

John P. Kubicek

Author

John Kubicek has worked in the informal education field for fifteen years, and is currently at the Canadian Museum of Nature in Ottawa. He can be reached at: jkubicek@mus-nature.ca

Abstract

The teaching of science in the K-12 classroom has been less than successful. Students typically do not develop science literacy and do not understand the role and relevance of science in society. Inquiry-based learning is an approach which promises to improve science teaching by engaging students in authentic investigations, thereby achieving a more realistic conception of scientific endeavour as well as providing a more learner-centred and motivating environment. It can also be used to support teaching the nature of science. The inquiry approach, while lauded by educators, is still not prevalent in the classroom, and is often misused. This may be the result of multiple factors, such as amount of classroom time, lack of effective means for students to conduct independent investigations, the difficulty of incorporating abstract concepts with inquiry, and lack of teacher expertise and experience. Computer technology has evolved now to the point where it can greatly facilitate the use of inquiry learning on many levels, and provide new tools for representing the nature of science in the classroom. This use of technology to support new teaching approaches and objectives holds great promise for improving science education in the classroom, as long as the inherent limitations are recognized and technology is used as a tool rather than as a foundation.

Résumé: L'enseignement des sciences dans les salles de classe de la maternelle à la douzième année n'est pas une réussite. D'ordinaire, les étudiants ne développent pas leurs connaissances en sciences et ne saisissent pas le rôle et la pertinence des sciences en société. L'apprentissage axé sur les enquêtes est une méthode qui promet d'améliorer l'enseignement des sciences en permettant aux étudiants de participer à des enquêtes réelles, obtenant par le fait même une conception plus réaliste des progrès scientifiques, cet apprentissage met de l'avant un environnement bien plus motivant et axé sur l'apprenant. Il peut aussi être

utilisé pour appuyer l'enseignement de la nature des sciences. La méthode des enquêtes, bien que soutenue par les éducateurs, ne règne pas dans les salles de classe et elle est souvent mal utilisée. De nombreux facteurs peuvent expliquer ces phénomènes, par exemple, le temps passé en salle de classe, le manque de moyens efficaces permettant aux étudiants de mener des enquêtes indépendantes, la difficulté à intégrer des notions abstraites avec l'enquête et le manque d'expertise et d'expérience des enseignants. La technologie informatique a tellement évolué qu'elle peut grandement faciliter l'utilisation de l'apprentissage par enquête à de nombreux niveaux et qu'elle présente de nouveaux outils permettant de présenter la nature des sciences dans la salle de classe. Cette utilisation de la technologie qui met de l'avant de nouvelles méthodes d'enseignement et de nouveaux objectifs permet de croire qu'il sera possible d'améliorer de façon significative l'enseignement des sciences dans les salles de classe, mais pour cela, il faut tenir compte des limites inhérentes et la technologie doit être utilisée à titre d'outil plutôt qu'à titre de fondement.

Introduction

Formal schooling provides a key opportunity to teach science literacy, but has arguably not been very successful in this regard. Krajcik (2001) cites Osborne & Freyberg (1986), Rutherford & Ahlgren (1989) and Linn (1998) in support of the conclusion that students at the elementary, middle and high school levels do not develop an understanding of science that is useful for their everyday lives. Other studies have suggested that students do not see how science applies to everyday life (Linn & Hsi, 2000), and that there is very little integration of science within everyday thinking among students (Cobern, Gibson, & Underwood, 1999). Research has shown that even students with the most grade success in science do not necessarily grasp fundamental concepts about nature and science (Cobern, et al., 1999). In a society increasingly permeated with developments in science and technology, an understanding of the nature of science, or NOS, enables students to be more informed consumers of scientific information (Lederman, 1999). The majority of students do not, however, possess adequate conceptions of the NOS (Wang, 2001).

Not surprisingly, then, science is said to be poorly taught in schools (Eisenhart, Finkel, & Marion, 1996). Several aspects of traditional school science teaching may be responsible for this. Schools have typically employed a didactic approach, with an emphasis on transmitting the content of scientific theories to students: "teachers dispense knowledge to passive student audiences, with textbooks alone constituting the science curricula; students are rarely involved in direct experiences with scientific phenomena" (Wise, 1996, p. 337). This approach does little to motivate real learning, and reflects the antiquated notion that students learn by being asked to memorize information. The Common Framework of Science Learning Outcomes K to 12 (Council of Ministers of Education, Canada, 1997) describes the goals of science education:

A scientifically literate individual needs to acquire certain knowledge, skills, and attitudes;

to develop inquiry, problem-solving and decision-making abilities; to become a lifelong learner; and to maintain a sense of wonder about the world. (p. 8)

Memorization of information emphasizes teaching the conclusions of others: "schools are reinforcing the message... that science education is about remembering the results of other's [professional scientists'] research ['facts'] rather than developing the ability to conduct one's own" (Claxton, 1991, p. 28). There appears to be a disconnect between the science of the school curriculum and the practice of science. Hawkey (2001) describes the current model represented in school science as "a cathedral at which worship is expected rather than a quarry from which resources are extracted as required" (p. 108). The teaching of science as a body of irrefutable knowledge does not provide students with knowledge and understanding that will be useful to them in their lives; in fact, this erroneous perception simply reinforces a trend of either blind acceptance or mistrust of scientific research. Furthermore, a typical feature of science education has been that teachers rarely or never go beyond science content in their instruction, and do not relate content to other domains of scientific literacy to provide a larger context (Cobern et al., 1999). As pointed out by Lemke (2001), "the most sophisticated view of knowledge available to us today says that it is a falsification of the NOS to teach concepts outside of their social, economic, historical, and technological contexts" (cited in Bencze, Bowen, & Oostveen, 2003, p.2).

The Inquiry Approach

The Common Framework of Science Learning Outcomes K to 12 (1997) encourages the inquiry approach to science teaching:

Development of scientific literacy is supported by instructional environments that engage students in active inquiry, problem solving and decision making ... set in meaningful contexts. It is through these contexts that students discover the significance of science to their lives and come to appreciate the interrelated nature of science, technology, society, and the environment. (p. 8)

Inquiry-based learning is gaining increasing support in science education, with a growing number of educators becoming interested in teaching which involves projects or inquiry (Polman, 1998). It is an approach which engages students in activities which mirror methods of scientific investigation, with content interwoven with or addressed in the context of inquiry. To be effective, inquiry learning should include the basic abilities of conducting a scientific investigation as well as an understanding of how scientists do their work. Inquiry-based learning should stress the importance of "learning the 'process' of science, such as formulating empirically investigable questions and supporting claims with evidence" (Polman, p.3). The effective use of inquiry-based learning engages students in self-directed inquiry, in learning to think scientifically, and in understanding the relationships between evidence and theory. It is not so much the outcome of the inquiry which is most valuable but the process used, and so it is important to provide time for discussion and to encourage pupils to make their ideas explicit (Watson, 2000). Working from this traditional understanding of science inquiry, substantial research supports the efficacy of inquiry as an instructional model (Byers & Fitzgerald, 2002). This research has informed the development of new curriculum guidelines.

The benefits of inquiry-based learning can be curtailed when activities are not open-ended and learner-directed. It is important that students can choose their own question or problem to investigate, and be able to steer their inquiry in directions of their own choosing. Not only does this increase motivation, it is also a more realistic form of inquiry, and thus builds a better understanding of the nature of science. When teachers resort to old familiar methods, such as using worksheets with predetermined outcomes or textbook-based instruction in conjunction with inquiry, students do not develop an understanding of the NOS: "the presentation of science as a process of following step-by-step instructions and filling in blanks on worksheets promotes erroneous and impoverished concepts regarding the nature of science" (Huber & Moore, 2001, p.33).

Inquiry, the NOS, and Computer Technology

New computer technologies are creating new opportunities for students to engage in serious inquiry (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000), and to undertake aspects of inquiry that they could not otherwise do (Novak & Gleason, 2001). In fact, some of these technologies can actually help transform science "from canned labs and the passive memorization of content to a dynamic, hands-on, authentic process of investigation and discovery" (Barstow, 2001, p. 41). Hawkey (2001) goes so far as to say that technology can now provide "a new opportunity to reconsider fundamental questions about what it means to be scientifically literate, about the nature of science and the relationship between practicing scientists, their work and the public" (p. 106).

Although these may at first seem like rather lofty claims, upon closer examination, there are indeed a number of distinct advantages available to the science classroom as a result of new advances in computer technology.

Few would argue that the learning environment created by the science teacher plays a role in shaping students' perceptions of the way science is practiced and how new knowledge is created. Many teachers are exploring a constructivist approach to teaching which recognizes that each individual's existing knowledge and attitudes affect their learning. Interestingly, the developmental mechanism of scientific theories, in the constructivist view of science, is similar to the constructivist view of an individual's knowledge construction (Tsai, 2000). This suggests that a constructivist approach to learning science may also make it easier to get students to learn how to "think scientifically". Inquiry-based learning, when authentic, complements the constructivist learning environment because it allows the individual student to tailor their own learning process.

The interactive nature of computer technology can support students in carrying out inquiry-based activities, using topics, questions, and even theories that they themselves define and develop. Tapscott (1996) notes, " precisely because this new technology is interactive, it does away with the passivity associated with the traditional learning model in which the student is viewed as an empty vessel to be filled by the knowledge and expertise of the teacher" (p. 144). Thus, the teacher becomes better equipped to act as a guide and facilitator, allowing the student to be engaged in a more realistic scientific

inquiry experience. Computer-supported learning environments make it easier for students to propose their own research focus, produce their own data, and continue their inquiry as new questions arise, thus replicating scientific inquiry more realistically. It can support the teacher in focusing more on supporting and sustaining the inquiry process. Furthermore, students who are permitted to use their own resources in developing, implementing and evaluating projects are likely to find, with little doubt, need for considerable revision. This, in turn, illustrates that the possibility always may exist for critique (skepticism) of methods associated with all scientific conclusions (Bencze et al., 2003).

By facilitating and supporting true inquiry in the classroom, computer technology can also improve the teaching of the NOS. It may be unrealistic to strive for a complete and thorough understanding and discussion of the NOS in the elementary classroom, but teaching towards a basic understanding is possible. Lederman and Schwartz (2001) describe seven elements of the NOS, including 1) the tentativeness or changeability of science, 2) the role of creativity, 3) the subjectivity of science i.e. influences of currently accepted knowledge and scientists' own biases, 4) its empirical basis, 5) its social/cultural embeddedness, 6) differences between theories and laws, and 7) the nature of observations and inferences. Teachers can use computer technology in different ways to support their representation of these elements of the NOS.

Unlike the impression created by textbook learning, which is that science consists of fixed, unchanging facts, the World Wide Web can much more effectively represent the fluid character of knowledge by its ability to revise information continuously and to provide access to multiple sources. It can provide access to older reports and articles as well as the most recent on the same issue or topic, providing opportunities to explore how scientific data, models and theories are modified and refined over time. The Web also provides access to resources from a wide variety of perspectives, thus providing opportunities for students to discover examples of social and cultural influences on science, and how multiple inferences can be drawn from the same set of observations. Different sets of data on the same topic can potentially be accessed, supporting an interesting lesson on the subjectivity of science. News reports on scientific studies can be easily retrieved and used to demonstrate how science tends to be presented in the media. Teachers can use databases which include many irrelevant as well as relevant variables, and many of the relevant variables can be correlated. They could then require students to develop strategies for teasing apart the effects of associated variables and to begin to question some of the methods used to gather data (Chinn & Malhotra, 2002).

Computer technology can facilitate the manipulation of variables in experiments and models. Students can thus predict, observe, and explore the effects of experimental parameters on dependent variables in more complex experiments than could ordinarily be replicated in the classroom. Simulated microcomputer-based laboratory experiments allow teachers to demonstrate the impacts of the choice of variables used in an experiment, supporting discussions about tentativeness and subjectivity. Since simulations are used by scientists themselves, an understanding of their strengths and their limitations is also

useful to developing a more informed perspective on an important method of science investigation. Simulations can also be used to further an understanding of the nature of science by facilitating the use of different methods to investigate the same issue. When these methods yield conflicting results, it may "impel learners to think about how to reconcile the rival methods or how to decide which is more reliable" (Chinn & Malhotra, 2002, p.208). The use of simulations can assist the teacher in shifting the emphasis to "thinking, conjecture and talk about scientific method, about the reasons, limitations and benefits of carrying out controlled experimentation, and about qualitative interpretation of evidence" (Miller, 2001, p. 194).

Models are another important tool used in science investigations, and are a valuable means of expressing an understanding of a process and of constructing knowledge. Raghavan and Glaser (1995), Driver et al. (1996), and Gilbert et al. (1998)², report that models and model-based reasoning have been found to be important in the development of science concepts and the development of students' understanding of the processes of science (Thomas, 2001). Computers will allow students to create scientific models which include multiple variables, and to test them by running through new simulation situations. They can then construct new models that accommodate their emerging understandings. In this way, students are informed of how scientific inquiry proceeds via experimentation through the successive refinement of models (Thomas, 2001). Research suggests that when using computer simulations and modeling, students tend to develop new strategies for solving problems, complete tasks of greater cognitive complexity, test personal hypotheses by making predictions, develop higher-order thinking skills, and engage in complex causal reasoning (Cox, 2000). It is important to note that the use of simulations has certain potential drawbacks as well, and must be incorporated into the classroom with care. For example, computer-simulated experimentation software characteristically dictates the direction of inquiry by predefining variables. Even though simulations can be interactive, students cannot test alternative models or novel variables that are not programmed into the system, and the potential value to the learner of identifying variables on their own is not available. Another cautionary note about simulations is their potential effect on the representation of reality. Maxwell (1999) identifies this weakness:

Through the distorting mediation of computers, physicality is denied, emotions are compressed through a cognitive prism, and spirituality is ignored. No amount of sophisticated computer graphics, animation or 16-bit stereo sound can fill the void created by the absence of direct physical contact with other humans, animals, plants and the greater natural world. (p. 44)

Computer simulations should not be used to replace real experiences, but rather to supplement them. The limitations of virtual representations should be pointed out by the teacher, and an appropriate context provided to students. David Abram appropriately states that "it is only at the scale of our direct, sensory interactions with the land around us that we can appropriately notice and respond to the immediate needs of the living world" (Abram, 1996, p.268). If technology is used in balance with real experience, though, and is placed in its proper context, it can enrich the classroom by providing new and contrasting contexts in which to understand experiences (Feldman, Konold, & Coulter,

2000).

Computers can facilitate the firsthand communication of multiple perspectives and sources of knowledge through synchronous and asynchronous connections to the outside world. This creates added potential to enrich discussions on subjectivity, social/cultural embeddedness, and observations and inferences, in science. Students can potentially interact with other students, teachers, and scientists, thus increasing the range and diversity of perspectives brought into the classroom, and providing access to realistic situations, expert advice, diverse knowledge sources, and multiple representations (Feldman, et al., 2000). Breuleux (2001) suggests that computer-supported networks have the potential of bringing in "more people, different perspectives, different voices... it opens the door not only for the voices inside the class to be heard outside, but also, reciprocally, for minds outside to be present within the class" (p.3). Barab and Hay (2001), Cohen (1997), Evans et al. (1999), and Moss et al. (1998), support the premise that the nature of science can be more effectively integrated into science instruction through programs which involve students in real science activities, in cooperation with scientists (Moss, 2003). In addition, computer-assisted interactions with students in other schools can enhance opportunities to experience collaboration, a fundamental aspect of scientific work. Real scientists collaborate throughout their working lives, making a strong argument that science students should learn to do the same (Scanlon, 1997). There is considerable support for the belief that computer technology can support more powerful, more complete experiences of collaborative knowledge-building. Computer-supported collaborative learning environments can provide students with experiences of "co-construction of shared understanding" (Thomas, 2001, p.33), can support a shift in focus from whole-group to small-group interaction, and can encourage teamwork and collaborative inquiry (Levin & Thurston, 1996). An example of this is provided by the GLOBE program (www.globe.gov), which uses the Internet to provide discussion areas for student discussions and collaboration, as well as access to scientists involved in GLOBE research, teacher support materials, a forum for teachers to exchange ideas, and libraries of information, including bulletins and news and events. The technology is transparently easy to use in a classroom equipped with a computer and readily available software (Klemm & Tuthill, 2003).

Computer-supported interactions with scientists should be designed to integrate with pedagogical objectives, and can complement open-ended inquiry activities. Interactions with scientists can provide an additional source of expert information, provide a window on an example of real science as it is being practiced, and even help to break down certain myths and misconceptions. Scientists may use different methods, and may have different views on science, and if designed properly, with teachers providing the right context, interactions with scientists can also support a better understanding of the NOS. Without proper design, though, interactions with scientists may not yield the results intended. Moss (2003), in critiquing one network science project, suggests that "there was little guidance given to teachers about which aspects of one program should be featured in order to facilitate an understanding of the nature of science for students" (p.28). As a result, this example of inquiry, although supported by a network, did not take advantage of the

window on science made available, and although students were engaged in active project-based work, they were merely uncovering and reporting content facts.

Teachers often cite the difficulty of teaching the NOS when dealing with abstract content. Many concepts in science, such as atoms or genes, are theoretical constructs based on experimentation, and may be more difficult to understand because they are unobservable. Other phenomena are equally unobservable in the classroom due to scale or accessibility. Computer technology can contribute to a better understanding of abstract concepts by facilitating observation of certain phenomena, and providing the means for students to experiment with these phenomena. This is useful in that it increases the cognitive connections between data and the real world it attempts to represent. Some examples of online tools which present such possibilities include EarthKAM (www.earthkam.ucsd.edu), a program that gives students direct access to a digital camera on the International Space Station so they can download real-time images of the earth. The Visualizing Earth Project (www.visualizingearth.ucsd.edu) provides access to visualizations and remotely-sensed images. In addition, it incorporates image analysis tools, and design features such as control over view angles and distance calibration, allowing students to actively manipulate image and data displays (Barstow, 2001). The BioLogica program (<http://biologica.concord.org>) offers tools for investigating and manipulating representations of genetics (Tsui & Treagust, 2004). ThinkerTools (www.thinkertools.soe.berkeley.edu) allows middle school students to visualize the concepts of velocity and acceleration. In controlled studies, researchers found that middle school students who used ThinkerTools outperformed high school physics students in their ability to apply the basic principles of Newtonian mechanics to real-world situations (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). The program Space for Species (www.spaceforspecies.ca) makes it possible for a student to track animal migration patterns and habitat changes online, and to then use this information to answer authentic inquiry questions. The Jason Project (www.jasonproject.org) uses computer simulations to enable a student to explore the Galapagos Islands habitat (Klemm & Tuthill, 2003), and the Exploring Earth program (www.classzone.com/books/earth_science/terc) allows students to see volcanoes erupting, weather storms forming and dissipating, ocean currents flowing in global patterns, and the latest images from spacecraft exploring other worlds (Barstow, 2001). These particular programs are not cited here because they necessarily represent the best examples of online programs available. They are pioneers in a developing field, though, and illustrate some of the potential that computer technology can offer to science education.

Many K-12 teachers lack experience and corresponding expertise with inquiry learning (Bencze et al., 2003) and have insufficient science backgrounds to teach the NOS (Lederman & Schwartz, 2001). Technology can assist teachers in both of these areas by supporting resource networks. Chatrooms, listservs, e-mail, videoconferencing and other communications methods can support networks for ongoing professional development, peer support groups, and training. Using computer technology, teachers can more easily access scientists, other teachers who have more experience in implementing computer-

assisted inquiry learning, and potentially curriculum developers, educational researchers, and professional trainers. They can theoretically also access a wide scope of authoritative information about science fairly easily and quickly, which they can draw from to enhance their knowledge.

Lack of time has also been cited by teachers as a factor inhibiting the teaching of the NOS (Lederman & Schwartz, 2001). Computer software can help teachers free up increased classroom time for the analysis, reflection and discussion which is so important to teaching the NOS. Electronic databases, including those accessible via the World Wide Web, permit students to gather second-hand data quickly and independently, thus freeing students to spend more of their time analyzing, interpreting and predicting than on mechanical tasks of data collection. Databases which are designed so that student can insert their own data, support record-keeping during the inquiry process, allowing students to maintain records of their ongoing progress in a variety of representations. They allow students to record the intermediate products of their investigations, as well as their plans, hypotheses, and observations (Edelson, 2001). This can save time spent reviewing and recollecting work from previous classes and can greatly facilitate reflection and discussion.

Simulated experiments or virtual labs can save time for both teacher and students normally spent on setups, cleanups and mindless procedures of lab work. This time can then be used engaging in analysis and discussion of elements of the NOS based on the results of those experiments. Tools such as sensors and portable laboratories permit the student to directly interact with the environment and collect new first-hand data within a practical time- frame, and increase the time available for thinking about what that data means. For example, students can use these tools to visit a local pond and collect measurements of various environmental conditions. Using sophisticated gadgetry similar to that used by scientists, they can then analyze, compare and discuss the results.

An understanding of the NOS will not necessarily come about automatically as a result of experience with inquiry. Rather, teachers must include discussions and reflections on the nature of science in their pedagogical framework. A growing body of research suggests that if students are to learn particular aspects of the nature of science, these aspects must be explicitly taught, rather than left to chance in the hope that the students will pick them up on their own (Huber & Moore, 2001). The explicit approach "intentionally draws learners' attention to relevant aspects of the NOS through discussion, guided reflection, and specific questioning in the context of activities, investigations, and historical examples" (Lederman & Schwartz, 2001, p. 137). The students' acquisition of knowledge of some of the aspects of the nature of science should be highlighted during their inquiry activities. The teacher needs to develop a balanced approach by which they can facilitate, guide and support open-ended inquiry as well as questioning, reflection and discussion about the nature of science. What is needed is "some kind of interactive process of guided participation, which allows the student to be an active inquirer and the teacher to be an active guide" (Polman & Pea, 2000, p.225). This represents a challenging new approach for many teachers, who must learn to play a unique role of structuring and guiding student

activities in the classroom without taking away the students' active role (p.225). Teachers need to identify the zone of proximal development for individual students and guide them towards autonomy using scaffolding techniques. For example, Hodson (1999) describes one model where teachers can use a three-stage process of modeling, guided practice and independent application to support authentic inquiry. The use of computer technology can assist the teacher at each of these stages.

Conclusion

Computer technology is opening up new possibilities in science education. The lack of success in teaching K-12 science has contributed to growing support for the inquiry approach over the more traditional approach of transmitting facts in the classroom. Inquiry has the potential to increase student motivation and to learn by "doing" science. This approach further increases the potential to better understand the NOS. Computer technology, which has considerably evolved in its ability to interact with the user, can support inquiry in a number of ways. Guided by the teacher, a student can use computers to support their own self-directed inquiry activities. This support can be in the form of access to raw data, and to multiple views and representations of science. It can be in the form of virtual experimentation and manipulation of models. It can be in the form of on-line simulations of theoretical or unobservable phenomena. And it can be in the form of virtual interactions with networks of expertise outside the classroom. Furthermore, the use of computer technology can benefit teachers by freeing up valuable class time for activities such as analysis and discussion about the NOS. Another benefit for teachers is the potential access the technology can provide to science content, professional development, and networking. Despite the many potential benefits of using computer technology, however, care must be taken to use it appropriately if it is to be pedagogically effective.

Telecommunications technology should never come at the expense of interaction within the classroom. The emphasis in computer-supported science education in the past has tended to be on learning the technical aspects of the technology, without giving enough attention to effective pedagogical application. The use of the technology depends more than ever on teachers, as it cannot work without a guiding hand, contextual discussion, and effective integration with the curriculum. The real potential for new technology to contribute to science education is in facilitating new teaching approaches, and an effective application design should reflect this. To make it work, teachers need to shift from a transmission to a transformative approach that supports authentic inquiry. This may require greater skills of guiding and scaffolding, and staying informed about examples of successful uses of technology to teach science. If teachers are provided with the necessary teaching resources, the training opportunities, and the testing and evaluation standards which will support these objectives, then improvements in practice can come about with continuing research and evaluation, lessons learned over time, and further innovations in technology.

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