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Contents

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

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From the Editor

This special peer-reviewed edition of the *Alberta Science Education Journal* highlights some of the research in progress in the CRYSTAL-Alberta Project. CRYSTAL-Alberta is a pilot program funded by the Natural Sciences and Engineering Research Council (NSERC) to promote science and engineering in schools and in the broader community. We expect that at least two special peer-reviewed issues of the *Alberta Science Education Journal* will be devoted to CRYSTAL-Alberta research reports in the next two years. The research projects described below are carried out under the leadership of the principal investigator of CRYSTAL-Alberta, Dr Stephen Norris, of the Faculty of Education at the University of Alberta.

Frank Jenkins, codirector of the Centre for Mathematics, Science and Technology Education (CMASTE) and outreach coordinator for CRYSTAL-Alberta, outlines the origin of the CRYSTAL projects in Canada and describes the type of educational projects CRYSTAL-Alberta is engaged in.

Brian Martin, Hans van Kessel and Frank Jenkins report on the use of applets and simulations of modern physics experiments to teach the Modern Physics unit in Physics 30. The simulations focus especially on the crucial experiments that changed the course of physics in the twentieth century.

Susan Barker and Heidi Julien report on the types of strategies high school students use when their science tasks require searching for information from outside sources. Many students turned out to be surprisingly unsophisticated in searching for relevant information.

Marie-Claire Shanahan, Julieta S Delos Santos and Ross Morrow report on strategies to help elementary students read science text. Their specific strategy involves using text pieces that integrate both narrative writing and adapted scientific writing.

Brenda Gustafson, Peter Mahaffy and Brian Martin discuss how Grade 5 teachers can best balance macroscopic and microscopic approaches to properties of matter, physical and chemical changes, mixtures and solutions, and so forth. In particular, the authors are developing a series of CRYSTAL-Alberta computer visualizations intended to help students shift to a particle, rather than a continuous, view of matter.

—Wytze Brouwer

Guest Editorial

This peer-reviewed edition of the *Alberta Science Education Journal* highlights some of the research in progress in the CRYSTAL-Alberta project. CRYSTAL-Alberta is a pilot program funded by the Natural Sciences and Engineering Research Council (NSERC) to promote science and engineering in the Canadian community, especially schools. This NSERC program recognizes that the supply of scientists (including mathematicians) from schools across Canada is its most important resource. There are five CRYSTALs (Centres for Research in Youth Science Teaching and Learning) across Canada: Pacific, Alberta, Manitoba, Quebec and Atlantic, with CRYSTAL-Alberta (at the University of Alberta and King's University College) being the national centre. The pilot is for five years maximum, with a maximum funding of $200,000 annually for each centre. Dr Stephen Norris, in the Department of Policy Studies in the Faculty of Education at the University of Alberta, is the principal investigator for CRYSTAL Alberta. (See www.nserc.ca, Science Promoters.)

The NSERC program is unique in that it requires research collaboration

- between researchers from the faculties of education and science (and/or engineering),
- between universities and schools (teachers and students),
- with user partners who are providing science and math education—formal and informal, and
- in research translation and outreach.

These are the kind of requirements or wishes that people talk about but never seem to attain. And here was the chance.

More than 40 universities submitted letters of intent. Of these, 17 were asked to submit full applications, from which 5 centres (including one national centre) were selected. The CRYSTAL-Alberta research and development proposal focused on

- research and development of math and science reasoning (and deep understanding) in secondary classrooms,
- research and development of textual and visualization components for reasoning and deep understanding, and
- creating text and visual prototypes (examples) for
    - ◦ classroom resource materials,
    - ◦ assessment resources,
    - ◦ instructional strategies and
    - ◦ curriculum outcomes.

In our view, the CRYSTAL-Alberta program is the most mainstream (from the standpoint of formal classroom education) of all of the five research programs. We had also chosen a research program that singled out difficult curriculum and instruction outcomes—reasoning and deep understanding. The thought is that if we are successful in showing how to develop, implement and assess a difficult outcome, we can be optimistic about meeting other difficult but important outcomes that are stated but (hypocritically) ignored. (See www.CRYSTALAlberta.ca.)

The research, research-translation and outreach components that are envisaged include science and mathematics textual and visualization resources. Since text (including talk) and visualizations represent much of what is done in classrooms, the resources are wide ranging in type and in learning style. Two websites present and provide the resources for download:

- The CRYSTAL-Alberta Outreach website (accessed through www.CRYSTALAlberta.ca), where textual resources that promote math and science reasoning can be downloaded
- The King's Centre for Visualization in Science website (www.kcvs.ca), where visualization resources that promote math and science reasoning and deep understanding are available for use online and/or for download.

The long-term goal is for the websites to present the classroom activities up front and to present the research in the background—just the opposite of how a typical research program/paper is presented. Having both of these components (that is, the outreach and the research) in one website is unique. The development is supported by the research. The more you want to know, the more you can know (from the website).

Prototypes (both concepts and exercises) have been created by both user partners and by researchers. Those created by user partners include, for example,

- laboratory activities based on a *create-test-use* concept (a synthesis of the natures of science in a useable classroom format),
- evidence-based classroom activities based on the concept of *evidential bases* (where evidence is presented in 10 different modes in the classroom),
- the nature of scientific research required for reading the popular press and the Internet (for example, introducing concepts like *placebo*, *double-blind*, *sample size* and *clinical trial*),
- the nature of scientific language as depicted in research papers (primary literature), lectures and classrooms (for example, appeals to evidence, authority and the nature of science),
- bibliography and resources for science vs pseudoscience (for example, astronomy vs astrology, and magic vs psychic surgery and psychokinetic powers), and
- inductive and deductive reasoning in mathematics and science (a common place for the two disciplines to meet).

Examples of prototypes created by researchers are

- visualizations (applets) to create, test and use modern-physics concepts,
- a visualization to create and test a linear equation that predicts the speed of a tsunami,
- prototypes for deeper understanding of linear equations,
- computer models for climate change and for organic molecules,
- examples of concepts of evidence in textbooks and
- visualizations to assist understanding of the particulate model of matter.

Ultimately, there is a need to collaborate with classroom and outreach partners for research, development and implementation of the textual and visualization resources. These collaborations include, for example,

- creating and testing prototypes to promote mathematics and science reasoning,
- testing and using prototypes created by researchers and/or partners,
- participation in the creation of various workshops for promoting math and science reasoning, and
- promoting math and science reasoning and deeper understanding (everywhere).

When reading the following peer-reviewed research papers, keep in mind that classroom resources either are already available or will be available on our two CRYSTAL-Alberta websites. It is necessary to test the resources in a classroom environment for the action research to continue. The idea is that users will adapt and model their resources after the prototypes created within this unique research and development program. Please read the research and test the prototypes. Collaborative feedback from your classroom testing is appreciated.

—Frank Jenkins

CRYSTAL - ALBERTA
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Using Applets to Teach Modern Physics

Brian Martin, Hans van Kessel and Frank Jenkins

A version of this article is available at www.uofaweb.ualberta.ca/cmaste//pdfs/Using%20Applets%20to%20Teach%20Modern%20Physics21Jan09.doc. The version below has been edited to conform to ATA style.

Abstract

Teaching modern physics poses many challenges. The Alberta science curriculum contains detailed outcomes and emphases that add to the complexity of teaching. In this paper we present a discussion of digital resources developed at the King's Centre for Visualization in Science and CRYSTAL-Alberta to help teachers meet this challenge. We also argue that effective use of such resources entails a shift in pedagogical emphasis from skill development to teaching that focuses more overtly on evidence-based reasoning. Exemplars are provided that demonstrate how teaching to encourage evidence-based reasoning can be realized and how the major goals of the curriculum can be met.

Alberta physics teachers have been handed a lofty challenge—to teach topics in modern physics from the basic concept of quantization to the presentation of the standard model of matter. At the same time they must honour the four pillars of the curriculum: attitudes, knowledge, STS (science, technology and society) and skills outcomes. New to the scene in Alberta high school science curricula are curriculum emphases; in the case of modern physics, this is a nature-of-science emphasis—an excellent fit. The integration of knowledge and skills is particularly problematic; modern physics, by its nature, pushes the student beyond the touch/feel world of Newtonian physics into a world with which the student (and sometimes the teacher) has little direct intuitive contact. In this paper we will argue that this calls for both the introduction of new teaching tools and, more significantly, a new pedagogical focus. To do this we will provide an overview of digital learning objects (applets and ancillary resources) that have been created over the past three years at the King's Centre for Visualization in Science (KCVS, at www.kcvs.ca) and the Alberta Centre for Research in Youth Science Teaching and Learning (CRYSTAL-Alberta, at www.crystalalberta.ca). The paper will conclude with an appendix providing a detailed correlation between KCVS's modern-physics digital learning objects (DLOs) and Alberta curriculum outcomes. In future papers, we will provide much more explicit treatments of specific topics in modern physics in the Alberta physics curriculum.

The Need to Visualize—And Why Seeing Is Not Enough

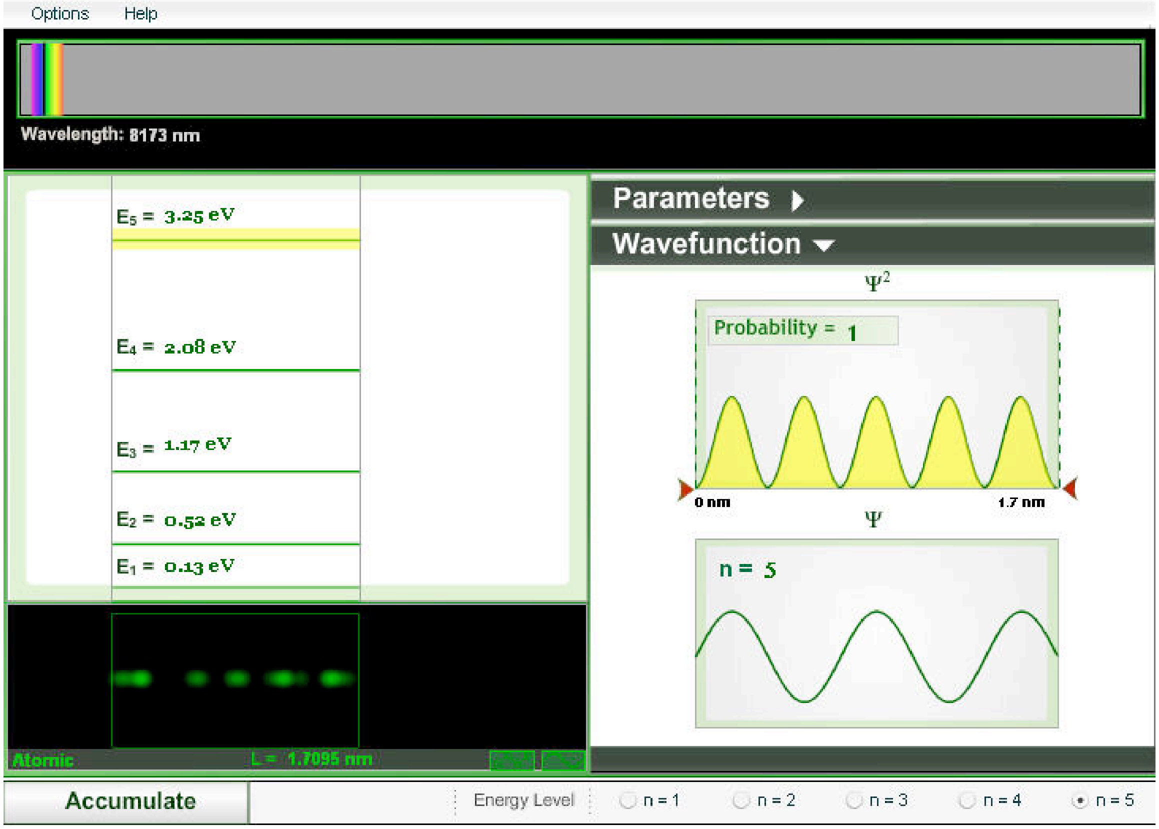
There is a vast literature devoted to identifying problem areas in the learning of modern physics from upper elementary grades to advanced undergraduate levels. A common motif found in the literature is the disconnect between a student's lived reality and the concept(s) being taught. Taber (2005), for example, looks at the barriers encountered by students attempting to understand the concepts of quanta and orbitals. In this analysis, Taber works from a constructivist learning theory to develop a typology of learning impediments: deficiency, fragmentation, ontological and pedagogic. In the case of a fragmentation impediment, the student is unable to incorporate the concepts being taught within his or her intuitive framework. From a learning theory perspective, the knowledge fails to create any linkages within the student's world and will never become robust knowledge. Sadly, Taber offers little in the way of remediation for the problem of fragmentation. If one takes the lessons of learning theory and constructivist teaching (Ausubel 2000) to heart, then the need to develop intuitive scaffolds for students is imperative. The hypothesis invoked herein is that applets (small, web-delivered computer programs) offer a way to develop these intuitive links. For example, the concept of quantization is introduced explicitly in the Alberta physics curriculum through a series of knowledge outcomes (30-D2.1k–.7k), STS outcomes (30-D2.1,2sts) and skill outcomes (30-D2.1s–.4s) (Alberta Education 2007). *Quantization* is a threshold concept (Meyer and Land 2006; Park and Light 2009) that is critical for a student to understand most of the modern physics ideas that he or she will encounter.

Figure 1 illustrates a simple applet designed to introduce the concept of quantization and to root it in prior knowledge—specifically the concept of standing waves (Physics 20, Unit D—mechanical and acoustic resonance).

In this applet the student is able to confine a particle (electron, proton or particle of student-assigned mass) to a one-dimensional region. This is, of course, the well-known particle-in-a-box model, which is a staple in a physicist's toolkit. By changing the dimensions of the box, the student is able to investigate how energy changes (eg, E_5-E_1) and to see the corresponding change in the wavefunction (bottom right in the applet) and thus a connection to standing waves. Another threshold concept, probability, is introduced with the accompanying wave-function tool and the generation of discrete spectra (top left) can occur via student-selected transitions between energy levels, *E*.

However, experience and research indicate that seeing is not enough to help develop intuitive hooks for the student. For the visualization to prove effective there is a ternary relationship among visualization, interaction and assessment, illustrated in Figure 2. The student interacts not only with the visualization, but there is also interaction with a critical assessment component. The assessment comes through components linked internally to the digital learning objects (eg, guided lessons and self-assessment) that can be used to provide both formative and summative

Figure 1 "Particle in a Box" applet, which introduces the concept of quantization



Wavelength: 8173 nm

E_5 = 3.25 eV

E_4 = 2.08 eV

E_3 = 1.17 eV

E_2 = 0.52 eV

E_1 = 0.13 eV

Probability = 1

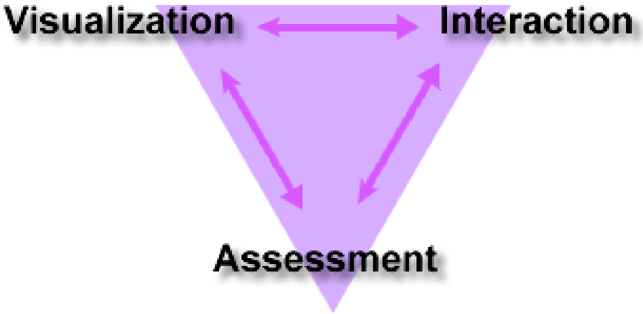
n = 5

L = 1.7095 nm

○ n = 1 ○ n = 2 ○ n = 3 ○ n = 4 ● n = 5

evaluation. Finally, there is a critical connection between the visualization and assessment. We argue that the effectiveness of a visualization is positively correlated to prior correct knowledge. That is, the more correct the student's understanding, the more effective the visualization. (There is, of course, an odious flipside to this—a poorly deployed or designed visualization could deepen a student's misunderstanding! We will address this point later in this paper.) Nurmi and Jaakkola (2006) investigated the effectiveness of digital learning objects as a function of instructional methods employed.

Figure 2 The ternary structure of an effective use of an applet



Encouragingly, they found that students using simulated learning objects (their term, which is equivalent to the applets/DLOs described here) to learn about electric circuits showed statistically important gains in mastery of concepts when compared to students using traditional text resources. This was most pronounced in blended teaching approaches in which simulations and laboratory activities (not just lectures) were combined. We argue that the assessment–visualization bridge illustrated in Figure 2 will play a similar role in enhancing applet effectiveness. The bottom line in all of this is that visualizations do not speak for themselves—their effectiveness is critically rooted in how they are employed by teachers and students.

Evidence-Based Reasoning

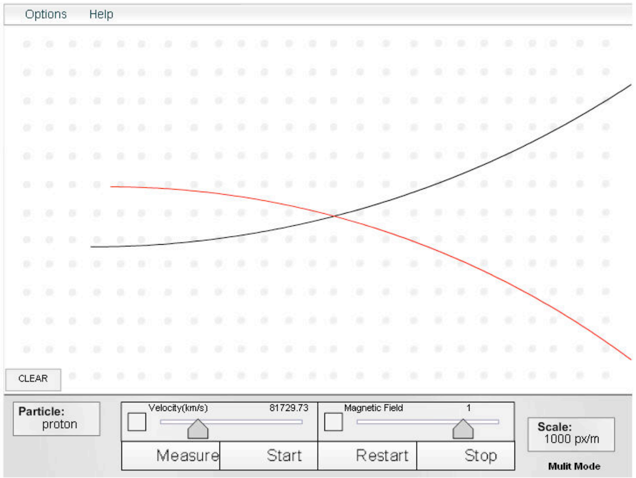
A fundamental question that should be on the lips of students is "How do we know this?" This question should become part of a critical attitude in which students are able to demand and use evidence to create warranted knowledge. For the curricular pillar of *attitude* to mean anything beyond commonplace, we argue, an explicit move must be made to nurture this mode of thinking—this habit of mind. To accomplish evidence-based reasoning and if the ternary relationship shown in Figure 2 is to be effective, the assessment role becomes critical.

The term *assessment* is multilayered and can imply a host of teaching strategies. It is important to stress that regardless of what strategy is employed, the subtext is to develop a teaching moment in which the student is asked to critically examine evidence and to create and/or evaluate claims to knowledge.

We illustrate a few of these approaches to assessment below.

1. **Teacher-directed questioning** in class, in which the teacher demonstrates a specific effect and then elicits student responses. This is a common approach used in many active learning settings (Moore 2003). For example, Figure 3 shows trajectories created by a proton and a muon, travelling with the same velocity perpendicular to a magnetic field. Many questions can emerge; for example, based upon the evidence gathered,
    - how do you know the particles have different charges?
    - how do you know which is the more massive particle? (How could you test this and what assumptions would be needed?)
2. **Student self-assessment**, in which the student is asked to perform a conceptual or numerical analysis of an event and then assess his or her answer. For example, the student could be asked to use an

Figure 3 Comparison of muon and proton trajectories



Particle: proton
Velocity(km/s) 81729.73
Magnetic Field 1
Scale: 1000 px/m

applet such as the one shown in Figure 3 to investigate (gather evidence about) how the curvature of a trajectory is related to charge, mass, magnetic field and velocity. Because the applet is able to very efficiently produce an infinite variety of instances, the student could be encouraged to identify those parts of a concept that he or she finds problematic, with the objective of guided remediation. The student is not only involved in self-assessment but also is learning how to do science and evaluate claims to knowledge by manipulating one variable and controlling all other variables.

3. **Creation and analysis of evidence**, in which a student uses an applet to investigate a phenomenon in depth. For example, Figure 4 shows a screen capture from the cloud chamber applet. Here the student could be asked to provide evidence that the process of beta decay has a peculiar energy signature—beta particles created by the same decay are not emitted with consistent energies. Having done this, the student could then be asked to explain why this suggests the possibility of an unseen particle in the beta decay process.
4. **Guided exploration**, in which the student uses digital learning resources to augment teacher instruction. For example, in trying to understand how a charged-particle velocity selector works, a student could use several KCVS applets to discover how electric and magnetic effects work in concert to produce velocity selection. Students manipulate electric and magnetic fields to direct a beam of particles through an opening. By playing with the applet they gain experience and understanding.

Figure 4 The cloud chamber applet demonstrating tracks produced by a beta decay process

Scale: 1000 px/m
Decay: Beta
Magnetic Field: 0.001 T
Isotope: Tritium

5. **Laboratory instruction**, in which the student either augments the use of an actual apparatus or simulates an apparatus to enact an important experiment. Figure 5 shows an example applied to the photoelectric effect. Ideally, students would have access to the actual apparatus, gathering evidence to create or test the concept.

A current project of CRYSTAL-Alberta, including KCVS, is to produce a rich set of teaching materials to support the modern physics applets in the various assessment modes described above. We are currently developing exemplars for all of these categories. A design feature of all of the applets produced will be a direct linking of applets to teaching materials, with the intent that the applet and supporting digital resources become a complete and robust set of teaching/learning/assessment tools.

Getting at the Nature of Science Through a Reconstruction of Critical Historical Experiments

One of the deep goals in teaching physics (or any science) is to enable students to appreciate the tentative and dynamic nature of scientific knowledge. Confusion in the mind of the public over what constitutes scientific knowledge is well documented and poses a real threat to creating a scientifically literate population. To ameliorate this situation, the Alberta science curriculum identifies *the nature of science* as a specific curricular emphasis, in Unit D—Modern Physics. In the next paper in this series, we will provide an overt example of how this curricular emphasis can be addressed through the use of the digital resources that we have described. In particular, we will focus on the role that the Thomson experiment (1899) played in providing critical evidence for the existence of the electron. Aside from building an important historical context in which to present important ideas, a careful reconstruction of the Thomson experiment can place the student in the situation of acquiring data, evaluating evidence and, through carefully constructed argument, formulating conclusions leading to the creation of knowledge.

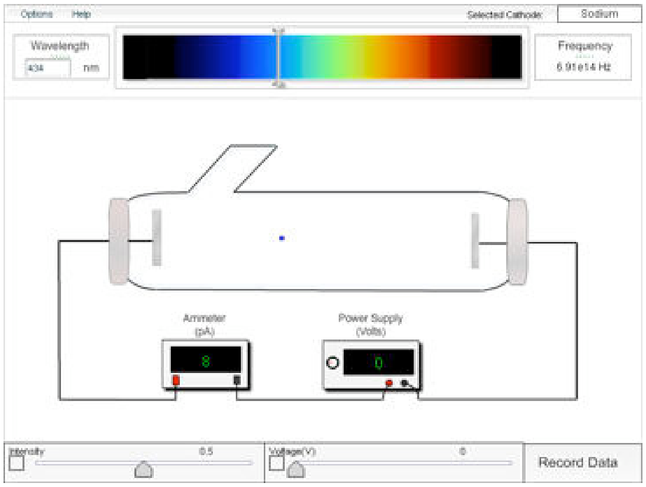
The Danger of Trivialization and Why the Teacher Plays a Critical Role

In the 2007 Oersted Medal address, Carl Wieman cautions

> Simulations are very powerful, but not necessarily beneficial. A good simulation can lead to the relatively rapid and very effective learning of difficult subjects. However, if there is something about a simulation that the student interprets differently than is intended, they can effectively learn the wrong idea. (Wieman, Perkins and Adams 2008)

The applets described here are not stand-alones, nor are they designed to replace active, engaged, skilled teaching. Rather, they are designed to equip the teacher to present difficult ideas more effectively. Frequent student assessment and instructional evaluation, however, are critical if we are to avoid the situation described by Wieman. An even more subtle danger inherent in the uncritical use of applets is the danger of trivialization. An example of this trivialization (which can occur by something as innocuous as a textbook diagram) is the presentation of Kepler's laws of planetary motion and the drawing of elliptical orbits. Students often fail to fully grasp that Kepler had no God's-eye view—his discoveries of the shape of planetary orbits and the Rudolphine tables represent one of the greatest scientific achievements of his time. Sometimes applets can trivialize great and difficult achievements. Figure 5 shows a schematic version of the Millikan photoelectric apparatus. Such a presentation obscures the great lengths that Millikan had to go to in order to carry out this experiment—it could give students the impression that the experiment is easy. Millikan described his apparatus as a "machine shop in a vacuum tube"; when first performed, the experiment was very difficult. To mitigate the danger of trivialization, the digital learning resources that accompany the applets described here contain important information on the assumptions and simplifications that were used.

Figure 5 Simulation of the Millikan photoelectric effect experiment.



Selected Cathode: Sodium

Wavelength 434 nm

Frequency 6.91e14 Hz

Ammeter (pA) 8

Power Supply (Volts) 0

Intensity 0.5

Voltage(V) 0

Summary

In this paper we have introduced the reader to a new set of digital resources devoted to the teaching of modern physics in Alberta high schools. If teachers are to effectively meet the goals and emphases laid out in the Alberta physics curriculum, new resources and, more important, new approaches to pedagogy will need to be employed.

The appendix provides a detailed summary of the digital resources available and a correlation with curricular outcomes. In future papers, we will provide more explicit treatments of a number of these resources to encourage teachers to use these materials to develop a more active-learning and evidence-based-reasoning approach to teaching physics.

Appendix

The following applets are on the website for the King's Centre for Visualization in Science, www.kcvs.ca.

Applet Title	Physics 20–30 Program of Studies*
Motion of Charged Particles in Magnetic and Electric Fields (3 applets)	30-B3.5k–.7k, 30-B3.1sts, 30-B3.1s–.4s
The Cloud Chamber	30-B3.5k, 30-B3.7k, 30-D3.1k, 30-D3.1sts, 30-D4.1k, 30-D4.2sts
Compton Scattering	30-A1.4k, 30-A1.3s, 30-C2.6k, 30-C2.1sts

The Cyclotron	30-B3.5k, 30-B3.7k, 30-D4.3sts,
Thomson’s E/m Experiment	30-D1.3k, 30-D1.1sts, 30-D1.1s–.4s
The Photoelectric Effect	30-C2.3k–.5k, 30-C2.1sts–.2sts, 30-C2.1s–.4s
Particle in a 1-Dimensional Box	30-D2.3k–.5k, 30-D2.7k, 30-D2.1s
Nuclear Stability	30-D3.2k, 30-D3.6k, 30-D3.3s–.4s
Radioactive Decay	30-D3.2k–.4k, 30-D3.1sts–.2sts, 30-D3.1s–.4s
Nuclear Potential-Strong Interactions	30-D4.2k
Millikan Oil Drop Experiment (3 applets)	30-B2.10k, 30-B2.1s–.4s
The Rutherford Experiment (4 applets)	30-D1.4k, 30-D1.1s–.4s

⁎ Note that, in addition to the outcomes listed, all of the applets promote a nature of science (NS) curriculum emphasis as required by the Alberta Education Physics 30 Modern Physics unit. For more information on outcomes for the Physics 30 program of studies, go to http://education.alberta.ca/teachers/program/science/programs.aspx and select Physics 20–30.

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Information to Go: How High School Students Find Information

Susan Barker and Heidi Julien

Abstract

This study examines how high school students find information when given an information-seeking task in science class. A vast body of research reflects deep concern about the level of information literacy skill development among secondary and postsecondary students, but even when educational curricula mandate skill development, many students are unable to demonstrate sophisticated information-searching and critical evaluation skills. The findings of this study, which included analyzing information-seeking tasks and conducting interviews with students in three biology classes in a large urban high school, illustrate a similar lack of skills. The science curriculum in the context in which the study was done is expected to be delivered within an inquiry pedagogy, and a supporting curriculum for developing information technology skills should also be expected to develop information literacy skills. Nevertheless, the students in this study demonstrated only rudimentary information-searching skills, and were unable to critically evaluate the information they found. Pressure on teachers to teach to examinations—that is, to focus on substantive content, rather than on information literacy skills—and a deficit of information literacy skills among teachers themselves are possible explanations for these results. The study is of particular interest to science teachers, but the broader implications of repeated indications of gaps in students' information literacy skills would indicate that schools must assume a larger responsibility for information literacy instruction. Leaving skill development to the postsecondary context will not ensure that citizens are sufficiently skilled to participate fully in twenty-first century life, either in workplaces or in their personal lives.

Introduction

Information-seeking tasks are commonly set by science teachers—for example, asking students questions that require them to find information to get an answer, setting creative tasks when they find information and then having them develop a poster or PowerPoint presentation, or even having them find information on a topic prior to starting a unit. The common denominator in these tasks, as the term suggests, is finding information. In an information society, where access to information and critical evaluation of that information are central to economic and personal well-being, information literacy skills are as essential as the basic skills of reading and writing. The term *information literacy* refers to the set of skills required to identify information sources, find information, evaluate it, and use it effectively, efficiently and ethically. In high school it is not unreasonable to suggest that teachers would expect most of their students to already have the basic reading and writing skills to be successful; is the same true for information literacy? Just how information literate are high school science students? What exactly do students do when we give them information-seeking tasks? How might the outcomes affect their understanding of science? What implications are there for the teaching of science?

In this paper we explore the answers to these questions using findings from research conducted with high school biology students in Alberta. Our research was motivated by a recognized gap between the importance that curriculum documents place on information literacy skills and the actual skills that students are able to demonstrate. This gap is surprising, because there is clear evidence that sophisticated information literacy skills are beneficial to academic success; yet research also shows that students are generally unsophisticated information seekers in academic contexts.

We specifically focused on high school science students because in science, an inquiry-based field of study, information-seeking skills, including critical evaluation of information, are important. Indeed, the Alberta provincial curriculum is supported by the document *Focus on Inquiry* (Alberta Learning 2004), which indicates that "inquiry-based learning is … a way to achieve the goals of the Alberta programs of study, since inquiry-based learning is a component of all Alberta curricula" (p ix). *Focus on Inquiry* notes that in inquiry-based learning classrooms, "data and information are actively used, interpreted, refined, digested and discussed" (p 4). Scientific inquiry is a specialist form of inquiry that models the practices and nature of science. Teaching science through inquiry has been advocated in North America for more than 40 years; yet only recently has it been given more prominence in the curriculum. When science is presented as a stable body of knowledge and facts, learners are discouraged from developing their own explorations and explanations of observed phenomena (Schwab 1962); therefore, inquiry approaches to teaching science, which encourage teachers to explore and explain, are advocated around the world. Learning outcomes associated with inquiry dimensions of science include generating a hypothesis, developing a plan for gathering data and constructing evidence based on data (eg, Schwab 1962). The main goal of such an approach is to acquaint students with investigative procedures similar to those used by scientists and to develop decision-making skills. All the recent research literature indicates that while the importance of scientific inquiry and its relationship with scientific literacy are clear, the way to achieve it is not (Schwartz, Lederman and Crawford 2004). Crawford (2000) similarly emphasized that teachers' ideas and practice about inquiry are varied and complex. Often, school science students begin science inquiry with sparse and disorganized background knowledge and should first conduct background library or Internet research (Windschitl 2008). Windschitl views such information-seeking tasks as being "supporting activities" of inquiry that help prepare students to participate more meaningfully in the core activities of inquiry by acquainting them with necessary concepts, ideas and skills. Thus, science classrooms where students follow an inquiry model of learning are an ideal environment in which to develop information literacy. Development of information literacy skills has been mandated by school curricula such as the Alberta program of studies, but the extent to which these mandates have led to demonstrable skill development is unclear.

The research literature includes some references to high school and/or science students, with the key findings as follows:

- Science high school students are challenged by evaluating the veracity and objectivity of information (Adams 1999).
- Science students demonstrate significant preference for the Internet and electronic resources over print resources (Barranoik 2001; Jones 1999; Shenton 2007).
- Students demonstrate poor search skills (such as having difficulty selecting search terms, evaluating websites, appropriately citing sources) (eg, Barranoik 2001; Fidel et al 1999; Scott and O'Sullivan 2005).
- High school students are unable to distinguish credibility in websites; that is, they demonstrate no higher-level thinking (metacognition) when credibility or accuracy is being assessed (Brem, Russell and Weems 2001).
- High school biology students' reading of scientific documents is superficial (Brill, Falk and Yarden 2004).
- Students seek the "right" answer and tend to judge relevance on the basis of convenient access and superficial criteria (Heinström 2006).
- Motivation is the most significant variable in students' searching behaviour.
- Minimal effort is a key driver of high school biology students' information seeking (Jones 1999).
- High school biology students prefer the Internet for speed of information access and the variety of information found.
- Information from those considered to be authorities is particularly valued (Lorenzen 2001).
- Students learn to use the Internet informally—for example, from friends, who themselves are not likely to be sophisticated users (Vansickle 2002).

The Alberta curriculum clearly identifies [the importance of] information-seeking skills, both in *Focus on Inquiry* and within subject areas. For example, in our study we worked with students studying Biology 20 (Alberta Learning 1998), in which the curriculum refers to the ability to "establish criteria to judge data or information; consider consequences and biases, assumptions and perspectives; … and, evaluate and assess ideas, information and alternatives" (p 5). Again, these skills are consistent with standard information literacy skills. Further, the biology curriculum includes the following expectations for high school students' experiences and learning:

- Understand that scientific language is precise, and specific terms may be used in each field of study
- Research, integrate and synthesize information from various print and electronic sources regarding a scientific question
- Apply given criteria for evaluating evidence and assess the authority, reliability, scientific accuracy and validity of sources of information
- Research, integrate and synthesize information from various print and electronic sources regarding a practical question
- Research, integrate and synthesize information from various print and electronic sources regarding a given question, problem or issue
- Select information and gather evidence from appropriate sources and evaluate search strategies

Moreover, the Alberta curriculum supports development of ICT (information and communications technology) skills (Alberta Education 2008), which are absolutely consistent with information literacy skills as understood more broadly. Thus, we see an interesting paradox in which the Alberta high school curriculum emphasizes the need to develop information literacy skills, which are integral to the process of science, yet little connection is made in science subjects to science inquiry and the nature of science. Our main research question was whether the Alberta curricular mandates translate into actual skills in the students.

Methods

The study design was qualitative and triangulated two methods: analysis of an in-class task assignment with questions relating to students' process of information seeking, and semistructured interviews with students.

Research Questions

We used the following research questions to explore the fit between curriculum mandate and student skills:

- How do high school students in Grade 11 and 12 biology classes locate and critically analyze scientific information relevant to their learning for these classes?
- What criteria do students currently use to evaluate scientific information found in their textbooks and in popular media, including the Internet?
- What aspects of scientific information do students deem trustworthy?
- What characterizes scientific information that students evaluate as relevant and worthy of serious attention?
- How do students understand the ways in which they have come to develop the evaluative criteria they apply? For example, have the criteria they apply come from classroom instruction, from personal experience or from other sources?

Procedures

The study participants included students from three Grades 11 and 12 high school biology classes in one multicultural urban public high school; most students in this study were between 15 and 17 years of age. Participants were asked to conduct a real-time information-searching task, which we designed with the classroom teacher to be consistent with regular learning outcomes. The topic was biomes, from the Biology 20 program of studies; students were required to collect information about biomes and present it in no more than three pages. Students were also asked the following questions as part of the assignment:

1. Where did you look information on biomes?
2. What information sources did you use for the biome assignment? Please write them down in the order you used them.
3. How did you decide what information to use?
4. How did you know that the information you used was accurate?
5. Thinking about the information you used, what made you decide to pay attention to it and decide that it was relevant to the assignment?
6. Thinking about why you decided to use the information you selected, how did you know how to make your decisions? How and where did you learn to select information for science assignments? For example, did you learn in school to use certain criteria for those decisions, or did you learn from your own personal experiences, from a friend, family or from someplace else?

The task was completed mainly during class time and was supervised by the classroom teacher, as would be the case for any other classroom activity; 82 assignments were completed. In addition, semistructured interviews were done with 24 students in these classes. The interviews used a critical-incident technique (cf Urquhart et al 2003) and focused on the information seeking and evaluation that had occurred during the classroom task. The authors and a research assistant conducted interviews in the teaching classroom on a noninstructional day. The interviews lasted between 10 and 15 minutes and were transcribed for analysis. (Interview questions are provided in Appendix 3.) Ethics approval was provided by the University of Alberta Faculties of Education, Extension and Augustana Research Ethics Board. Caregivers/parents and students provided separate consent for participation in the task and the interview. Analysis of the task data (student answers to questions) and the interview data was conducted qualitatively without software; themes were identified inductively, primarily by a single coder (a research assistant), with discussion and input from the study authors. Thus, final coding was done by multiple coders.

In addition to the triangulation of data sources, the trustworthiness of the study design and results was addressed by applying standards of quality for qualitative research. Credibility was confirmed by the classroom teacher in discussion following the study (that is, the teacher said that the study results "rang true") and by contextualization of the study within the local educational curriculum. Transferability is addressed by the study's focus on a classroom task that was consistent with regular class work and by the detail provided about the local context. Generalizability beyond the local context cannot be certain, except that results were consistent with those reported broadly in the literature. Evidence for dependability is evident in the consistency of findings in both sources of data. Finally, the use of multiple coders and quotes from student interviews to illustrate findings helps ensure the confirmability of the results (Lincoln and Guba 1985). The limitations of the study include the geographic limits of data collection, although those are necessary to compare local curricular mandates with student performance.

Results and Discussion

Findings from the in-class task were generally consistent with previous published research findings. Overall, even though students were given access to a wide range of information sources, the Internet was the most frequently used source for the students' research (59 per cent of sources identified). Students reported that they used the Internet in general, with Google as the most-used search engine, or to access a specific site, such as Wikipedia. The dominance of Google in student's responses was noticeable—students regarded Google as "the Internet" and used the two terms interchangeably. In addition, Google was used indiscriminately as a source of all information necessary for school and home (that is, for both academic and personal information seeking). They placed great confidence in the websites that Google provided, and many students used the first site listed from the search. Indeed, a neologism seems to have emerged—the verb *to google*. *To google* is widely used by students and teachers alike; for example, Chandra stated, "I just googled it and then I compared between different pages to see how accurate it was and then I went with the one that showed up the most." The largest proportion of students' responses as to why they turned to the Internet (35 per cent) focused on the perceived relevance of information found (that is, it answers the task questions). Accuracy of information was determined by comparing multiple resources for consistency in the information provided (42 per cent). Students usually looked at the first three sites from a Google search; comparable information in these three sites gave students a measure of the information's validity. For example, Carrie noted, "I usually just click the first one and read it, and then I'll click a couple more and if they all say kind of the same thing, then I'll keep that, because you're getting it from multiple sources, so chances are it's real." Credibility was judged by noting that references were provided (48 per cent of respondents). Relevance was assessed according to whether the information found answered the task question to be addressed (41 per cent of responses)—that is, by topical relevancy. Students reported that they skimmed information for relevant key terms to assess relevancy. The largest proportions of participants stated that they learned how to select information for science classes by experience with non-science school projects (38 per cent) and through nonacademic personal experience (29 per cent). Friends and family were frequently mentioned as people from whom the students had learned.

Students in our study indicated that they preferred to use the Internet because it is convenient and familiar, and searching by key word is easy. As Natasha stated, "Well, I'm—it's more reliable than going to the library and trying to find a book ... 'cause it takes less time." Robert noted, "Well it's much more convenient than, you know, you want to do something else with your time. If you get the information right here, you can finish the task quicker." It was thus surprising that few students mentioned cutting and pasting text from websites to save time, and there were no references to plagiarizing information unaltered from a website. Kendra stated that the Internet is "… a lot more easy to access, whereas the library and the textbooks we have to go to the library." However, students' searching skills are quite unsophisticated: in general, they search by pasting the assignment question or task directly into the search box, scanning the first three or four websites that appear, and comparing the content of these top sites for consistency. Interestingly, many of the students use and like Wikipedia, although there was some uneasiness—students commented that Wikipedia is often the first webpage listed from a Google search but they did not recognize it as a valid source of information. Jimmy said, "Wikipedia was just another place to compare because Wikipedia is an open source. And then, so, being an open source it is not exactly always reliable." Some students mentioned that university sites are reputable and reliable, and they try to use information from these sites for school purposes. However, examples given were American university sites rather than Alberta sites. To illustrate, Allison said, "I use the University of Berkeley site 'cause they're a generally trusted university name and you can assume that you can trust the research they've done." Set class textbooks were also viewed as valuable because the students expressed faith in the teacher and in the school. Andy said, "Well, I used it [a textbook] because I knew it would be reliable. If the school would give it to us and it not be reliable ... then that would kind of be defeating a bunch of purposes." However, students reported that their textbooks were not easy to use and that they rarely used other sources of information, such as encyclopaedia. One student who had used his grandmother's encyclopaedia to obtain information was unaware of the limitations that this placed on the validity of the information.

Personal experience rather than direct instruction is the main source of students' skill development. When asked directly, students generally expressed confidence in their information-finding and evaluation skills. Eva stated, "I guess just basically from years of experience I can tell whether or not something is reliable or not reliable." Robert said, "If Wikipedia's not first, then I just go with the first site Google gives me." Overall, the students revealed unsophisticated evaluation skills. Understanding of critical evaluation criteria, such as authority, accuracy, objectivity, currency and coverage, was not evident from the students' comments.

Students reported that their primary search strategy is keyword searching. While this approach is useful for new vocabulary (for example, *podcasting*), when there is no thesaurus, when searching results in few hits or when a known item is sought (for example, a specific author), there are significant limits to the value of keyword searches. The students in this study are unfamiliar with the benefits of searching by controlled vocabulary to improve comprehensiveness and precision. In addition, they apparently are unaware of how search engines identify potentially relevant sources. Thus, the limitations of searching by Google and of searching with only one search engine are not understood.

The school was very multicultural and had a Mandarin language program. One student, for whom English was not his first language and who was a recent immigrant to Canada, could not easily articulate what he had done to find information, but he had used the Internet using English keywords rather than his native Mandarin language.

Conclusions

It is clear that despite clear curricular mandates to develop information literacy skills, actual skill levels of the students in the study were underdeveloped. Although *Focus on Inquiry* (Alberta Learning 2004) calls for the development of sound information-searching skills, it is clear that students are not developing such skills. Actual classroom practices and teachers' understandings and attitudes were not explored in this study, so their relationship to the results reported here remains uncertain. It is possible that teachers believe that students already have these skills or, perhaps, that they themselves lack sophisticated skills and are therefore unable to provide guidance to their students. One reason for the lack of emphasis is that information-seeking skills are not directly assessed in the provincial exams, so even when such objectives are listed in the curriculum they are unlikely to be taken seriously by teachers. This observation was pointed out by an

Alberta science teacher at a Science Council professional development workshop where this study was discussed. Assessment-led teaching is not confined to Alberta, but is common worldwide, thus reinforcing the belief that for content or skills to be taken seriously, they need to be assessed.

Science lends itself very well to discussions about the construction of knowledge and the accuracy of information that students find on the Internet. For example, the tentative nature of scientific knowledge is a critical issue to address when developing information-seeking skills in science. A student in our sample who used his grandmother's encyclopaedia to find information for all school tasks and personal interests, irrespective of the topic, did not think about why he might need to use more contemporary resources. The 11th edition of *Encyclopaedia Britannica*, published in 1911, presents quite a different view of the world than we see today. In fact, the word *biome* (the topic of the students' science task) is not even included. Older books contain many descriptions of biological phenomena that would be considered incorrect today—for example, the structure of the cell membrane in pre-1980 books. In order to counter these concerns, teachers could present relevant scientific information from both historical and contemporary resources to demonstrate how knowledge and understanding have changed and why recent resources have the potential to be more accurate. An excellent example of such a task is a role play presented by Warren (2001), who uses scientific knowledge about scurvy from a number of periods in history. This role play requires several students to act out the role of a medical doctor, each at a specific time in history, and they have to make a diagnosis and prescribe treatment for scurvy based on the scientific information available to them at that particular time in history. The survival rate of their patients is clearly linked to the scientific information.

Students viewed the trustworthiness of information that they accessed predominantly in terms of the site or resource rather than by evaluation of the content. For example, university sites were mentioned as being accurate, but domain names like *angelfire.com* were considered by one student to suggest unreliability. Evaluating information on websites by examining domain name only is a risky practice; students need to be better equipped for evaluating content. A comparison of using domain name to judge website accuracy with making judgments about the accuracy of information in a book based on the title of the book shows that the basis for making that judgment is obviously flawed. In addition, it would help if teachers described to students how search engines work and websites are ordered. Of concern is the dominance of Google, which is revered as *the* way to find information—without any question or concern about underlying marketing strategies and economics filtering that information. A simple task would be to present a search to the class that uses two or more different search engines to demonstrate just how serendipitous the process is and as a starting point for discussions about the activities of information brokers such as Google.

We see that, overall, students gave less emphasis to the *process* of finding information than the end product of the search. Barranoik (2001), too, found that high school biology students showed that they were more concerned with the content than the process. In our study many students found it hard to recall precisely what they had done or why, despite specific questions addressing the process in their assignment. Rarely are such questions asked of students despite increasing evidence of the benefits of metacognition (Brem, Russell and Weems 2001). The ultimate goal was information to go—finding precise information in the easiest way possible in the shortest amount of time. Therefore, we recommend that teachers give more emphasis to the *process* of finding information, perhaps assigning marks for process, as was done in the task set for this research.

The connections between information literacy, scientific literacy and science inquiry seem to be underutilized, and we argue that more attention to making these connections could help students better understand the nature of science. However, an important point is that finding, evaluating and using information is a critical part of how a scientist conducts research inquiry; thus, if school science inquiry models the practices of scientists, emphasis on this part of the process could also enhance an understanding of the nature of science. In a science context, the parallels of information seeking with science inquiry could benefit both teachers and students, each having the potential to reinforce the other, and could offer the additional bonus of helping students understand the processes of science. The whole process of information seeking is remarkably similar to the stages of science inquiry, despite being considered by Windschitl (2008) to be a subset or complementary activity to science inquiry.

Introducing information-seeking tasks in the context of the work of scientists may be a helpful strategy; for example, would a scientist working in stem cell research use his or her grandmother's encyclopaedia to find information to help plan a new experiment? This sort of question could lead to useful discussions about the nature of scientific knowledge.

Another useful strategy in our increasingly diverse classrooms is for students for whom English is a second language to be encouraged to search in their first language. This opportunity could be used to highlight differences that could arise from searching in different languages and to consider the significance this has for science. For such students, searching in their first language may improve their understanding in specific content areas and give them a break from the constant demands of having to translate everything. In addition, such an approach may make it possible for parents and guardians to be included in the student's school work.

Presenting the task as a scientific question or encouraging students to pose a question to answer is a good way to start. Teachers might consider using a constructivist approach by eliciting students' prior understanding about the topic. One way to relate information seeking to science inquiry is presented in Table 1. Such a side-by-side comparison helps reinforce the processes of scientific inquiry in addition to information-seeking processes.

Alternatively, highlighting the role of information seeking as a precursor to scientific inquiry (Windschitl 2008) would be equally useful.

Our next steps include interviewing teachers to explore their own information-seeking and information literacy skills. Williams and Coles (2007) interviewed teachers in the United Kingdom and found that teachers lack information literacy skills, especially in searching, and evaluation skills. Asselin (2005) found that a lack of time to teach information literacy is a significant barrier for teachers. We are in a curious time—many students have better ICT skills than their parents or teachers, and this can be intimidating. Perhaps it is inappropriate to expect teachers to deliver curriculum in areas where their own skills require significant development. In addition, we are exploring ways to develop more sophisticated research and information evaluation skills for both students and teachers. There are some resources for teachers already, but some—for example, Ebenezer and Lau's (2003) resource book for K–12 teachers, *Science on the Internet*—are simply collections of lists of reputable websites and fail to address the information literacy skills highlighted in this paper. Undoubtedly, information literacy needs to be explicitly addressed in the classroom. In scientific disciplines, scientific literacy and information literacy are inextricably linked. Teaching students skills in searching for and evaluating information has the potential to help them understand better the nature of science and scientific knowledge, in addition to helping them learn more widely applicable information literacy skills for use in daily life. Although the value of these skills is unchallenged, significant challenges to inculcating them remain.

Table 1. Links between information seeking and scientific inquiry

Information-Seeking Task **Goal: Finding credible information to meet an identified need**	**Science Inquiry** (partly adapted from Windschitl, 2008**)** **Goal: Developing defensible explanations of the way the natural world works**
Elicit prior knowledge	Elicit prior knowledge and organize what we know and what we'd like to know.
Plan search strategy (identify key words, appropriate synonyms and combinations; identify possible credible sources)	Generate hypothesis
Execute search strategy (iteratively, according to results)	Seek evidence to support or refute the hypothesis
Evaluate information found according to standard criteria	Construct an argument
Communicate or present results as required	Communicate findings

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Hybrid Adapted Primary Literature: A Strategy to Support Elementary Students in Reading About Scientific Inquiry

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For many years, the trend in science education has been to advocate hands-on opportunities for students and move away from teaching practices that rely heavily on textbook reading. Teachers are encouraged to provide opportunities for exploration and experimentation and to engage students in *doing* science. This is the view promoted by the *Common Framework of Science Learning Outcomes, K–12*: "Students learn most effectively when their study of science is rooted in concrete learning experiences, related to a particular context or situation, and applied to their world where appropriate" (Council of Ministers of Education, Canada 1997). Yore, Craig and Maguire (1998) argue, however, that this emphasis has stifled efforts to use text in a valuable way in the science classroom. Fang (2006) argues that current strategies deny students the opportunity to engage with and learn the specialized language of science and to see concrete examples of scientific reasoning. These researchers contend that to really engage students in inquiry, the answer lies not in removing scientific text but in supporting students to learn with and from it.

To begin to accomplish this goal, this study examines hybrid adapted primary literature—text pieces that integrate both narrative writing and adapted scientific writing—as a way to help students learn to read scientific text. We describe the creation and pilot testing of one of these resources and examine whether this hybrid resource might offer promising opportunities for students to understand the processes of scientific inquiry and the reasoning, motivation and work of scientists.

Advantages of Students Reading Primary Literature

Within the context of science, *primary literature* refers to writing done by scientists that describes and explains their research to other scientists (Baram-Tsabari and Yarden 2005). This category of scientific writing can include, for example, scientific journal articles, papers from conference proceedings and research abstracts. There has long been recognition that reading primary literature would be of great value to students. For example, Schwab (1962) argued:

> Papers by scientists reporting scientific research have two major advantages as materials for the teaching of science as enquiry. ... They afford the most authentic, unretouched specimens of enquiry that we can obtain … The second advantage of original papers consists in the richness and relevance of the problems they pose for enquiry into enquiry. (p 81)

Note the emphasis that Schwab places on the ability of primary literature to encourage "enquiry into enquiry"—the process of asking questions and learning about science, scientists and scientific inquiry. Similarly, Brill, Falk and Yarden (2004) outline the wide range of opportunities that arise when students are exposed to research literature written by scientists. These opportunities include understanding the rationale for research designs and procedures; exploring the important connection between chosen research questions and research methods; increased familiarity with scientific communication and the language of science (for example, in terms of expressions of uncertainty and appeals to authority/evidence); practice in questioning and critiquing the methods and findings of researchers; and an introduction to the ongoing nature of scientific research. Generally stated, primary literature can be an excellent way to teach students about the nature of science, particularly those aspects that are reflected in scientific writing. We should note that we recognize that scientific writing is not a mirror of the scientific research process (and is not "unretouched," as Schwab asserted), but we nevertheless believe that it provides valuable information to students about research and communication in science.

Descriptions of the nature of science generally include the purpose of scientific endeavours; how science is pursued, constructed and communicated; and the historical, social and cultural context of science (McComas, Clough and Almazroa 1998; Chiapetta and Koballa 2002; MacDonald and Gustafson 2006). And while there are certainly exceptions (for example, Jenkins et al 1996), the nature of science is often not strongly emphasized in science textbooks, the primary reading source for most students (McComas, Clough and Almazroa 1998). Textbooks often do not convey a systematic curriculum of the nature of science or illustrate situations in which a scientist is seeking an explanation and solution that may not exist (Myers 1992). Textbooks also do not give attention to the debates that may have preceded general acceptance of an idea (Myers 1992). For example, the concept of the atom was widely debated before being accepted in the scientific community. In addition, students may perceive textbooks as always having a right answer and may, therefore, have a false sense of textbooks' "correctness" (Myers 1992). Primary literature, however, offers students a first-hand account of the challenges of scientific research, the tentativeness of scientific findings and the lengthy debates that often arise in the development of scientific knowledge.

Challenges in Using Primary Literature

There is, however, a great challenge in using primary literature in the classroom because the scientific genre can be difficult for novices to read (Baram-Tsabari and Yarden 2005). As Fang (2006) argues, science represents a culture of its own, with attendant language and communication norms. The language of science is not the same as everyday communication—it contains unique vocabulary and syntax developed over time to meet the communication needs of scientists. It helps scientists establish connections between claims and evidence in the development, support and refutation of theory. The language of science supports scientists in writing to create new knowledge and to communicate scientific procedures, results and understandings (Yore et al 2004).

Brill, Falk and Yarden (2004) note the difficulties that two students encounter as they read primary literature, including new and unknown scientific terminology and unfamiliar text style. Fang (2006) similarly outlines the challenging features of the language of science textbooks: technical vocabulary, including words with Latin or Greek origins; ordinary words with nonvernacular meanings or usages (students are often unaware of the precise and different meanings that words—for example, *theory*—have in science); abstract nouns created from everyday concrete words (for example, *light diffraction* and *cell division*); and difficult grammatical structures, including the passive voice, which is often used for efficiency of expression and for greater appearance of objectivity. These features combine to make scientific texts dense, abstract and difficult to read. For example, the following sentences illustrate some of the difficult features often found in science textbooks:

> The faster a stream flows, the clearer its water tends to be and the higher its oxygen content (*passive voice*). Swift currents quickly wash loose particles downstream, leaving a rocky or gravelly bottom (*complex sentence structure*). The tumbling and splashing of swiftly flowing water (*complex noun phrase)* mixes in air from the atmosphere, increasing the oxygen content of the water (*complex noun phrase*). (Fang 2006)

Adapted Primary Literature and Hybrid Adapted Primary Literature

To combat some of these difficulties, researchers such as Falk, Brill and Yarden (2008) have proposed the use of adapted primary literature (APL). The adaptation process maintains the structure and style of the original scientific writing, but adjusts for the conceptual understanding, reading level, vocabulary and mathematical skill of the students. In some instances, additional background information is included and nonessential elements, such as equations, are omitted. The discussion is often adapted (for example, by including further information and more explicit links between ideas) so that students can more easily make connections between the results and the conclusions drawn by the researchers. Using these approaches, APL has been shown to be effective and valuable in high school science classrooms; students develop a deeper understanding of both the content of the discipline and the processes of scientific inquiry (Baram-Tsabari and Yarden 2005; Brill, Falk and Yarden 2004; Brill and Yarden 2003).

There are, however, still difficulties in using APL with younger students because, while the adaptation process simplifies the words and the scientific content, the complex structures described above (for example, the passive voice and abstract noun phrases) are often kept. Scientific writing with these features is still an unfamiliar and difficult genre for many students. In addition, Fang (2006), in reviewing the obstacles presented by science textbooks—including those written specifically for an elementary school audience, notes that the transition from narrative reading in the early elementary years to expository writing in later years can be a treacherous crossing for many students. He also argues that attention is not sufficiently paid to helping students make this transition in elementary science.

Here, therefore, we propose and explore a hybrid form of scientific writing for students. This hybrid form integrates more familiar narrative writing with APL. In the context of this study, *narrative* is taken to refer to writing that is action oriented (not written in passive voice) and concrete (without widespread use of abstract noun phrases), and that directly identifies the people involved and describes their thoughts, motivations and actions. These are nonfiction narratives that can still be classified as informational based on their content (descriptions of scientists and scientific ideas) but, because of the structure of the sentences and the emphasis on people doing things, are best described as narratives. It should also be noted that this narrative can also bring in aspects of the scientific inquiry process that might not be reflected in regular scientific writing. In focusing on the people involved, these narrative descriptions can include descriptions of motivations, challenges, upsets and disagreements. It may provide students with a more complete picture of the nature of science than adapted primary literature can.

The example resource that was used in this pilot study, which is described in detail below, included a narrative introduction to the scientists and their research, followed by an adapted version of one of their scientific journal articles (that is, a piece of adapted primary literature). Taken together, we have called these two components (narrative plus APL) *hybrid adapted primary literature* (HAPL). The aim is first to help children gain, through narrative, an understanding of who the scientists are, their motivations in undertaking the research and the reasoning processes they used to arrive at their research questions and methods. Then children can approach the more complex APL with an already developing understanding of the scientific research that they will read about. We propose that this structure will make the scientific writing easy to understand and help students engage comfortably and thoughtfully with the adapted primary literature.

Developing and Testing the Hybrid APL Resources

Here we describe the creation and pilot testing of one example of HAPL created to fit the Alberta Grade 6 science program of studies. The primary literature that inspired it was an article from the journal *Geology* that described researchers using computer-generated pictures to assess whether flow patterns observed on Mars are likely the result of wet or dry flow.

Development and Description

The first step in the development process was the selection of an example of primary literature that could be revised into classroom-ready HAPL. We searched scientific journals for recent articles that addressed concepts related to the Grade 6 program of studies. We also made it a priority to select articles that described direct collection and analysis of data; review articles were not considered. Potential candidates for adaptation were selected based on the following criteria: (a) the accessible nature of the evidence and procedures (for example, qualitative comparisons of pictures or measurement of quantities familiar to students, such as temperature and volume); (b) the availability of supporting materials for writing the narrative section of the HAPL (for example, press releases, interviews and accounts of the same research from popular science sources such as *Scientific American*, *Discover* and *National Geographic*); and (c) the contemporary interest of the topic—topics that might be interesting for students and that were likely to continue to appear in the news and other public outlets. The article chosen for the HAPL example described here was from the journal *Geology*. It described scientists comparing photographs of gullies on Mars to computer-generated pictures of wet and dry flow (for example, water vs sand flow) to determine the most likely explanation of the Mars gullies (Pelletier et al 2008). This study had also been reported in a press release from the home university of the lead researcher and had been picked up and reported on by several popular science websites.

The first step in creating the HAPL example was to adapt the journal article from primary literature to adapted primary literature. Working section by section through the original article, we scanned sentences and paragraphs for essential information and rewrote them using vocabulary appropriate for Grade 6 students. Sentences were shortened and calculations, statistical analysis, scientific jargon and technical terms were removed. The overall structure of the article and the grammatical style of the genre were maintained. For example, the opening paragraph in the original primary literature was

> The bright gully sediments deposited on Mars within the past few years (Malin et al 2006) have attracted great interest as possible signatures of liquid water flow under the present Martian climate. The distributary geometry of these deposits resembles that of debris-fan deposits on Earth, suggesting that they were transported by a mixture of sediment and liquid water. This discovery, together with that of Amazonian-aged gullies morphologically consistent with fluvial erosion (Malin and Edgett 2000; Gilmore and Phillips 2002; Balme et al 2006; Heldmann et al 2007), has challenged the prevailing notion of a dry recent Mars. Alternatively, the recent gully deposits could be the result of dry mass wasting if source-region slopes are sufficiently steep. Granular materials can exhibit fluid-like behavior (Treiman 2003; Shinbrot et al 2004; Bart 2007) and hence may produce depositional landforms very similar to those created by liquid water flow. (Pelletier et al 2008, p 211)

In our adapted version, the opening paragraph became

> The bright new marks on Mars' gullies have attracted great interest as possible evidence of recent water flow on Mars. These marks resemble marks made on Earth by mixtures of water and small grains of soil and sand. This has made some scientists believe that the streaks could be caused by water. On the other hand, the streaks could be the result of dry particles of sand and dirt. When they move, these materials can act as though they are flowing. It is possible that dry materials could have made these streaks.

We also decided, for the sake of keeping the text as simple as possible, to remove the references in the text. In future pieces, however, we acknowledge that the references might offer a valuable opportunity to address the connections between scientists and to model the fair use of materials from other authors.

The adapted version of the article (the APL) then became the central element of the example of hybrid adapted primary literature. A narrative introduction to the study was written from the information available in the press release and popular science writing about the study. It described the context of the research, including research that had come before it, and openly discussed the reasoning processes and motivations of the scientists. For example, the narrative section began with the following paragraph:

> In 2006, Michael Malin made an exciting discovery when he noticed bright new streak marks in pictures of Mars. These streaks looked like the marks that water leaves when it flows through sand at the beach. The streaks had not been there when the last pictures were taken in 1999. He, and other scientists, thought that they may have found evidence for recent water flow on Mars—maybe even a place where microscopic life could be found.

The introductory narrative was designed to guide students' thinking and encourage them to read and analyze the text in small sections. A questioning sequence was written to parallel the conceptual sequence of the scientific article to familiarize students with the logical flow of ideas in scientific writing before reading the APL. For example, once presented with the available evidence and before reading about what the scientists did, students were asked to predict how scientists could analyze the evidence. The narrative section went as far as describing the analysis procedures and then introduced the APL. The findings and conclusions were presented only in the APL. The APL was then followed by discussion questions designed to encourage students to identify the conclusions of the study and the evidence that supported those conclusions, and to connect the information in the narrative and the APL sections.

Testing and Revision

The purposes of this pilot testing were (a) to explore the possible effectiveness of HAPL as a strategy for teaching students to read scientific text and to support their understanding of scientific inquiry and the motivations, reasoning and work of scientists; and (b) to identify ways in which the HAPL example could be improved and refined for further classroom use. This paper describes one class of Grade 6 students as they used the HAPL example as part of their regular science class. Data were collected through classroom observations, students' written answers to the accompanying questions and student focus groups. The analysis consisted of qualitative thematic coding, with attention paid to students' understanding of the scientists and the processes of scientific inquiry. It is important to note that this was an exploratory pilot study of a single resource. It did not involve comparing the HAPL to any other strategies or engaging in pre- or post-testing of any kind. The goal was just to explore the responses of students as they used it and to use the information to improve the HAPL resource and assess the initial value of HAPL as a strategy.

To analyze students' understanding of the resources and the accompanying questions, each student response was summarized and coded to indicate depth of response and comprehension of the question. Comprehension was rated using a scale from 1 to 5; a score of 5 indicated a response that was detailed and showed complete comprehension of the question. For example, the question "What could he do to find out which hypothesis is the more likely explanation?" had the following response: "He could compare what those situations look like on Earth then compare it to what he sees on Mars and see if any of them look similar. He could also see what other planets look like and see if they have any streaks like that." This response was rated as a level 5 because it captured the essence of the method employed by the scientists when analyzing the data (in this case, to compare the pictures from the Earth-referenced computer models to the pictures taken on Mars), and included extrapolation to other sources of data (for example, examining streaks on other planets). A score of 1 indicated a response that showed little or no comprehension of the question. For example, to the question "What did the scientists do to confirm that the dry flow created the 'fingers' like in the real streaks?" one student responded: "Didn't understand the question." This response was ranked at 1 because the student stated explicitly that he did not comprehend the purpose of the question.

Based on these scores, revisions were made to the questions and to the overall HAPL resource. All questions with average ratings below 4 were considered for rewording unless field notes provided an explanation other than lack of comprehension—for example, that students did not have time to finish writing the response. Revisions were made based on the general patterns found in the student responses; for example, for the question "Why might these streaks be evidence of recent water flow on Mars?" many students provided one explanation when there were two in the article. The revised question was reworded to indicate there were two reasons, "Name two characteristics of these streaks that are evidence of recent water flow on Mars." Grammar revisions were intended to reduce the use of abstract nouns and to ensure simple sentence structure. We felt that simplified grammar structure would aid the students in their comprehension of the material.[1]

Students' Understanding of Science and Scientists

Results of the pilot test suggest that the hybrid form is a promising way to engage elementary students in reading APL. It also supports hybrid APL as a valuable way of developing students' understanding of scientists and scientific inquiry. One of the key themes illustrated students' recognition that scientists rely on evidence and that evidence is collected and analyzed in detail, often over long periods of time. For example, students wrote: "They had to study it, it was not a snap question where you can get it right away," "He has two explanations so to test one you have to print off a picture of what it might look like if it was dry materials," and "Mars doesn't have water on it [because] ... the dry material flow looked a lot more like the streak than the liquid water did."

In particular, students were able to relate to the ways in which one group of scientists used comparisons as evidence: "He could compare what those situations look like on Earth then compare it to what he sees on Mars and see if any of them look similar. He could also see what other planets look like and see if they have any streaks like that"; "He would compare the colours of the two pictures in the gully, he would compare where the streaks might be and where they were formed. He might also look at the angles and direction"; and "He could compare the water model picture and the sand model picture to the real one."

The students, through reading the hybrid APL, also recognized the difficult and time-consuming work and effort that scientists put into their research. For example, they wrote: "Scientists do many, many experiments before they can conclude on an answer. They also do many analyses on their evidence before presenting it." Compared to a detective, "the scientists took more time to solve it and [are] still trying and it is more difficult."

Students also thought of the scientists as people with individual curiosity and motivation. They proposed several reasons why these scientists would have wanted to conduct these studies: "Because it could have been a breakthrough in our knowledge about Mars"; "Maybe, because of [the scientist's] curiosity"; "Because it would be really interesting if there's a streak in Mars"; and "They wanted to finish the research, and quickly find the conclusion."

Finally, students also recognized that the research reports were not repositories of absolute knowledge—they were reports of the scientists' understanding at that point. Students recognized the dynamic and developing nature of scientific knowledge and were keen to suggest what additional information could be gathered or what further studies could be done. Students were also encouraged to challenge what they read and were able to propose questions that they would like to ask the scientists: "I would like to find out if they did anything else to try and find out because they need more information than just that" and "Do they think there might be a sign of life on planet Mars? Why do they think it is water?"

Conclusion

The data suggest that hybrid adapted primary literature (writing that includes both narrative and adapted primary literature) is a promising way of engaging and supporting elementary students in reading APL and in developing their understanding of science and scientists. Through the combined use of narrative and scientific genres, students were able to expand their understanding of the connections between evidence and explanation in science, the personal motivations of scientists, the tremendous effort and time required for scientific research, and the place of research reports, not as repositories of absolute knowledge but as reports of scientists making sense of available evidence to the best of their abilities.

The encouraging results of this pilot test will serve as a base for further exploration of hybrid adapted primary literature as a strategy. Further studies are currently under way to examine in more detail students' reasoning as they read HAPL, the impact of the narrative section on students' ability to read and understand APL, and the longer-term effects of integrating several pieces of HAPL into a unit of study. Other work in progress is examining the exact differences between primary literature, APL and HAPL, and working towards guidelines for teachers and others interested in writing APL and HAPL for students.

Endnotes

1 The revised version of the resource entitled "Recent Water on Mars? Maybe, Maybe Not" is available on the CRYSTAL-Alberta Outreach website, www.uofaweb.ualberta.ca/crystaloutreach. Accompanying teacher resources are also available and can be found in the section labelled "Scientific Reasoning Text" under the subsection "Adapted Primary Literature."

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Classroom Chemistry: Considering Small, Unseen Particles

Brenda J Gustafson, Peter Mahaffy and Brian Martin

Abstract

In this discussion paper, the authors question the current Grade 5 classroom chemistry (Alberta Education 1996) focus on the macro-properties of matter and ask whether it would be worthwhile to strike a balance between macroscopic and particulate explanations of matter. Suggestions are given for how to introduce Grade 5 students to small, unseen particles and the role that helping students understand the nature of models plays in their making sense of particle explanations. This sets the stage for the development of CRYSTAL-Alberta computer visualizations intended to help students shift to a particle view of matter.

Introduction

In Grade 5 classroom chemistry, students explore the states of matter, the properties of water and the production of carbon dioxide. Activities in which students discuss physical changes, make crystals, identify evidence of chemical reactions, use acid/base indicators, and explore mixtures and solutions encourage students to use their senses to observe the macro-properties of matter.

These kinds of engaging activities may lead some students to ask questions that can be answered only by moving beyond a focus on macro-properties to considering the particulate nature of matter. For example, questions such as "Why are solids different from liquids?", "Why does heating and cooling lead to a change of state?" and "Why does mixing vinegar and baking soda result in the formation of carbon dioxide gas?" can open the door to explanations involving small, unseen particles—their movement and spacing in solids, liquids and gases; how heating and cooling can affect this movement; the existence of empty spaces between particles; and the idea that particles can join together to make new particles with different properties. Compounding the situation is that Grade 5 students may have already heard terms such as *atom* and *molecule* in their everyday lives (for example, from parents, older siblings and the media) and may already wonder how these terms connect to their classroom activities.

But should Grade 5 teachers venture into the territory of models of the particle nature of matter when science programs often postpone this topic to later grades? Similar to the *Common Framework of Science Learning Outcomes* (CMEC 1997), Alberta science programs currently assign this learning outcome to Grade 7—a decision that likely reflects the belief that younger students are not developmentally capable of understanding explanations involving an abstract, unseen world.

In this article we present research on students' understanding of the particle model of matter and the challenges this model presents to students of all ages. In light of these challenges, we discuss an inherent dilemma faced by Grade 5 teachers and argue that learner expectations that strike a balance between the macroscopic and the particulate levels of understanding might be a worthwhile consideration. We conclude with teaching strategies that can be used by Grade 5 teachers to help students begin their transition to a particulate view of matter and information about Grade 5 computer visualizations that we are currently developing with our CRYSTAL-Alberta project.

Understanding the Particulate Model—What Does the Research Say?

Students' conceptions of the particulate nature of matter have been the subject of extensive research for at least three decades. Researchers have repeatedly shown that understanding the particulate nature of matter poses challenges to students from all grade levels, including those enrolled in undergraduate science courses (Andersson 1990; Barker and Millar 1999; Boz 2006; Cros, Chastrette and Fayol 1988; Gabel and Samuel 1987; Griffiths and Preston 1992; Novick and Nussbaum 1978, 1981; Osborne and Cosgrove 1983). This research has identified the aspects of the particle model that have proven particularly difficult, including the ideas that all matter consists of discrete particles and that those particles have dynamic properties (Eliam 2004). In a research study of students aged 7 to 10, Nakhleh and Samarapungavan (1999) found that 20 per cent of them thought matter was "made of one piece" that cannot be broken down or divided, while 60 per cent thought matter was "made of little pieces" that were small but could still be seen. In her work with students aged 9 to 11, Stavy (1990) observed that many viewed matter as solid and concrete; only 15 per cent of the 14- and 15-year-olds in the same study used ideas about particle theory to answer researchers' questions. In a study of 300 students aged 13–17, Boz (2006) observed that students in all age groups had difficulty understanding particle movement in solids. Albanese and Vincentini (1997) questioned 30 14- to 16-year-old students to find that many thought the particulate world was totally isomorphic to the macroscopic world except for scale. For example, students connected their observations of the macroscopic properties of matter (for example, carbon is black) in unhelpful ways to a particle-level view (therefore, carbon atoms must also be black). Abraham, Williamson and Westbrook (1994) surveyed 100 secondary and college science students and found that 47 per cent had no understanding of how particles move during phase change.

Clearly, research shows that all students can struggle with understanding particle-level models, an observation that has implications for all concerned with students' science learning. But what is it about particle-level understanding that proves difficult? Novick and Nussbaum (1978, 1981) explain that students experience a fundamental disconnect between their sensory perceptions of matter and the particle explanations. Simply, a wood table looks like it *is* made of a continuous, unmoving material, and that kind of perception serves students well in their everyday lives. Novick and Nussbaum (1981) add that students attempting to accommodate sensory perceptions with mental models of particles must overcome "basic cognitive difficulties of both conceptual and perceptual nature" (p 187). Nakhleh and Samarapungavan (1999) label this transition to the particulate view as involving an ontological shift—suspending beliefs about continuous, unmoving matter and shifting to the belief that ideas about small, unseen particles can be used to explain the properties and behaviour of matter. This shift requires an act of imagination and time to consider how the shift may prove fruitful. Kind (2004) adds that "we cannot expect children to change their thinking overnight … children may accept the existence of particles readily, but take a long time to assimilate the implications of this model for the behavior of matter" (p 13).

In light of the perceptual and conceptual challenges presented by particle models, are Grade 5 teachers well advised to remain focused on the macroscopic properties of matter? Interestingly, researchers report that a singular focus on the macroscopic properties of matter also has its liabilities. Students who are given numerous opportunities to explore observable properties during their elementary years can develop misconceptions about matter that may be particularly strong and difficult to relinquish even when they are confronted in later years with particle-level explanations (Brook, Briggs and Driver 1984; Millar 1989; Stavy 1990). For example, categorizing matter as solid, liquid or gas may lead some students to conclude that solids are made of hard matter, liquids of softer matter and gases of very light matter—ideas that are unhelpful when attempting a shift to a particulate view. Other resistant misconceptions linked to a lengthy focus only on the macroscopic properties of matter include the ideas that

- matter is continuous (Benson, Wittrock and Baur 1993; Happs 1980),
- solids can decompose (for example, rusting nails) (Hayes 1979) and
- matter ceases to exist when it dissolves or evaporates but is still capable of leaving behind its smell and taste (Russell, Harlen and Walt 1989; Stavy 1990).

Clearly, Grade 5 teachers face a pedagogical dilemma. Focusing on macroscopic properties can result in misconceptions that may linger into adult years and, in part, contribute to the conceptual challenges reported in many studies. Ideas related to particle models that might help challenge misconceptions are relegated to the Grade 7 program, with the implication that these ideas are beyond the developmental capabilities of younger students. But perhaps we can find a middle ground through questioning assumptions about students' capabilities and rethinking how to help students begin the transition to a particulate world view.

Raising Questions About Students' Capabilities

Nakhleh and Samarapungavan (1999) observe that the "literature reflects disagreement … about the extent to which elementary children are capable of understanding causal principles that involve the action of unseen or abstract entities" (p 779). Proponents of Piaget's developmental stage theory argue that elementary students should remain focused on concrete experiences and would likely oppose Grade 5 students venturing into the abstract world of small, unseen particles. For them, Grade 5 children are simply not developmentally ready to think about the unseen. But research shows that the transition to a particulate world view is also difficult for older students supposedly operating at a formal operational stage. Nakhleh and Samarapungavan write that "indeed the world of atoms and molecules is no more visible or accessible to high school students than it is to young children" (p 801). Although no one would dispute claims that with age most students gain in their capacity for understanding increasingly complex and abstract ideas, perhaps difficulties with particle theory have less to do with developmental stages and more to do with the inaccessibility of the unseen world.

Teaching About Small, Unseen Particles: Ideas for Teachers

We are not advocating that Grade 5 teachers be charged with the responsibility to teach about the nature of chemical bonding, chemical formulas and the periodic table, or even introduce terms such as *atom* and *molecule*. We do, however, think that Grade 5 children can be introduced to some ideas and experiences that could serve to start them on the journey towards the ontological shift (a shift in beliefs) needed to use ideas about small, unseen particles to explain the properties of matter they can observe with their senses. Useful ideas about small, unseen particles that most Grade 5 children could understand include the following:

- Matter consists of small, unseen particles that are constantly in motion and collide often with each other.
- An increase in temperature causes the small, unseen particles to move faster and collide with each other more frequently.
- Solids consist of small, unseen particles that are closely packed and vibrate in a fairly fixed position.
- Liquids consist of small, unseen particles that are able to slide past each other.
- Gases consist of small, unseen particles that move in random directions colliding with each other and with the container.
- Empty spaces exist between small, unseen particles.

Kind (2004) recommends an initial teaching strategy that involves being honest about the challenge of believing that matter consists of small, unseen particles. "Entry points" (Nakhleh and Samarapungavan 1999) for this discussion could include reference to other instances when students are asked to believe in an unseen world (for example, we wash our hands because we believe that unseen germs are on our skin; we can taste salt in the ocean even though dissolved ions are invisible). Discussing how students use their imagination when viewing animated movies, playing video games and reading books provides another entry point to getting them to think about how they will also have to use their imagination to think about small, unseen particles.

A critical teaching strategy involves making small, unseen particles visible. Because particles that make up matter are too small for direct observation, they join the ranks of the many science phenomena that have to be taught using models. Gilbert (1997) explains that a model is a representation of an "idea, object, event, or process" (p 2). In classrooms, models include the pictures, diagrams, concrete materials, computer animations and snap-together plastic spheres that can be used to portray aspects of small, unseen particles. Glynn (1991) warns, however, that using models is a double-edged sword in that they can promote students' understanding of an entity but could also introduce even more misconceptions.

Care is needed, therefore, to help students first understand the nature of models and how every model has its strengths and limitations (Glynn and Takahashi 1998; Gobert 2000; Justi and Gilbert, 2002; Treagust, Harrison and Venville 2002). Several researchers have developed strategies to help students understand the nature of models (Clement 1993; Glynn 1991; Harrison 2004; Treagust, Chittleborough and Mamiala 1998; Venville 2008). These strategies place responsibility on students to think about how the model is similar to and different from the real thing. Using an example of a familiar family photograph (a pictorial model) and the FAR (focus–action–reflection) strategy (Venville 2008), a teacher would perform the following steps:

- **Focus**—Ask children what they already know about the people in the photograph. Ask children what they already know about photographs.
- **Action**—Support children's thinking as they consider the following questions: How is the photograph like the real people? How is the photograph unlike the real people?
- **Reflection**—Ask children how photographs both help and hinder them to understand things about the people depicted. Ask children why people use photographs when they are not exactly like real people.

Through critiquing familiar models, students can develop the understanding that models are "good enough" for explaining only some ideas about the real thing (Millar 2005). This critical stance will help them avoid some of the pitfalls associated with using models to teach about small, unseen particles. For example, a reliance on pictorial models in which small, unseen particles look like balls could result in students believing that if they could see particles then they would appear to be round. Reliance on 3D concrete models could lead students to believing that particles are hard, coloured spheres. Clearly, Grade 5 teachers would have to play an active role in gradually introducing aspects of small, unseen particles and guiding children to think critically about selected models.

Figure 1 Picture of an aluminum pop can beside a picture of small, unseen particles in solid phase

A final consideration involves the need to use multiple models to depict small, unseen particles. Different models offer different "conceptual vantage points" (Grosslight et al 1991) that are particularly helpful when dealing with nonobservable phenomenon. Duit (1991) claims that multiple models act as antidotes for model-induced misconceptions in that they encourage students to see that there can be several valid models for the same phenomena (Grosslight et al 1991). Grade 5 teachers, therefore, may use pictorial models, concrete models and even body-movement models to represent different aspects of small, unseen particles. For each model, teachers can help students think about how the model is like particles and how the model is unlike particles.

Looking Forward

Challenges remain in knowing how best to develop teaching resources that can assist Grade 5 students in developing a critical stance toward models and begin using ideas about small, unseen particles to explain the macroscopic properties of matter. Given these challenges, we are collaborating to design and produce computer-based digital learning objects to provide Grade 5 teachers with a tool to answer some of those theoretical *why* questions that children ask during classroom chemistry. These computer visualizations use examples from students' everyday lives and feature the simultaneous representation of the particulate alongside the macroscopic (see Figure 1).

The computer visualizations allow a portrayal of the dynamic nature of small, unseen particles and provide opportunities for students to interact with the visualizations. This CRYSTAL-Alberta project is meant to help Grade 5 teachers engage both the macroscopic and particulate levels of matter, assist students to see the unseen world and, perhaps, help those students avoid developing entrenched misconceptions about matter that are difficult to relinquish in later grades.

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Note: The Virtual Classroom computer visualization developed during year 1 of the project can be accessed at www.kcvs.ca/projects/elementary/elementary.php.

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