introducing new scientific concepts or ideas to children.

Illustrations were used extensively in the books to help readers build concrete knowledge and to clarify difficult or complicated scientific topics. Photographs representing objects in a realistic way were frequently used. However, nearly one-fifth of the books did not provide realistic illustrations. Those books generally used drawings that were poor. For example, a book on birds contained hand-drawn pictures that were not to scale and that used inexact colours, reducing the usefulness of the illustrations in bird identification. Yet illustrations play an important role in introducing scientific concepts. A photograph of germs under a microscope is more appropriate in many cases than a drawing of germs.

It is unfortunate that many of the books did not provide user guides, discussion questions or activities. If designed well, a book can provide teachers with good ideas for asking questions to promote discussion and for leading activities that may interest children in learning more about the topic. Many of the books would be more useful if they asked open-ended questions rather than yes-or-no questions, if they related questions or activities to children's life experiences, and if they encouraged children to use new words in discussions. We understand that many trade books are written for general consumption. However, since many of the books are used by teachers to teach reading and science, it is fair to note that many fail to provide supportive teaching resources.

It is clear that the science trade books we surveyed did not sufficiently emphasize vocabulary development. Many of the books provided general support for children's learning of new vocabulary, but they were varied in how and to what extent they emphasized new words. Overall, the books included few or no questions for discussion and few or no experiments. Despite the increasing evidence of the benefits of adult–child interaction in children's vocabulary development, questions for discussion are rarely included in science trade books. However, armed with the criteria that we have provided for judging trade books, creative teachers can develop ways to supplement the books in the areas in which they are deficient. We hope to help by making our evaluations available in the form of a searchable online database of science trade books.

Appendix A

Evaluation Criteria and Questions

Defining Key Vocabulary

1. Are definitions of scientific vocabulary provided in a glossary?
2. Are definitions of scientific vocabulary provided in the text?
3. Is the majority of scientific vocabulary defined suitable for children in the recommended reading level?

Repeating Key Vocabulary

4. Are important or key scientific words highlighted (bolded or italicized) in the text whenever they appear?
5. Are new words repeated in the book?

Relating to Readers' Life Experiences

6. When new scientific vocabulary or concepts are introduced, does the book relate them to children's life experiences?

Providing Examples or Context

7. Does the book provide examples of the scientific vocabulary?
8. Is the new scientific vocabulary used or repeated in context?

Using Illustrations

9. Does the book relate the scientific vocabulary to illustrations?
10. Do the illustrations present the named objects realistically?

Including Topic-Related Questions

11. Does the book provide a users' guide for teachers?

12. Does the book provide open-ended questions that invite children to use the new vocabulary?
13. Does the book provide activities that create opportunities for peer discussion by using the new vocabulary learned?

Note

We acknowledge the support of the principal, teachers and librarian at Elmwood School, Edmonton Public Schools, in conducting this study. It would not have been possible without their permission to access their extensive collection of science trade books.

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Concepts of Evidence in High School Chemistry Textbooks

Elizabeth Vergis

This study focused on how evidence is represented in high school chemistry textbooks. Concepts of evidence, as articulated by Gott et al (2003), were identified and compared across three leading textbooks used in Canada. I attempted to answer the general question of how comprehensively and systematically those textbooks represent evidence.

Science is heralded as a core subject in the K–12 curricula of Canada and other industrialized countries. If this status is to be maintained, then science must have universal worth—providing value both to those working in a nonscience environment and to the minority who will pursue science as a lifelong career. For most students, science is part of their general education—one aspect of their preparation for life. Consequently, there is a growing call for science education to better prepare students for citizenship (Jenkins 1997; Millar and Osborne 1998).

Science education in the service of general education takes as its aim the improvement of scientific literacy and of the public understanding of science. Although there is no single definition of *scientific literacy* (Norris and Phillips 2003), a common understanding is that it is related to making informed decisions about the interrelated educational, scientific and social issues that confront us every day and that have a scientific underpinning (Glynn and Muth 1994). Scientific literacy thus involves more than having science knowledge. To be scientifically literate, people must have the ability to read and evaluate the science-related information they encounter, as well as the ability to communicate their thoughts to others (Holliday, Yore and Alvermann 1994). This evaluation of scientific information or data can be enhanced by a proper understanding of concepts of evidence.

Despite the growing call for science education to better prepare students for citizenship, there have been few attempts to develop a curriculum commensurate with this goal (Millar 2006). Science courses that are scant in the way they treat the “nature, practices, and processes” (Osborne et al 2003, 693) of this subject produce students who are naive or very limited in their understanding of concepts of evidence in science when they leave school. The education that students get in science can also foster in them a negative attitude toward the subject itself (Osborne and Dillon 2008). Indeed, as early as the elementary and middle grades, students begin losing interest in science (Bordt et al 2001). By high school, students of all achievement levels find science hard, dull and meaningless (p 9), leading to a growing trend (at least in Canada) for students to drop science in high school.

To address this situation, we must reconsider the aims and purposes of science education. It is my contention that an understanding of scientific evidence and its relationship to scientific concepts is valuable in enabling and empowering citizens to use science in their everyday lives, and in addressing many of the factors that lead to early and enduring disenchantment with science. Evidence and its interpretation are at the centre of any controversy in science (such as global warming or evolution) and, of course, are central to the empirical sciences.

However, I do not wish to challenge the position that learning science requires the acquisition of substantive knowledge and skills. The substantive knowledge includes understanding the facts, concepts and theories of science. The skills include knowing how to use an analytical balance, how to draw a graph, how to set up a distillation apparatus and how to focus a microscope. However, it is not always recognized that these skills have a distinct knowledge base connected directly with the understanding of scientific evidence. The skills must be exercised within a procedural understanding of such ideas as variables and their manipulation, accuracy, fair testing, and the validity and reliability of evidence. It is these ideas that Gott et al (2003) have collectively termed *concepts of evidence*. Concepts of evidence (CoEs) constitute a knowledge system similar to substantive knowledge that has traditionally been perceived as central to science education (Gott and Duggan 1996).

If we accept that concepts of evidence form an important part of scientific knowledge, and a part that is crucial to the citizen, then decisions must be made about the best way to teach CoEs. There is growing suspicion that CoEs are neither systematically nor comprehensively presented in the secondary school science curriculum (Gott and Johnson 1999). There is also widespread concern that the traditional substantive knowledge is so vast that there is insufficient time to cover both it and more general issues, such as the understanding of evidence (Millar and Osborne 1998). As a consequence, it has been suggested that the substantive content of science courses be reduced to make room for such knowledge as the understanding of evidence, because it is this latter knowledge that students will primarily use in coping with controversial socioscientific issues, such as global warming or evolution, that will arise in their later lives as adults (Layton et al 1993).

Background

Several studies have shown that there is "a poor match between the scientific content generally taught in high school and university science courses and the type of scientific understanding required for success in science-based occupations" (Aikenhead 2005, 243). Duggan and Gott (2002) discovered that in all the industrial, science-rich workplaces they investigated, most of the employees' understanding of the required scientific concepts was attained on the job, not in science courses. Aikenhead (2005) investigated the "science-related knowledge . . . used by nurses in their day-to-day clinical reasoning when attending patients" (p 242). He looked at the "knowledge-in-use" employed by six acute care nurses working in the surgical unit of a hospital (p 242). Aikenhead established that as the nurses attended to the data gathered from their patients, they used a core set of concepts of evidence much as Gott et al (2003) describe.

Kuhn, Amsel and O'Loughlin (1988) focused on how the ability to partake in scientific reasoning develops in young people. They studied the ability of students of varied ages in evaluating the theories handed to them (or theories they themselves had proposed) using the evidence provided. They also examined how the students' own theories affected this evaluation process (Kanari and Millar 2004). In this study, the word *theory* represented a profession that "a given dependent variable does, or does not, covary with a given independent variable" (p 749). Kuhn, Amsel and O'Loughlin (1988) concluded that the coordination of theory and evidence is a process controlled by developmental change. Many young students fail to consider the fallibility of their own hypotheses, and the plausibility of theories other than their own. The ability to clearly distinguish evidence and explanation (or conceptualization) requires time to sprout and develop. According to Kuhn (1989, 674), "these skills in coordinating theories and evidence are the most central, essential and general skills that define scientific thinking." Kuhn also reviewed the research done in this area and demonstrated that the processes that constitute scientific thinking show marked differences depending on who the subjects are—children, lay adults or scientists. She proposes

> a framework for conceptualizing the development of the scientific thinking process, centering on progressive differentiation and coordination of theory and evidence. This development is metacognitive, as well as strategic. It requires thinking about theories, rather than merely with them, and thinking about evidence, rather than merely being influenced by it, and, hence, reflects the attainment of control over the interaction of theories and evidence in one's own thinking. (p 674)

Experimental skills have a distinct knowledge base that is connected directly with the understanding of scientific evidence. Procedural knowledge includes ideas "that are essential in the collection, understanding and evaluation of scientific evidence" (Roberts and Gott 2000, 83), among other things. Procedural understanding is a set of ideas complementary to substantive understanding but related to the knowing-how of science. It is concerned with the understanding needed to put science into practice. "It is *the thinking behind the doing*" (Gott and Duggan 1995, 26). Consider this example: in a plant growth study, *procedural understanding* refers not only to the measuring itself but also to the decisions that have to be made about what to measure, how often to measure and over what period of time. Lubben and Millar (1996) define *procedural* *knowledge* as "knowing how to carry out practical tasks" (p 957), including measuring. It also includes an understanding of the notion of fair test, as well as understanding the nature of a line graph, how it differs from a bar chart and how it illustrates patterns between variables. The building blocks that constitute procedural knowledge, relating substantive knowledge and evidence, are concepts of evidence.

Concepts of Evidence

Concepts of evidence were developed by Gott and Duggan (1995) to describe the procedural understanding necessary for working in all science disciplines. In this early version, the descriptors could be interpreted as being restrictive in that they were more closely allied to lab-based investigations, rather than being applicable to the many other types of science-based work, especially where relationships between naturally changing variables are studied (such as in biological fieldwork). More recently, Gott et al (2003) have defined CoEs in such a way that they can be much more readily applied to the range of contexts found in all branches of science. According to Roberts and Gott (2004, 11), CoEs supply "the underpinning ideas about how evidence can be *collected, verified, analysed and interpreted.*" They can be thought of as the building blocks of procedural knowledge.

This compendium of CoEs comprehensively but tentatively defines concepts of evidence ranging from the ideas associated with a single measurement to those associated with evaluating evidence as a whole. The latest version of the compendium (Gott et al 2003) includes 21 categories, as shown in Appendix A. The categories include Observation, Measurement, Instruments: Calibration and Error, and Reliability and Validity of a Single Measurement, and each is assigned one of three degrees of complexity. Each category is subdivided, and some of the subcategories are shown in Appendix A. This list of CoEs was informed by research and writing in primary and secondary science education, in science-based industry, and in the public understanding of science. Gott et al (2003) hypothesize that although some of these CoEs are fundamental and appropriate at any age, others may be necessary only for a student engaged in a particular branch of science.

What Is Evidence?

Evidence can be defined as the "information bearing on the truth or falsity of a proposition" (Feldman 1999, 293). In a philosophical sense, "a person's evidence is generally taken to be all the information a person has, positive or negative, relevant to a proposition" (p 293). Put simply, evidence is information supporting or refuting an assertion.

Evidence "plays a central role in our understanding of knowledge and rationality" (Feldman 1999, 293). One is said to have knowledge when one holds a belief that is not only true but also backed by strong evidence. Our senses are "a primary source of evidence" (p 293). Therefore, "for most, if not all, of our beliefs, ultimately our evidence traces back to sensory experience," and experience counts as evidence (p 293). "Memory and the testimony of others" are two further sources of evidence reliant on the senses (p 293). Evidence can also be gathered through reason and reflection (p 293).

Methodology

This study is primarily analytic and evaluative, designed to determine what CoEs are present in the particular textbooks chosen, in what abundance, and how and with what curricular implications they are distributed.

Sampling

For this study, sampling took place at three levels. At the first level, chemistry textbooks were selected using a purposive technique. From all the high school chemistry textbooks currently authorized by Canada's provincial and territorial ministries of education, the three most commonly used were chosen:

- *Nelson Chemistry* (Jenkins, van Kessel and Tompkins 1993) (hereafter, *Nelson*)[1]
- *McGraw-Hill Ryerson Chemistry 11* (Mustoe et al 2001a) and *McGraw-Hill Ryerson Chemistry 12* (Mustoe et al 2001b) (hereafter, *McGraw-Hill Ryerson*)
- *Chemistry* (Chang 2005) (hereafter, *McGraw-Hill*)

McGraw-Hill caters specifically to students in the International Baccalaureate (IB) program.

At the second level of sampling, to facilitate the selection of topics within textbooks, the Alberta Chemistry 20 (Grade 11) and Chemistry 30 (Grade 12) curricula were used.[2] Two prescribed topics were chosen at random: Solutions (covered in Grade 11 only) and Acids and Bases (covered in Grades 11 and 12). Generally, Solutions was covered in a single chapter in each of the three textbooks, and Acids and Bases (started in Grade 11 and completed in Grade 12) spanned about two and a half chapters.

At the third level of sampling, all the pages under each topic were included, except for end-of-chapter summaries, exercises (including dry labs and wet labs), samples of solved problems, molecular models, structural formulae showing mechanisms, biographies of scientists and accounts of their daily work, keywords, and review questions. I focused exclusively on the prose aspects of the textbooks, recognizing that the books are multi-semiotic.

Identifying Situations

The pages included in the samples were read and studied first to identify situations. By *situations* I mean places in the text describing an observation, or a diagram depicting a change that could be observed. The observation may be one that is described in the body of the text, or a physical or chemical change that will be observed during the course of an experiment or investigation that students are asked to conduct or that is demonstrated to them by the teacher. A situation can also be the description or photographic representation of an observable change in any form of matter within the body of the textbook.

The situations identified were consecutively numbered, starting with 1.

Coding Situations

I searched each situation to see which of Gott et al's (2003) CoEs were present. Categories and subcategories of CoEs in each situation were identified. Comments about the various categories and subcategories of CoEs in each situation were carefully noted where necessary. Each situation was coded by at least one major category of CoE, and frequently by one or more subcategories. On some occasions, no suitable subcategory was found, but a new subcategory was proposed for addition to Gott et al's classification system.

Each textbook was examined for all references to procedural understanding of the ideas that are essential in the collection, understanding and evaluation of scientific evidence (that is, understanding of concepts of evidence). When the procedural idea was clearly pointed out in the text, with an indication of how it could be taught, it was considered to be an explicit reference. A reference was considered to be implicit if an opportunity was provided to teach the idea but the idea itself was not clearly spelled out. Implicit references, therefore, were dependent on teachers spotting the procedural idea and working it into the lesson. An implicit reference to a procedural idea is obviously more open to individual judgment and bias than are explicit references. Thus, the data related to implicit references must be treated with a degree of caution.

Reliability of Coding

The coding of the CoEs was evaluated independently by a professor of chemistry, who coded Situation 5—the iodine clock reaction—from *Nelson,* using the same system of classification of CoEs as I used. I categorized each reference to a procedural idea as either explicit (where the procedural idea was clearly pointed to in the text) or implicit (where the procedural idea was not clearly spelled out).

The chemistry professor and I had 100 per cent agreement with the explicit references; however, with the implicit references, our agreement was only 78 per cent. This may be because implicit references to procedural ideas are more open to individual judgment and interpretation, and the coding will therefore depend on whether a chemist or an educationist is doing the coding.

Data Tabulation and Standardization

Once the situations had been identified, and the CoEs in each had been categorized and subcategorized, the frequency of occurrence of each CoE by situation was determined and compared by grade level, publisher and topic. The total set of identified CoEs was examined in comparison with Gott et al's (2003) system to identify any gaps in the depth, accuracy and appropriateness of the occurrences. In making comparisons between textbooks, I adopted the measure of the number of CoEs per set number of words of text as a way to standardize the number of CoEs observed.

Results and Discussion

The data obtained from identifying CoEs for *Nelson* will be discussed in detail. Similar data were obtained for the other two textbooks, but for brevity only data comparative to *Nelson* will be reported here.

Nelson

Table 1 shows the frequency of CoEs by situation in *Nelson* under the topic Solutions (Grade 11). The 19 situations under this topic are numbered in the first column. The frequencies of CoEs are shown in the columns labelled 1–21 (refer to Appendix A for the CoE descriptions). The last column lists the total number of CoEs in each situation. Some situations contain hardly any CoEs (for example, Situation 10 with 1 CoE, and Situation 6 with 2 CoEs), while others have many CoEs (for example, Situation 15 with 71 CoEs, and Situation 16 with 41 CoEs). Many CoEs have zero representation. The mean number of CoEs per situation in Table 1 is 22. The CoEs appear with frequencies ranging from 2 (for CoE 8, Sampling a Datum) to 51 (for CoE 5, Instruments: Calibration and Error). Instruments: Calibration and Error is by far the CoE that occurred most frequently. The last row of the table gives the frequency of each CoE per 500 words of text. These numbers are used subsequently when comparing the frequency of CoEs across publishers.

The longer version of this article (available at www.uofaweb.ualberta.ca/edpolicystudies/crystalalberta.cfm) contains two additional tables similar to Table 1.

Table 1

Frequency of CoEs by Situation in *Nelson* (Solutions–Grade 11)

	Concepts of Evidence																			
Sit. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	19	20	21	Total
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
2	1	1	1	2	3	3	3	0	0	2	2	2	3	1	1	2	1	2	2	0	32
3	1	1	1	2	3	3	3	0	0	2	2	2	3	1	1	2	1	2	2	0	32
4	2	1	1	2	4	3	3	0	0	2	2	2	3	1	1	2	1	2	2	2	36
5	1	3	2	1	4	3	3	0	1	1	2	2	3	2	1	2	1	1	2	2	37
6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
9	1	1	0	0	0	0	0	0	0	0	2	2	3	1	1	2	1	2	2	2	20
10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
11	1	1	1	1	3	2	3	1	0	1	2	2	3	1	1	2	1	2	3	2	33
12	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
13	2	2	2	2	4	3	5	0	0	4	0	0	0	0	0	4	0	0	0	0	28
14	1	2	2	2	2	3	3	1	1	2	2	2	3	1	1	2	1	2	2	0	35
15	5	6	7	5	14	5	12	0	0	10	0	0	0	0	0	6	0	1	0	0	71
16	2	4	6	2	7	3	5	0	0	4	2	1	0	1	1	2	0	1	0	0	41
17	2	1	1	1	2	3	4	0	1	0	3	2	0	0	0	0	0	1	0	0	21
18	0	2	1	1	4	3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	15
19	1	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	9
Total	24	32	26	22	51	35	48	2	4	28	19	17	21	9	8	26	7	17	15	8	419
Frequency /500 Words of Text	1.78	2.38	1.93	1.63	3.79	2.6	3.57	0.15	0.3	2.08	1.41	1.26	1.56	0.67	0.59	1.93	0.52	1.26	1.11	0.59	31.11

The first additional table (labelled Table 3 in the longer article) depicts the frequency of CoEs by situation in *Nelson,* still at the Grade 11 level but under the topic Acids and Bases. There are only four situations here (compared with the 19 in Table 1), but 17 textbook pages are devoted to this topic (compared with the 13 devoted to Solutions). The situations have a total number of CoEs varying from 12 to 50. The mean number of CoEs per situation is 31. There is a smaller proportion of CoEs with zero representation in this table (23 per cent) than in Table 1 (46 per cent). The frequencies for individual CoEs range from 2 for CoE 9 (Statistical Treatment of Measurements of a Single Datum) to 12 for CoE 6 (Reliability and Validity of a Single Measurement). With a total occurrence of 3, CoE 8 (Sampling a Datum) is next in line. Similar to what was reported in Table 1, in this table CoE 8 is still near the lowest frequency and CoE 5 (Instruments: Calibration and Error) is near the highest.

The second additional table (labelled Table 4 in the longer article) depicts the frequency of CoEs by situation, still in the topic Acids and Bases but at the Grade 12 level. There is a dramatic six-fold increase in the number of situations from 4 in Table 3 to 24 in this table. The corresponding number of pages in the textbook has increased from 13 to 39. The number of CoEs per situation ranges from 14 to 59. All the situations listed in this table contain a significant number of CoEs (with a mean of 40), and generally they contain more CoEs than the situations in Table 3. The individual CoEs range in total frequency from 14 for CoE 9 (Statistical Treatment of Measurements of a Single Datum) to 85 for CoE 5 (Instruments: Calibration and Error).

Comparisons Between Publishers, Topics and Grades

Figure 1 compares the total number of situations per 500 words of text in the three textbooks. *Nelson* has the most situations per 500 words of text, followed closely by *McGraw-Hill,* and then by *McGraw-Hill Ryerson* (which has less than half of the situations per 500 words of text that *Nelson* has).

Figure 1

Number of Situations per 500 Words of Text (by Publisher)

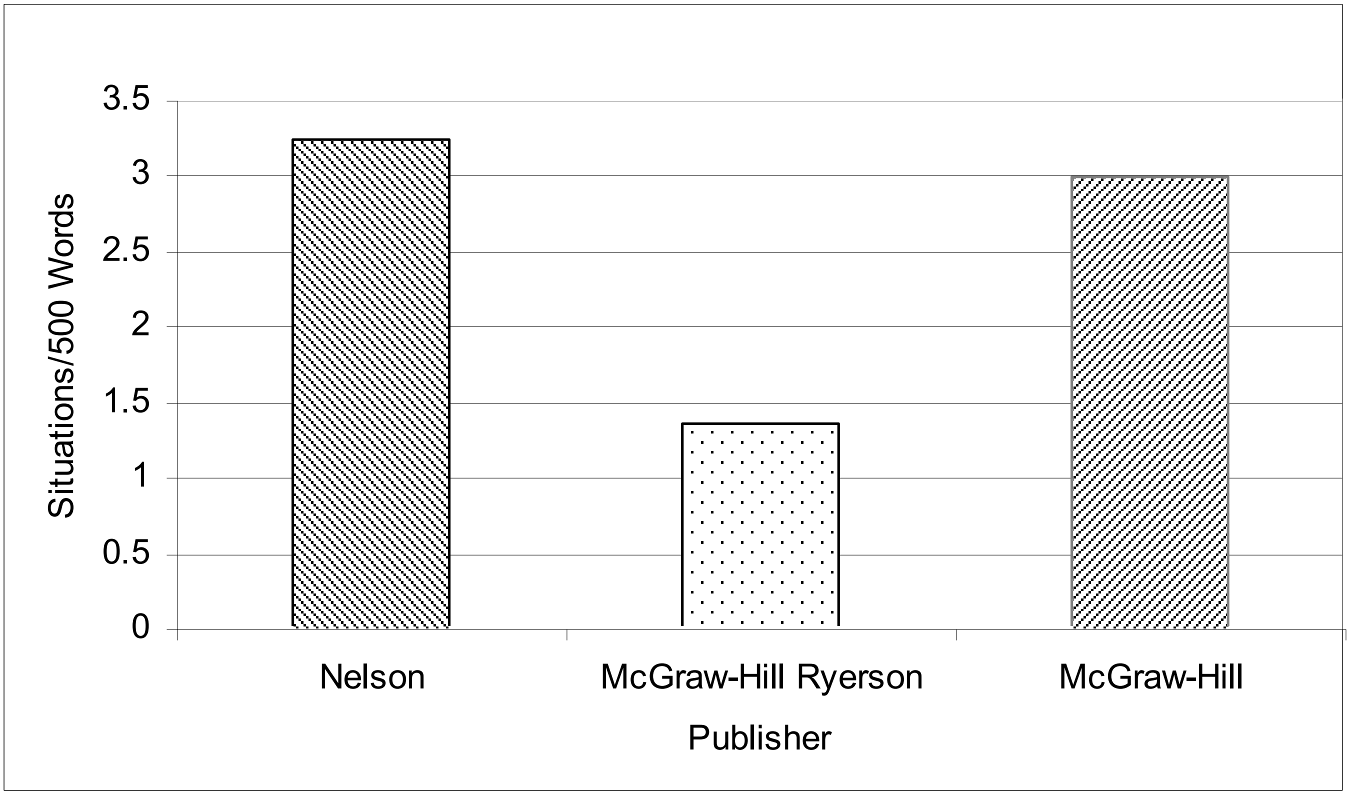


Figure 2 depicts the number of situations per 500 words of text by topic and by publisher. The greatest number of situations is found in the topic Solutions, followed by Acids and Bases (Grade 12). Under Solutions, *McGraw-Hill* has the most situations per 500 words of text, followed by *Nelson; McGraw-Hill Ryerson* has the fewest situations. Under the topic Acids and Bases (Grade 12), *Nelson* has the most situations per 500 words of text, followed by *McGraw-Hill.* For the topic Acids and Bases (Grade 11), *McGraw-Hill* has the most situations, followed closely by *Nelson.*

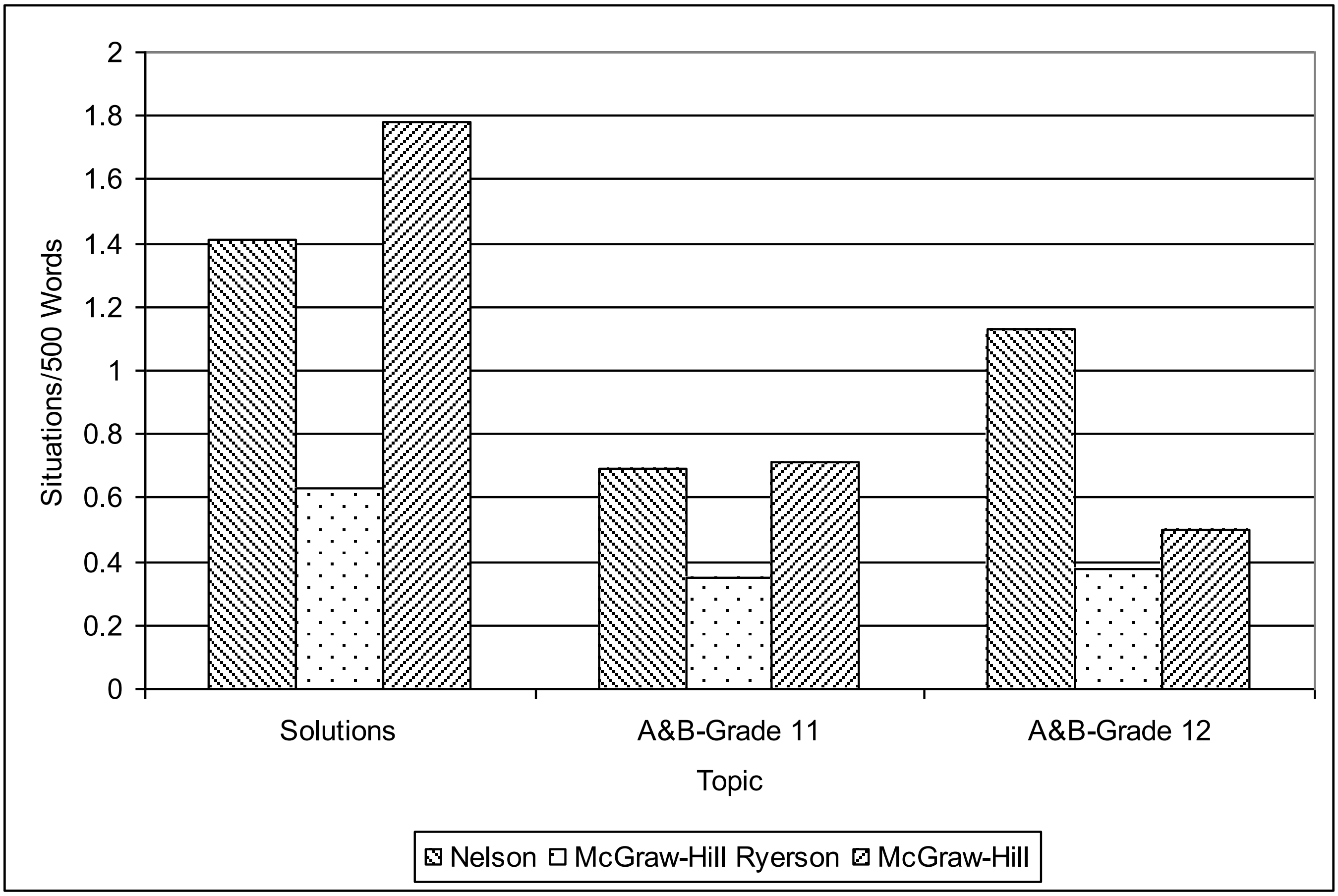
Figure 3 displays the mean number of CoEs per situation (that is, how laden the situations are with CoEs). The same ordering is found in two of the textbooks (*Nelson* and *McGraw-Hill Ryerson*), with Acids and Bases (Grade 12) having the greatest number of CoEs per situation, followed by Acids and Bases (Grade 11), and then by Solutions. In *McGraw-Hill,* there is little variation across topics.

In Figure 4, the frequencies of CoEs per 500 words of text have been rank ordered. The five CoEs that occur most frequently are associated with the basic and fundamental handling of data, and it is perhaps appropriate that these CoEs are emphasized at the high school level, although they should also have been covered in earlier grades. The five CoEs that occur least frequently deal with more sophisticated handling of data and laboratory instruments. In the middle range of frequency of occurrence are the most sophisticated CoEs, which focus on investigations as a whole, with their design, logic and relevance outside of science.

It strikes me that this distribution of frequencies is not entirely sensible. For example, although it might make sense for the simplest ideas about evidence to be treated the most frequently, it does not make obvious sense that the next most frequently treated ideas would be the most sophisticated and holistic of the entire set, seemingly skipping over those that lie in the middle in terms of complication.

Figure 2

Number of Situations per 500 Words of Text (by Topic and by Publisher)



Gaps in the Occurrence of CoEs

Each of the 21 categories, according to Gott et al's (2003) classification, has varying numbers of subcategories (ranging from 1 to 8). Although all 21 categories of CoEs were represented in the textbooks, some subcategories were not. These include 1.5, 2.6, 5.6, 11.6, 11.7, 12.3, 12.4, 17.2, 17.3, 19.4, 19.8, 21.3, 21.4 and 21.5 (see Appendix A).

These subcategories constitute gaps in the occurrence of CoEs in the textbooks when compared with Gott et al's (2003) classification system. Some of these subcategories are absent because they are inappropriate for chemistry at this level.

Conclusions and Implications

The leading question addressed in this study was, How is evidence represented in high school chemistry textbooks?

I completed a thorough examination of the three textbooks most widely used in Canada, and found that the treatment of CoEs varies widely across textbooks and across topics (within textbooks). I also found a wide variation in the overall treatment of CoEs across the textbooks and the topics.

A grade-level comparison can be made between Solutions and the first part of Acids and Bases, which are both covered in Grade 11. In all the textbooks, there are more situations in Solutions than in Acids and Bases, although I can discern no reason for this trend.

The comparison across grades and within the same topic can be done between Acids and Bases as covered in both Grade 11 and Grade 12. There are more situations in Grade 12 than in Grade 11 in all textbooks except *McGraw-Hill Ryerson,* which has the same number of situations at both grade levels. One would expect this if there were a marked difference in complexity between the treatment of Acids and Bases at the two

Figure 3

Mean Number of CoEs per Situation (by Topic and by Publisher)

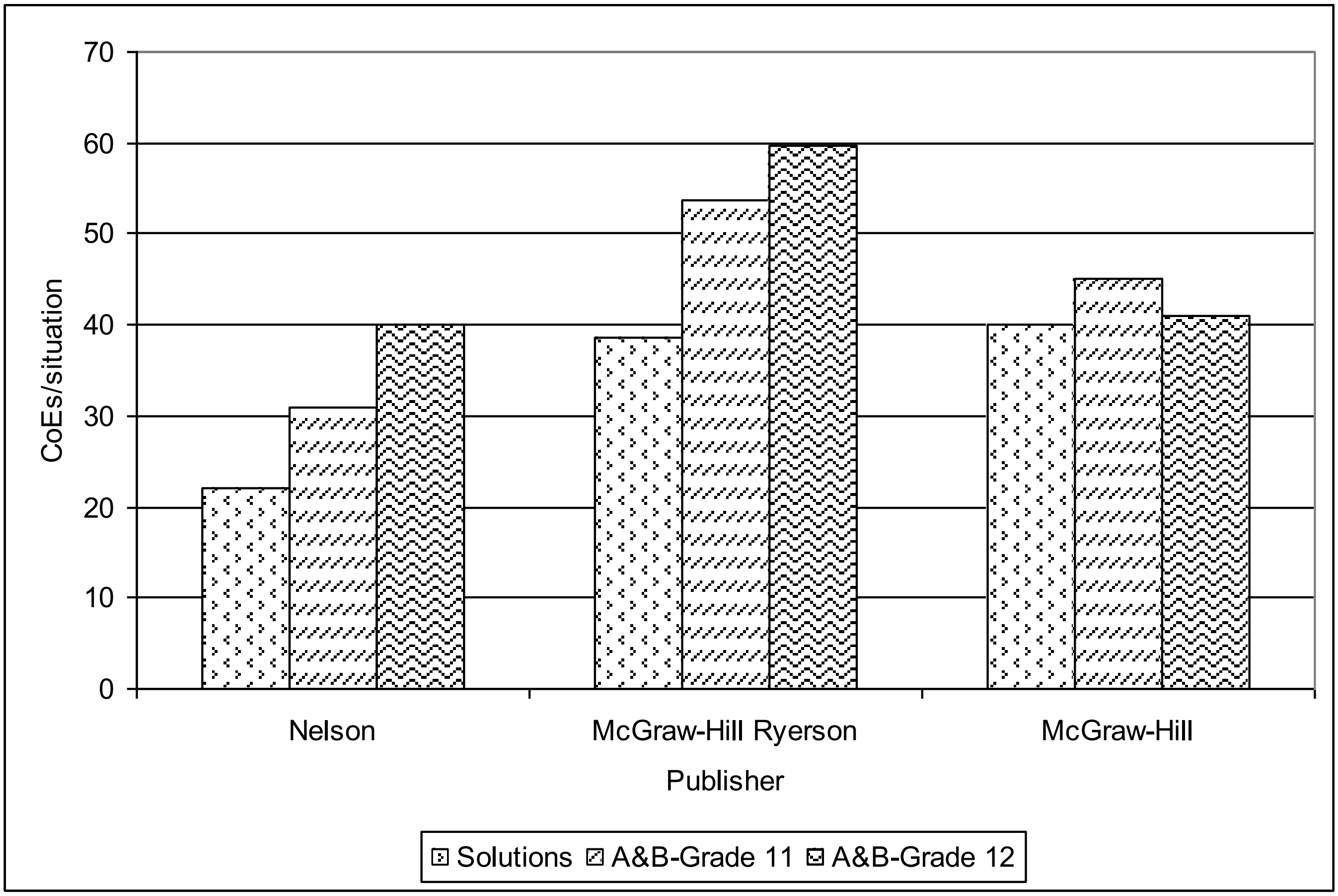
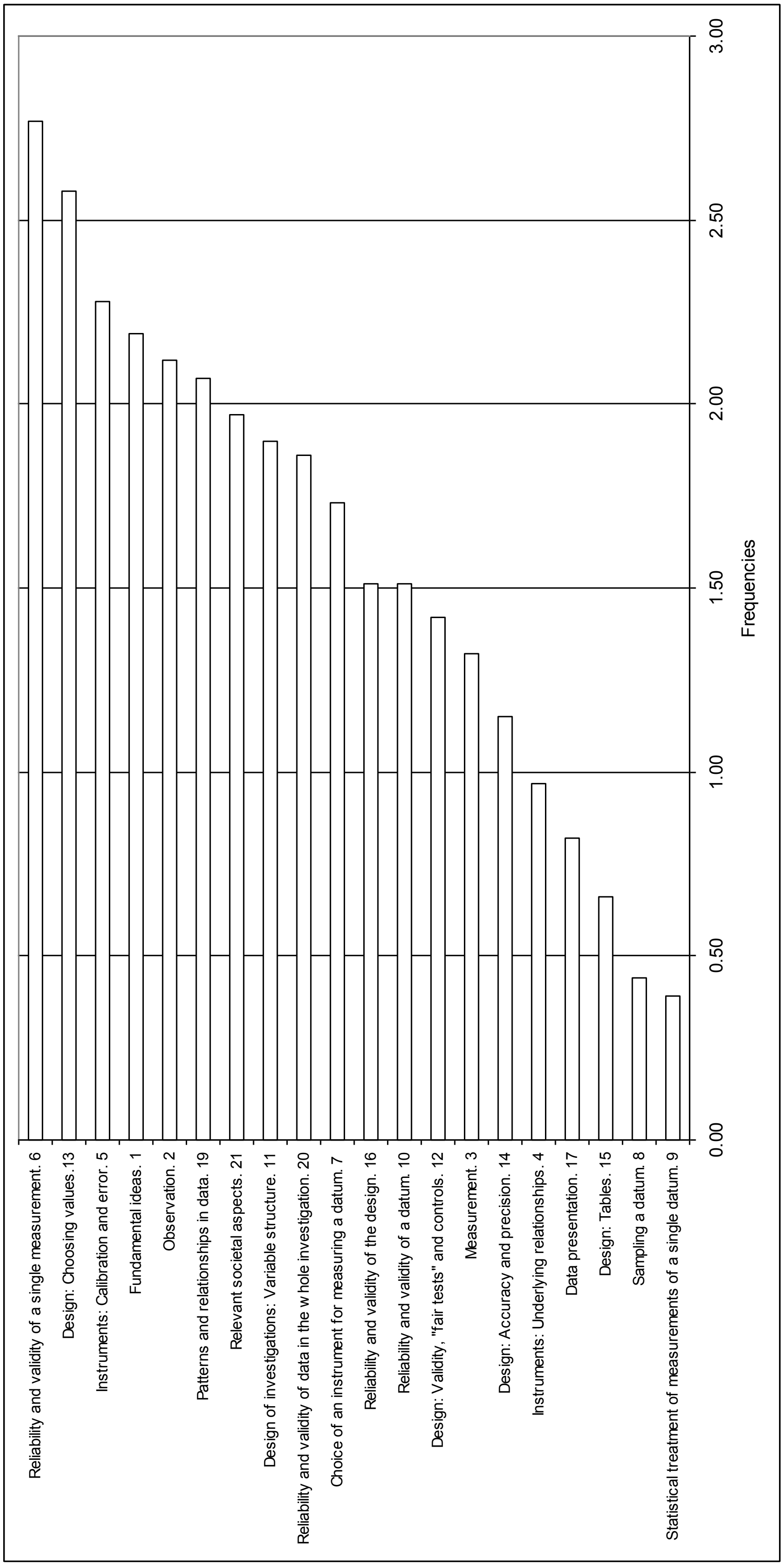


Figure 4

Average Frequencies of CoEs per 500 Words of Text Across Publishers and Topics



grade levels, but such a difference was not readily apparent. The substantive knowledge at the Grade 12 level may be higher than the Grade 11 level for Acids and Bases, but the CoEs encountered at the Grade 12 level are not particularly more complex.

When we compared across textbooks, *Nelson* had the most situations per 500 words of text, followed by *McGraw-Hill.* The third position was taken by *McGraw-Hill Ryerson.* I have no explanation for the different number of situations per 500 words of text, or for the differences in the number of CoEs per situation.

Gott et al's (2003) interest in concepts of evidence rests on their insight that just as there is a curriculum for teaching substantive scientific content, there needs to be a curriculum for teaching the knowledge base that underlies the procedural skills that can be directly applied to a task. They see CoEs as being the foundation of such a curriculum.

In Appendix B, I have organized the CoEs into topics, such that the topics might form the basis for a curriculum. Although many of these topics are treated lightly in current science curricula, there is little experience in making them a primary focus, competing directly for space in the curriculum with the substantive content. Therefore, it is not clear to me whether any of the topics are psychologically prior to others. My intuition is that at all grade levels, all the topics should be taught, adjusting for depth of coverage. It is difficult to imagine treating any of the first five topics in isolation without referring to the others. For example, it is difficult to make sense of sampling a datum without some notion of the experimental design and the instrumentation used. Likewise, it is difficult to imagine talking about design with no reference to the data that are to be collected.

I found no increased sophistication in how CoEs were employed. I have no explanation at all for why there was so much variation in the occurrence of situations across textbooks, and why different textbooks had different frequencies of CoEs per situation. All the textbooks have been approved for delivery of the same chemistry curriculum to meet the same objectives. Perhaps the explanation lies therein, because the curriculum objectives most comprehensively and systematically articulated are those dealing with substantive scientific knowledge. It seems that the experience of evidence that students receive is mainly dependent on the textbook selected and the use teachers make of the textbook. The textbooks themselves imply very different approaches to the treatment of evidence, with no obvious rationale for why this is the case.

This study raised many more interesting questions for further research and investigation. One of the more pressing questions concerns the methods by which the understanding of CoEs can be taught and tested. Given that we are in the realm of knowledge that underlies procedural skills (activities such as the use of measuring instruments and the construction of tables and graphs), we must wonder whether only performance assessment suits the situation. Perhaps there are versions of paper-and-pencil tests that can work, but research is needed to demonstrate this. Roberts and Gott (2004) recommend a written test for procedural understanding that addresses the issue of assessing scientific literacy in high schools. They advocate that final high school exams, such as the General Certificate of Secondary Education (GCSE) exams in the UK, should focus on the core ideas in science across biology, chemistry and physics, along with the inclusion of vital ideas about the role of evidence in science.

Finally, I return to my general concern with the comprehensiveness and systematic nature of the treatment of evidence in the three textbooks. Although there are variations I cannot explain, I concluded that CoEs are treated comprehensively by these textbooks, in the sense that the textbooks invoke the use of all the concepts.

Systematicity is another matter, and this question goes to the heart of a curriculum of procedural knowledge, which is related to the "knowing how to do it and when" of science and is concerned with the understanding required to put science into practice. I saw no systematic treatment of the CoEs. Except for the larger number of CoEs in Grade 12 Acids and Bases than in Grade 11 (which indicates at best very little about a systematic curricular difference), I saw no attempt to gauge the treatment of evidence by a psychological theory of development or by an epistemological theory of the role of the various concepts in the evidentiary structure of chemistry. In short, I could find no curriculum of procedural knowledge related to evidence in these textbooks.

In drawing this conclusion, I wish to add the qualification that it is not necessarily a critique of the authors of the books. The authors were writing within the constraints imposed by provincially authorized curricula and needed to have their books sanctioned for use by ministry of education officials. All of this suggests to me what I have always believed: not all curricular change can come from the grassroots; at least some must start at the top with those who set the broadest goals of science education. Until procedural knowledge is made an explicit goal, we are unlikely to find comprehensive and systematic curricular treatment of it.

Final Remarks

It is imperative that procedural knowledge—the "thinking behind the doing" in science—be given as important a place in the high school science curriculum as substantive content knowledge. Only then will evidence be given the treatment it deserves, comprehensively and systematically. This is a promising way of ensuring that the importance of evidence in science will be imparted impartially, to both the minority of students who will pursue a career in science and the majority whose direct encounter with science will end at the high school level.

Appendix A

Categories and Subcategories of Concepts of Evidence

Adapted from Gott et al (2003)

1. **Fundamental Ideas**
Degree of complexity = 3
1.1 Opinion and data
1.2 Links
1.3 Association and causation
1.4 Types of measurement
1.5 Extended tasks

2. **Observation**
Degree of complexity = 1
2.1 Observing objects
2.2 Observing events
2.3 Using a key
2.4 Taxonomies
2.5 Observation and experiment
2.6 Observation and mapping

3. **Measurement**
Degree of complexity = 2

4. **Instruments: Underlying Relationships**
Degree of complexity = 2
4.1 Linear relationships
4.2 Nonlinear relationships
4.3 Complex relationships
4.4 Multiple relationships

5. **Instruments: Calibration and Error**
Degree of complexity = 2
5.1 End points
5.2 Intervening points
5.3 Zero errors
5.4 Overload, limiting sensitivity/limit of detection
5.5 Sensitivity
5.6 Resolution and error
5.7 Specificity
5.8 Instrument use
5.9 Human error

6. **Reliability and Validity of a Single Measurement**
Degree of complexity = 2
6.1 Reliability of measurements
6.2 Reliability of instruments
6.3 Reliability based on human error
6.4 Validity

7. **Choice of an Instrument for Measuring a Datum**
Degree of complexity = 2

8. **Sampling a Datum**
Degree of complexity = 3

9. **Statistical Treatment of Measurements of a Single Datum**
Degree of complexity = 3

10. **Reliability and Validity of a Datum**
Degree of complexity = 2

11. **Design of Investigations: Variable Structure**
Degree of complexity = 3
11.1 The independent variable
11.2 The dependent variable
11.3 Correlated variables
11.4 Categoric variables
11.5 Ordered variables
11.6 Continuous variables
11.7 Discrete variables

12. **Design: Validity, "Fair Tests" and Controls**
Degree of complexity = 3
12.1 Fair test
12.2 Control variables in the laboratory
12.3 Control variables in field studies
12.4 Control variables in surveys
12.5 Control group experiments

13. **Design: Choosing Values**
Degree of complexity = 3

14. **Design: Accuracy and Precision**
Degree of complexity = 3

15. **Design: Tables**
Degree of complexity = 3

16. **Reliability and Validity of the Design**
Degree of complexity = 3

17. **Data Presentation**
Degree of complexity = 3
17.1 Tables
17.2 Bar charts
17.3 Line graphs
17.4 Scatter graphs
17.5 Histograms
17.6 Other forms of display

18. **Statistics for Analysis of Data**
Degree of complexity = 3

19. Patterns and Relationships in Data
Degree of complexity = 3

19.1 Types of patterns
19.2 Linear relationships
19.3 Proportional relationships
19.4 "Predictable" curves
19.5 Complex curves
19.6 Empirical relationships
19.7 Anomalous data
19.8 Line of best fit

20. Reliability and Validity of Data in the Whole Investigation
Degree of complexity = 3

20.1 A series of experiments
20.2 Secondary data
20.3 Triangulation

21. Relevant Societal Aspects
Degree of complexity = 3

21.1 Credibility of evidence
21.2 Practicality of consequences
21.3 Experimenter bias
21.4 Power structures
21.5 Paradigms of practice
21.6 Acceptability of consequences
21.7 Status of experimenters
21.8 Validity of conclusions

Appendix B

Topical Arrangement of the 21 Categories of CoEs

Adapted from Gott et al (2003)

Design

11. Design of Investigations: Variable Structure
12. Design: Validity, "Fair Tests" and Controls
13. Design: Choosing Values
14. Design: Accuracy and Precision
15. Design: Tables
16. Reliability and Validity of the Design

Instruments

4. Instruments: Underlying Relationships
5. Instruments: Calibration and Error
7. Choice of an Instrument for Measuring a Datum

Basics

1. Fundamental Ideas
2. Observation

Measurement

3. Measurement
6. Reliability and Validity of a Single Measurement

Datum/Data

8. Sampling a Datum
9. Statistical Treatment of Measurements of a Single Datum
10. Reliability and Validity of a Datum
17. Data Presentation
18. Statistics for Analysis of Data
19. Patterns and Relationships in Data
20. Reliability and Validity of Data in the Whole Investigation

Society

21. Relevant Societal Aspects

Notes

A longer version of this article is available on the CRYSTAL-Alberta website (www.uofaweb.ualberta.ca/edpolicystudies/crystalalberta.cfm).

1. This textbook has been updated with a new edition since our analysis was conducted. Frank Jenkins, the textbook's main author, has reviewed the results of our study and, in a personal communication, has said that they apply equally to the new edition.

2. Alberta's programs of study for science can be found at http://education.alberta.ca/teachers/program/science/programs.aspx.

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