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From the Editor

In this issue we deal with a number of different issues:

Ali Rezaei presents research on the introduction of two physics instruction software packages (including Alberta's modular approach to physics). A distressing finding of the research was the lack of conceptual understanding of physics among practising physics teachers.

David Visser presents a summary of the current philosophical relationship between science and religion, and suggests that a more conciliatory dialogue is possible. Visser gives a number of interesting recommendations for science teachers for remaining sensitive to the needs of their students.

Wytze Brouwer presents two fictional interviews with Albert Einstein and one with Mileva Maric, Einstein's first wife. They give the general reader an overview of Einstein's physics, his views of society, and Mileva's view on their relationship as students and as a married couple.

Anita Kamal presents an historical overview of science curriculum policy in Alberta from 1922 to the present.

Frank Weichman introduces skiing and ski hills in an analogy of electrical currents and other electrical phenomena.

Thelma Gunn and Lance Grigg present a question-based approach to science teaching to help students better process science textual materials. An easy-to-use template with examples is provided to focus student reading and enhance understanding.

—Wytze Brouwer

Using Computers to Evaluate Teachers' Understanding of Physics Concepts

Ali R Rezaei

Introduction

The video *A Private Universe*, a production of the Harvard-Smithsonian Center for Astrophysics, Science Education Department, Science Media Group, was an eye opener for science education. In the video, interviews with Harvard graduates revealed misconceptions about science among the best students in the United States. According to Mazur (1997), another eye-opener was the release of the force concept inventory (FCI) developed by Hestenes, Wells and Swackhamer (1992). He called it an eye opener because he realized that students' misconceptions could not be diagnosed with the conventional standard or teacher-made tests, or even the problem-solving strategies he had used for many years while teaching at Harvard University. Research in science education has repeatedly shown that only certain types of questions can evaluate the ability of students to resolve concepts from one another and apply them to real situations. However, the successful construction of conceptual tests is rarely reported in the literature.

So far, FCI and a few other conceptual tests have been used exclusively to evaluate students' misconceptions. However, misconceptions are not limited to students; they are also common among teachers (Mestre 1994). For example, after a comprehensive study of 159 science teachers' misconceptions, Kruger, Palacio and Summers (1992) concluded that "virtually none of the primary school teachers had a correct (in the Newtonian sense) view of the instances involving forces and motion with which they were presented." Although FCI is a reliable test to evaluate teachers' misconception, many scientific conceptions can not be easily evaluated with paper-and-pencil tests, such as FCI. As discussed later in this paper "The Inventive Model and MAP" could be used to create interactive modules for evaluation of teachers' misconceptions in physics. Using such multimedia and/or Internet tools with sophisticated interactive simulations to investigate teachers' misconceptions is considered to be important and ultimately could be a third eye opener in the area of science education.

Theoretical Background

The Quality of Current Educational Software

The quality of educational software particularly for the purpose of conceptual learning has been the subject of so many studies since early 1980s. Komoski (1989) estimated that 1,500–2,400 new packages are published in the United States each year and that the proportion of good quality software is something between 5 to 10 per cent. The United States Department of Education reports that a significant proportion of computer software in schools is obsolete by today's standards. A survey of educational software companies reveals that 67 per cent have no formal guidelines regarding the criteria used to guide software development (Roth and Petty 1998). According to the literature, there are many reasons for the low quality of educational software, including the lack of a theoretical model for the instructional design. After reviewing hundreds of research papers on instructional design and dozens of educational software, I have developed the inventive model as a theoretical framework for science instruction and, particularly, for software development in science education (Rezaei and Katz 1998, 2002, 2003). The inventive model was developed to pave the way from *edutainment* (or *infotainment*) toward high-quality educational software.

Even if teachers find good-quality software, it is often difficult to integrate it into their lesson plan. Some parts of the software do not match the goals and objectives of the course. The modular approach to physics (MAP) has been developed to overcome this difficulty. This approach provides customized instruction for teachers. Teachers usually prefer to make their own instruction rather than using someone else's design. This online navigation and arrangement tool provides modules instead of units of instruction, allowing teachers to select the modules they want to use and arrange them how they want. All of the modules are designed based on my many years of experience and on research findings, including the inventive model. In summary, although some high-quality educational software in physics exists, almost none provide instruction based on the users' prior knowledge and misconceptions.

The Inventive Model

The inventive model is a theoretical model for educational software development, as well as a conceptual-change model for improving conceptual learning. Research findings consistently show that students' misconceptions are deeply seated and likely to remain after instruction or resurface some weeks after students have displayed some initial understanding (Mazur 1997; Mestre 1994; Halloun and Hestenes 1985). Research also shows that instructional approaches that facilitate conceptual change are more effective than other approaches that disregard students' cognitive structure (Mazur 1997). However, teachers and educational software developers rarely build their instruction on a valid measure of students' misconceptions. The instructional design used in the inventive model is based on a longitudinal and systematic evaluation of students' misconceptions.

Theoretically, the inventive model has four phases. The first phase starts with a systematic analysis of students' preconceptions. Although students' preconceptions are unique and private, most of them are similar and public. Therefore, in the instructional design of the inventive model, both kinds of preconceptions are addressed. Simulations and videotaped experiments are developed based on the literature on students' common misconceptions. However, teachers also offer feedback based on individual students' answers to conceptual questions. The software based on this model could either be used by the teacher in class as an instructional tool or by the students after class, individually or collaboratively.

In the second phase, advance organizers or other cognitive strategies, such as concept maps and/or analogies, are used to activate students' prior knowledge and bridge it to the new concepts to be learned (an earlier paper by Rezaei and Katz [1998] explains how these cognitive strategies are integrated into the inventive model). In both this second phase and in the last phase, students' acceptable concepts are refined and reinforced through guided discovery (Dykstra, Boyle and Monarch 1992). If the majority of students have a deep misconception, the teacher will move to the third phase to rectify the misconception. However, if the students' preconceptions are close enough to the scientific conceptions, the teacher will move directly to the fourth phase, in which students' conceptions are refined.

The third phase includes different activities, such as having students

- test their preconceptions through hands-on activities or computer-based simulations;
- compare their preconceptions with natural phenomena and related scientific theories, and identify any conflicts between their misconceptions and the scientific theories; or
- work through a multiperspective demonstration and problem-solving situation to convince them that they need to replace their misconception with a new concept, or explore plausible alternatives by themselves or as suggested by their classmates or the teacher, and choose the more convincing one.

In the fourth phase, the teacher explains the correct answer and demonstrates the advantages of the conceptions currently accepted by the science community through a multiperspective demonstration. The teacher may also help students summarize what they have learned.

The basic rationale of the inventive model is that conceptual change does not simply occur when students see a conflict between their preconceptions and the scientific realities; rather, students must test their preconceptions and come to understand the advantages of scientific explanations. This will only happen if the teacher provides the required cognitive tools and a clear contrast between the student's conceptions and scientific conceptions through a variety of demonstrations.

Therefore, the key factor in the inventive model is the multiperspective presentation. The author believes that generalizations based on a single experimental design could be misleading. However, considerable time is required to probe students' conceptions and present new concepts from different perspectives through a variety of demonstrations. An effective way of dealing with time limitations in formal science classrooms and in many inquiry approaches is to use computers with the instruction and the inquiry processes. I have developed the multimedia physics CD-ROM, based on the inventive model, as a practical way of achieving this goal. Videotaped or simulated science experiments were designed, developed and presented based on longitudinal studies by teachers. Dozens of science experiments, animations, sound clips, simulations, pictures, graphs, tables, concept maps, analogies, metaphors and advance organizers are available in a multimedia program on the CD-ROM.

Research on the Inventive Model

The inventive model was used in experimental research (Rezaei 2003). For the research, 143 Grade 10–12 students from three high schools were randomly assigned to three groups. The inventive model was compared with a radical constructivist approach and the conventional physics instruction. The inventive model group scored significantly higher than the radical constructive group on the conceptual post-test. The inventive model also led to greater conceptual change in students' understanding of Newton's laws of motion. Finally, it was observed that 3 hours of working on the inventive model CD-ROM was as effective as 16 hours of conventional physics instruction. According to the qualitative analysis, most students actively interacted with the software during the whole program. The inventive model was effective in rectifying students' misconceptions for more than 50 per cent of the students. It should be noted that successful reports of conceptual change are rare in the literature.

I was surprised to observe some misconceptions among teachers while they were previewing the CD-ROM and teaching their students. Although this experiment was not targeting teachers, I asked several physics teachers to provide me with feedback about the software, and the misconceptions were observed during the evaluation process. I decided to do more research to investigate teachers' misconceptions in physics using MAP.

Modular Approach to Physics (MAP)

The MAP project is a multi-institution venture funded by the government of Alberta and coordinating the efforts of groups at six colleges and universities in Alberta, including King's University College, the University of Calgary and the University of Alberta, the three of which produced the applets for MAP (Martin, Austen, Brouwer, Wright and Laue 2001). [An applet is a small application or program, often written in Java, that runs in another program, such as a web browser.] Two versions of the course are provided. One is pre-organized or sequential, and the other can be customized. Teachers and students can choose to follow-up the sequential version by customizing their own units. The online courses based on this model are available at http://canu.ucalgary.ca and http://turing.kingsu.ca/~map.

One purpose of the proposed project is to compare the effectiveness of these two versions, the results of which could influence the future of online course development. MAP has been used at the University of Calgary, the University of Alberta, King's University College and the University of Athabasca. However, no empirical research on its effectiveness has yet been reported.

The content of the MAP system is delivered by an applet called CANU Navigator. CANU (Content Arranging and Navigating Utility) is a content manager that presents content and allows users to build their own instructional design.

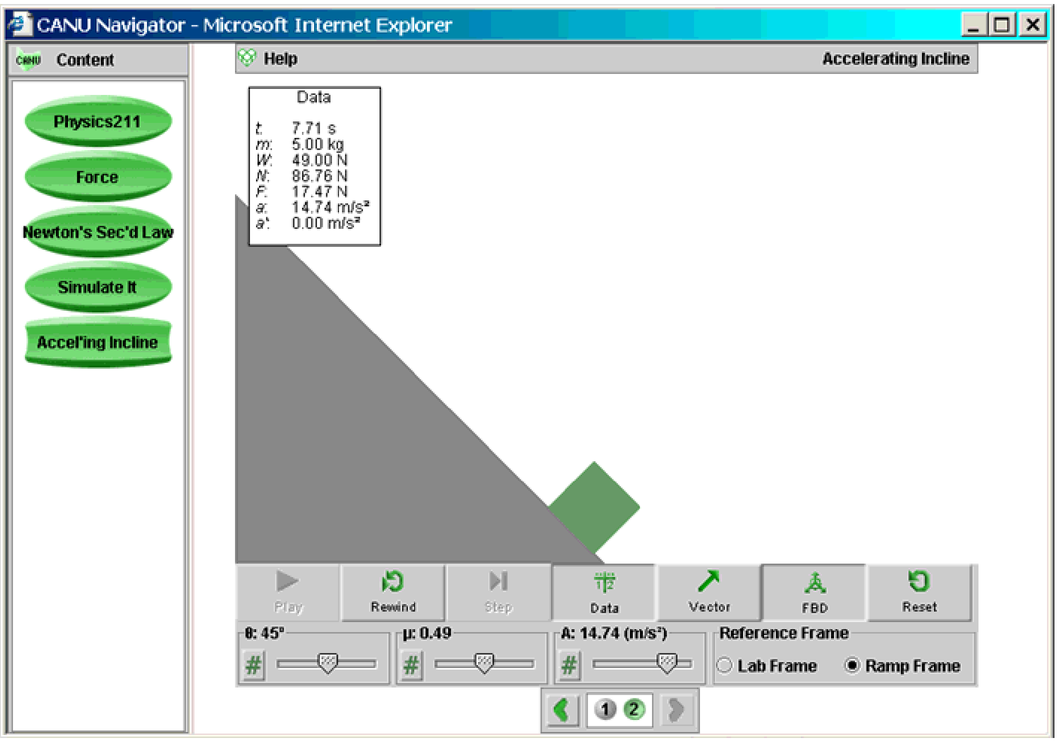
The content is grouped into packages called courses. For each concept there are five options:

- Get a Glimpse—Includes introductory material that draws attention to an important aspect of the concept to be studied, without being technical. The presentation might involve a video or flash animation, or a picture with some text.
- Explain It—Includes lesson-like material that explains the concept in an interactive manner, often with the aid of one or more interactive applets. Some of the accompanying text has an audio track.
- Simulate It—Includes simulations to accompany the Explain It items, but here they are made available directly instead of embedded in a lesson. This allows quick access to the simulations for in-class use. The simulations also have a larger screen format than when used in the Explain It context. Detailed explanations of the features of a simulation are available under Help on the applet's menu bar. Some simulations have suggested activities that can be carried out with the simulations.
- Test Yourself—Includes collections of questions in either multiple-choice, numerical-answer or fill-in-the-blank format. These questions are based on the material in the other items. The questions are conceptual, which requires applying the concept to another situation.
- Get Information—Includes textbook-like material that summarizes the important points. This material is not presented interactively. Get Information items are often linked to other content items to provide quick access to relevant background information. These links are provided in the Related Items panel in the MAP window.

Examples from the Tutorial

Example 1—This applet shows the motion of a block on an incline with or without friction. The incline is either at rest or accelerating horizontally. The user may change the slope, friction and acceleration, and then click the play button to observe the motion. The motion can be observed either from the Lab or the Ramp (incline) frame.

Figure 1: Simulation of Motion on an Incline with and without Friction



Data

t: 7.71 s
m: 5.00 kg
W: 49.00 N
N: 86.76 N
F: 17.47 N
a: 14.74 m/s²
a': 0.00 m/s²

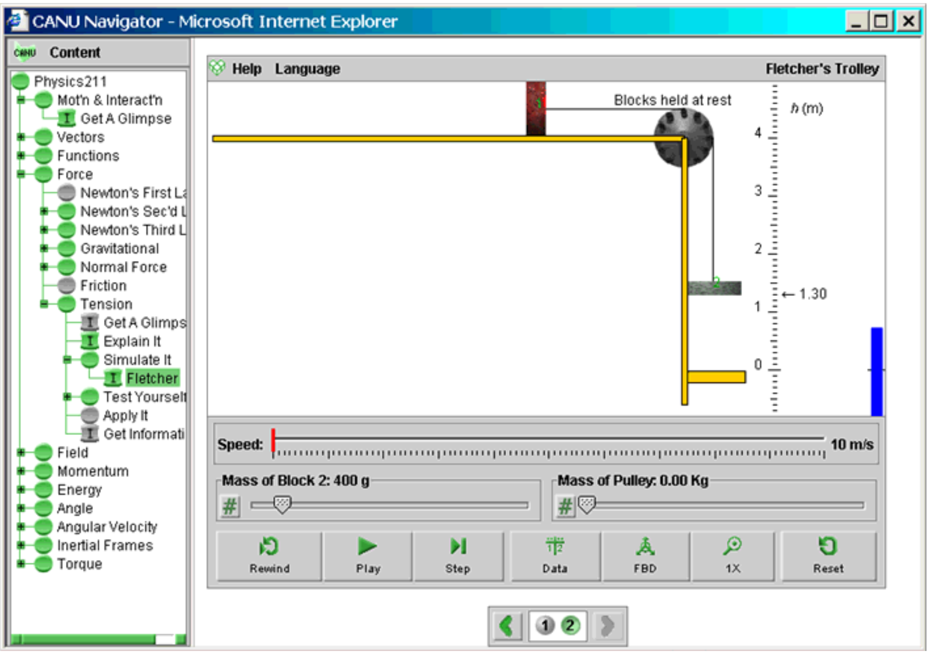
θ: 45°
μ: 0.49
A: 14.74 (m/s²)
Reference Frame ○ Lab Frame ● Ramp Frame

Example 2—This applet simulates the forces in Fletcher's Trolley, including string tension. Fletcher's Trolley is a system of two blocks, one of them moving horizontally and one of them vertically. The blocks are connected by a string that is guided over a pulley. The applet lets users vary the mass of the blocks and the pulley.

The Results of the Pilot Study on MAP

A workshop using MAP was conducted with 27 high school teachers from Calgary. Only four modules were tested: Friction, Elevator, Spring Scale and Collision. A 14-item questionnaire, similar to FCI questions, was developed and used in pretesting and post-testing. Each question was weighted one point, except question four, which was weighted three points. The maximum possible score on the test was 26. The results of the descriptive analysis are given in Table 1. A paired sample t-test was used to compare the pretest and post-test. Although the t-test (t = 3.56) showed a significant increase in teacher's performance on the test due to the instructional treatment, the overall poor performance of the teachers on the pretest and post-test was shocking. In fact, 45 per cent of teachers failed the test (scored below 60 per cent). Even after the workshop, about 33 per cent of teachers failed the post-test. Only 10 per cent of the teachers showed a coherent understanding (scored more than 90 per cent) of the physics concepts as measured by the pretest questionnaire. However, after the workshop, about 30 per cent of teachers showed a coherent understanding of physics concepts as measured by the post-test questionnaire.

Figure 2: Simulation of Fletcher Trolley



Mass of Block 2: 400 g

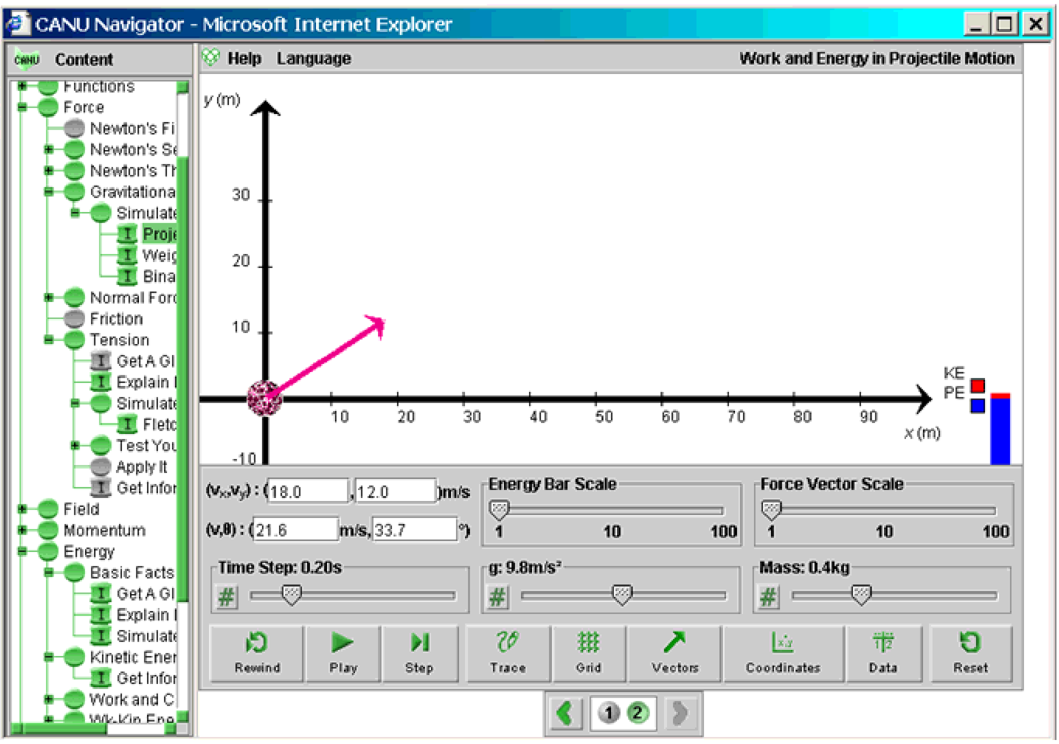
Mass of Pulley: 0.00 Kg

Table 1: Teacher's Score on Pretest and Post-test

	N	Minimum	Maximum	Mean	Standard Deviation
Pretest	27	8.75	23.50	15.8426	4.03718
Post-test	24	9.50	23.75	17.2500	4.08537

Example 3—This applet shows projectile motion in a uniform gravitational force field (force field of constant magnitude and direction near the surface of the earth). The projectile's kinetic and potential energies are represented at any moment by an energy column. The user may change the mass, the angle of projection or the force of gravity, and observe the motion. The simulation also shows the kinetic and potential energy at any moment.

Figure 3: Simulation of Projectile Motion



(v_x,v_y) : (18.0 ,12.0)m/s

(v,θ) : (21.6 m/s, 33.7 °)

Time Step: 0.20s

g: 9.8m/s²

Mass: 0.4kg

Conclusion

Currently, MAP can not record students' interactions with the online software. However, a detailed analysis of teachers' interactions with the computer (such as keeping track of which items are chosen, which buttons are clicked and the amount of time spent on a question) could be an invaluable source of information on teachers' cognitive processes.

For example, the applet on Instantaneous Acceleration lets the user investigate the relationship between the position, velocity and acceleration vectors in a motion that can be controlled through the acceleration vector. The user can click on the acceleration dial to set the magnitude and direction of the acceleration of a moving car and observe the displacement and velocity of the car at any moment. However, the current version of MAP does not let the user or the researchers evaluate the users' conceptual understanding of this concept. An important improvement will be having the applets record the user's mouse movements while they are finding answers to practical questions. For instance, the user might be asked to change the acceleration of the car as it moves to follow a given path or a given time-versus-velocity curve. The program should be able to not only save the users final response but also record the user's interactions as they work with MAP. This kind of interactive evaluation, which has been tested successfully in the inventive model, is almost impossible in traditional paper-and-pencil tests and even conceptual tests, such as FCI. Using such interactive evaluation would reveal even more-deeply seated misconceptions among students and teachers.

Regarding the literature in conceptual physics instruction, as well as the above reports on the inventive model and MAP, the following conclusions could be made:

1. Only certain types of questions can be used to evaluate the ability of students to resolve concepts from one another and to apply them to real situations.
2. Many scientific conceptions could not be easily evaluated with paper-and-pencil tests.
3. Using multimedia and/or Internet tools with sophisticated interactive simulations to investigate students' misconceptions is important and could be a third eye-opener in science education.
4. Misconceptions are not limited to students. According to the above observations, they are also common among teachers.
5. In the first pilot study, several misconceptions are observed among teachers while they were interacting with the physics software.
6. In the second pilot study, only 10 per cent of the teachers showed a coherent understanding (scored more than 90 per cent) of the physics concepts as measured by the pretest questionnaire.

Both the number of teachers examined in the above pilot studies and the scope of the survey was extremely limited. Furthermore, both studies have been conducted in Canada. Although some university physics instructors in Canada are using MAP, no data is available on the number of American teachers using MAP. A comprehensive study needs to be done on a larger sample, with more controls and in a larger scope of physics content. Furthermore, many scientific conceptions could not be easily evaluated with paper-and-pencil tests, such as FCI. Therefore, a detailed analysis of teachers' interactions with computers is needed to investigate teachers' understanding of physics concepts.

Either the physics CD-ROM or the online MAP could be used to investigate teachers' misconceptions. The CD-ROM version is limited to Newton's laws of motion and could be used by teachers who do not have access to the Internet. The online MAP system is a comprehensive advanced physics course for high school teachers. Although both software have been developed for teaching, they can be used as a means to evaluate teachers' misconceptions.

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Science and Religion: A New Dialogue?

David Visser

For many years, the relationship between science and religion has been characterized by much conflict—especially the last couple of centuries with the development of modern science. The assumption has been that as we develop a *rational* scientific understanding of our world, the *irrational* beliefs that mark our religious understandings will gradually and naturally disappear. It has thus seemed warranted to some that the following dichotomies exist: science versus religion, rational knowledge versus irrational belief, objective facts versus subjective faith and so on.

Lately, however, the credibility of the conflict thesis between science and religion is challenged by scholars studying the issue from a variety of perspectives. These include scientists who are taking a deep interest in theological matters and theologians who are becoming aware of the implications of scientific developments for religious beliefs. Members of the two groups often work collaboratively and are producing a rather large amount of work dedicated to uncovering and developing a fruitful relationship between scientific and religious thought. Some historians (Numbers 1992; and Lindberg and Numbers 2003) and sociologists (Stahl, Campbell, Petry and Diver 2002) are also working hard to shed light on the complex relationship between science and religion.

One of the most productive and influential members of this rather new field is Ian Barbour. Some of his best-known works include *Religion in an Age of Science* (1990), which was recently updated as *Religion and Science: Historical and Contemporary Issues* (1997) and *When Science Meets Religion* (2000). He has developed a four-part typology for relating science and religion, which he has named Conflict, Independence, Dialogue and Integration. This article explores these four categories and hopefully sheds some insight on their usefulness and applicability. As we shall soon discover, Barbour himself strongly disagrees with the Conflict thesis and sees some limited usefulness in the Independence position. He does see a natural progression to the Dialogue and Integration modes for those who seek an approach that neither deifies science nor denigrates religion but rather takes seriously what both have to say about our world and our place in it.

But does Barbour's approach demonstrate significant progress in the understanding of science and religion as two bodies of knowledge that have significant things to say to one another? Or does it represent the idiosyncratic views of those who desperately seek a rapprochement of these two fields at any cost? These are some of the questions that will be looked at in this article. In addition, the views of other scholars, many of whom support Barbour's methodology but also some who are critical of his ideas, will be brought to bear on these issues. Finally, some of the implications that this discussion may have for science teachers and science education in general will be presented.

Conflict

Two works were influential in promoting the Conflict thesis in the latter part of the 19th century: J W Draper's *History of the Conflict*

Between Religion and Science (1874) and A D White's *A History of the Warfare of Science with Theology in Christendom* (1896). Historians such as Welch have recently challenged the assumptions and motivations of these earlier authors. Welch points out that "both books turn out to be bitter attacks on *institutional* Christianity much more than serious discussions of substantive issues" (1996, 29–30, emphasis in the original). Nonetheless, these works continue to be cited by authors such as Mahner and Bunge (1996), who are determined to promote the idea that science and religion are irreconcilable.

Biblical Literalism

The question of how to interpret scripture is an old and vexing issue. In the Christian tradition, there has been a renewed emphasis on literal interpretations of the Bible, even of the creation accounts in early Genesis. This development in the 20th century has complex cultural roots and has gained an impressive foothold in parts of North America. Historian Ronald Numbers has documented this movement in his book *The Creationists* (1992) and describes how it has led to what is known as "scientific creationism," something that Barbour describes (in a rare use of strong language) as "a threat to both religious and scientific freedom" (1992, 16). One of the hallmarks of this "science" is the claim to complete historicity for the six-day creation story in Genesis 1, which obviously leads to a distinctly anti-evolutionary line of thinking. In the blunt words of founder Henry Morris, "Satan himself is the originator of the concept of evolution" (cited in Morris 1994, 5).

The interpretation of Genesis 1 remains an important—and controversial—issue for many Christian scholars. According to theologian Rikki Watts,

> On one level, how one reads Genesis 1 has in some circles become a litmus test of Christian orthodoxy, whether conservative or liberal. Hold the "wrong" view and one is either a dupe of secular critical theory or a troglodyte literalist . . . On another level, the importance of stories of origins cannot be overestimated. They define us. (2002, 1)

Watts does an impressive job looking at the cultural context of the ancient Hebrews for whom Genesis 1 was originally written and he also critically analyzes the literary style of the text (something the biblical literalists are loath to do). In short, he applies some thoughtful hermeneutics to distill the main message and reminds us that

> in our scientific world it is easy to forget that there are ways of telling the truth other than algebraic formulae or Western-style history . . . some of the most important and meaningful things in our lives are best shared using metaphor and poetic image. (2003, 3)

Watts contends from his literary analysis that "unless we have a previous agenda" (a desire to construct a modern scientific worldview from an ancient cosmology), it is unwise to read an actual historical account in Genesis 1 (2002, 4). Through his comparison with other creation accounts of other civilizations, he argues that, for a band of Hebrews who had recently escaped slavery in Egypt, "Might it not be that Genesis 1 was written with a particular concern to declare that it was Israel's god . . . who was alone responsible for the good and perfect order of creation?" (2002, 9). One of Watts' main points is that one can miss important theological truths from the text by overemphasizing its literal nature.

Lately some anti-evolutionary groups such as the intelligent design movement have been edging away from a literal approach to scripture. This has caused some infighting and consternation in the creationist camp and led to even more eccentric scholarship on the issue. Robert Pennock has documented these events in his book *The Tower of Babel* (1999). He claims that all the disagreement that has resulted over issues of interpretation should give us "sufficient reason to doubt whether revelation could possibly supply the purported unified basis for such a science. Broaden one's view to observe battlegrounds of theological disputes among competing religious traditions and even angelic scientists would fear to tread there" (1999, 204).

Scientific Materialism

Barbour contends that scientific materialists mainly hold two beliefs: "(1) the scientific method is the only reliable path to knowledge; (2) matter (or matter and energy) is the fundamental reality in the universe" (1997, 78). The first belief demonstrates a conviction in the epistemological supremacy of science. According to educational theorist William Cobern, the significant problem with this view is

> the claim that empirical science can be an autonomous, self-sustaining generator and guarantor of knowledge that has no need of any extra-scientific *synthesis* (that might be a meta-narrative, metaphysic, or worldview), which weaves science into the human community's sense of meaningfulness, morality, and purpose. (2000, 231, emphasis in the original)

In commenting further, he adds: "All forms of knowledge including empirically demonstrated knowledge require some form of foundation that is itself not empirically demonstrable in any nontautological fashion" (2002, 234). The scientific materialists don't seem to realize that the institutions of science have come under significant scrutiny in the latter part of the twentieth century. The rejection of logical positivism by many scientists and philosophers as a credible epistemological account of how we obtain scientific knowledge (although positivistic thinking lingers on) was a significant event. According to Ian Hacking, "philosophers long made a mummy of science. When they finally unwrapped the cadaver and saw the remnants of an historical process of becoming and discovering, they created for themselves a crisis of rationality. That happened around 1960" (1983, 1).

The second belief is a metaphysical position (not provable by science) that hints at the reductionistic thinking that often goes hand in hand with scientific materialism. Many scholars have pointed out (Barbour included) that a reductionist science is no friend of religion or spirituality of any kind. Gregg Easterbrook contends that this outlook tends to displace "belief in anything beyond genes, machines, and the vibration of atoms. Many have waited, expectantly or even impatiently, for the moment when science fully refutes obsolete conceptions of meaning and purpose" (1998, 24). He expresses the danger in embracing a philosophy where those who enjoy privileged positions in society blame "only a callous universe—not lack of action by persons in privileged positions—for the needs of the less fortunate . . . If it's all pointless anyway then why not enjoy your ironic airs, your capital gains, and your information-age sinecure?" (1998, 29). Essayist Wendell Berry puts it plainly and beautifully when he says that the "principle that is opposite to reduction—and, when necessary, its sufficient answer—is God's love for all things, for each thing for its own sake and not for its category" (2000, 103).

Barbour points out the three variants of reductionism: methodological, epistemological and ontological (1997, 230–33). He describes methodological reductionism as a "useful research strategy . . . [that] may be accepted . . . as long as it does not lead to the neglect of research programs at a variety of levels, from molecules to ecosystems" (1997, 231). Epistemological reductionism can be roughly described as the "everything is physics" approach. Barbour shows through several examples the significant limitations of this view (1997, 231–32). Finally, ontological reductionism is the metaphysical underpinning of scientific materialism. This is the aforementioned assertion that "matter is the fundamental reality in the universe" (1997, 78). This last view is clearly anathema to religious or spiritual concerns, but it is important to point out again that it is not scientifically justifiable in any way.

To sum up, Barbour's view on the Conflict position is that

> both scientific materialists and biblical literalists have failed to recognize significant distinctions between scientific and religious assertions. The scientific materialists have promoted a particular philosophical commitment as if it were a scientific conclusion, and the biblical literalists have promoted a prescientific cosmology as if it were an essential part of religious faith. (2000, 36)

Furthermore, Barbour contends that "both sides err in assuming that evolutionary theory is *inherently atheistic*, and thereby perpetuate the false dilemma of having to choose between science and religion. The whole controversy reflects the shortcomings of fragmented and specialized higher education" (1997, 84, emphasis added).

Thus the Conflict position is seen as basically a "dead-end street" by Barbour and many of his colleagues. It can be concluded that in order to harmonize science and religion (if that be one's desire), and see any progress in relating the two disciplines, one would need to relinquish either of the extreme positions described in this section and seek a more realistic expectation of what scientific or religious knowledge can provide. Barbour suggests that a helpful move might be to emphasize the distinctiveness in each discipline and keep them well apart—in other words, move to the Independence position in his typology.

Independence

Viewing science and religion as independent entities represents more than the pragmatic interests of conflict avoidance, according to Barbour. The "separation into watertight compartments is [also] motivated . . . by the desire to be faithful to the distinctive character of each area of life and thought" (1997, 84). He points to the differing methods, languages and purposes of science and religion as arguments to support this move (1997, 84–89). Many scholars trace the Independence thesis back to the philosopher Immanuel Kant, who argued (among other things) that science and religion involve different forms of knowledge. Barbour claims that the "ghost of Kant still hovers over those who say that science deals with facts and religion deals with values" (1997, 47).

The theology behind Protestant neo-orthodoxy emphasizes divine revelation without an adherence to biblical literalism. In this line of thinking, one needs to separate the important biblical messages from the incidental and often ancient science in which these messages are often contained. The results of scientific theorizing are not viewed as being important to one's faith (Barbour 1997, 85). Consider the words of evangelist Billy Graham (1964):

> I don't think that there's any conflict at all between science today and the Scriptures. The Bible is not a book of science. The Bible is a book of redemption. . . . I believe that God created man, and whether it came by an evolutionary process . . . or not, does not change the fact that God did create man.

Existentialists such as Søren Kierkegaard go even farther in denying the importance of a "rational" science and instead focus on the personal and experiential side of our existence almost exclusively. In Kierkegaard's opinion, "the attempt to describe a world that could be known with objective certainty was not a movement of faith. So he became history's most ardent apologist for subjectivity as truth" (Austin 2000, 155).

At the other end of the Kantian spectrum we find the logical positivists of the early 20th century who put their "faith" in empirical facts and the rational, logical conclusions that they produce. For them, the subjective, religious sides to our natures can be ignored because they lack any conceptual clarity or empirical data to back up their truth claims. What they do have in common with the existentialists, however, is the view that science and religion deal with very different realms and are best kept apart.

One does not have to go to the extremes of the positivists or the existentialists, however, to appreciate the Independence argument. It can be clearly demonstrated that the languages used by scientific and religious endeavours often serve entirely different functions (Barbour 1997, 87–89). It also seems reasonable to assert that "the goal of science is to understand lawful relations among natural phenomena, while that of religion is to follow a way of life within a larger framework of meaning" (2000, 52). Science essentially deals with *how* questions and religion delve into the metaphysical realm to tackle the *why* questions. It can therefore be argued that science and religion may exist in a complementary relationship rather than in conflict. This approach is also a good political solution because it promotes peace between the two camps and is thus favoured by many scientists and nonscientists alike.

But Barbour is not satisfied with the Independence position. To those in religious traditions who would ignore scientific findings, he would argue that "a way of life presupposes beliefs about the nature of reality and cannot be sustained if those beliefs are no longer credible" (2000, 37). Philosopher Nicholas Wolterstorff is also critical of scientists who do not allow any of their religiosity to affect their work or theorizing. His view is that religious people who believe science "is and always will be all right just as it is . . . are brothers beneath the skin with the logical positivists" (1984, 24). In this sense, rather than a complementary relationship developing between science and religion, a decidedly compartmentalized approach becomes all too easily the norm. This is likely the strategy used by many of the approximately 40 per cent of scientists in Larson and Witham's famous study (1997, 435–36) who professed a belief in a personal God capable of answering prayer.

This position may only survive careful scrutiny, however, by "not posing awkward questions," according to Mano Singham (2000a, 427). To those practicing the "epistemological dichotomy" (Barbour 1990, 11) of always separating natural laws from spiritual laws, it becomes difficult to explain how God acts in a world that shows no evidence of having its natural patterns interrupted. This is just one of the problems faced by those who hold to a forced dichotomy between the natural world and a supernatural realm, and the related view that our scientific and religious spheres can always be kept separate. Wolterstorff's complaint is that scientists who regularly adopt this posture lack an understanding of key theological and philosophical issues (1984, 108) and thus have difficulty relating the two worlds of science and religion.

Nevertheless, the Independence position represents an important step forward from the Conflict position. Barbour points out one of the scholars that produced important work in this area: Steven Jay Gould (Barbour 2000, 99–100). In his book *Rocks of Ages* (2001a), Gould argues that science and religion belong to different *magisteria* (a term he uses for "domain of authority in teaching"). He calls this strategy his NOMA principle, which stands for "non-overlapping magisteria" (2001a, 5). In a now familiar move, he claims the

> magisterium of science covers the empirical realm: what the universe is made of (fact) and why does it work this way (theory). The magisterium of religion extends over questions of ultimate meaning and moral value. The two magisteria do not overlap, nor do they encompass all inquiry . . . To cite the old clichés, science gets the ages of the rocks, and religion the rock of ages; science studies how the heavens go, religion how to go to heaven. (2001a, 6)

Gould grants the two realms equal status, so long as the boundaries between them are respected. He does admit, though, in a seemingly contradictory manner, that the "two magisteria bump right up against each other, interdigitating in wondrously complex ways along their joint border . . . the sorting of legitimate domains can become quite complex and difficult" (2001b, 742). Thus Gould is willing to admit the difficulties in keeping science and religion completely separate and appears to move a little beyond the Independence position to what Barbour would call the Dialogue category.

Gould's position is perhaps not surprising, given the public opposition between his views and those of the scientific creationists, an ongoing conflict throughout his career that no doubt played a role in his becoming an apologist for keeping science and religion respectfully apart. His testimony also played a part in the famous Arkansas trial (*McLean v Arkansas* 1982) that, in the eyes of many, set out a clear demarcation point between science and religion. In this case, Judge Overton set out the criteria for what the essential elements of a practice must be (based also largely on philosopher Michael Ruse's testimony) in order to be "scientific" in the eyes of the law (and thus permissible to be taught in the public science classroom). The essential elements are:

1. It is guided by natural law
2. It has to be explanatory by reference to natural law
3. It is testable against the empirical world
4. Its conclusions are tentative, ie, are not the final word
5. It is falsifiable (Pennock 1999, 5)

Overton's opinions, however, do not make this position a completely open-and-shut case, and a number of philosophers of science have since objected to these criteria. They point out that the word "law" is a problematic term for the regular processes that we see in nature for a variety of reasons. Philip Quinn also indicates that if the second criterion were necessary, then evolutionary theory would have been considered "unscientific" until the science of genetics and heredity was discovered (1984, 42). Furthermore, many creationist predictions (to which the legislation was initially directed) are in fact testable and have been falsified by considerable evidence gathering (1984, 44).

Barbour's own assessment of the Independence position is as follows:

> If science and religion were totally independent, the possibility of conflict would be avoided, but the possibility of constructive dialogue and mutual enrichment would also be ruled out. We do not experience life as neatly divided into separate compartments; we experience it in wholeness and interconnectedness before we develop particular disciplines to study different aspects of it. (1997, 89)

Despite this view, it is probably wise for scientists with limited theological training and theologians with limited scientific training to maintain an Independence position in Barbour's typology. Much conflict results from those whose perceptions of a particular field are reduced essentially to a caricature and who overgeneralize and conflate key understandings.

Dialogue

One can roughly view the Dialogue model as science and religion talking to each other. Obviously many atheistic or agnostic scientists do not see the need for any dialogue because they believe that religion does not have anything important or relevant to say to scientists. Scientist/theologian John Polkinghorne's view, however, is that

> science and religion have things to say to each other. My own characterization of that mutual conversation would be that religion must listen to what science has to tell it about the nature and history of the physical world, and that religion can offer science a deeper and more comprehensive account of reality within which the latter's search for understanding can find an intellectually comfortable home. (1996, 5–6)

Many scholars in this debate do not see this move as being harmful to science. In fact, it could actually be beneficial. According to philosopher Mary Midgley, "We do not need to esteem science less. What we need is to esteem it in the right way. Especially we need to stop isolating it artificially from the rest of our mental life" (1992, 37). In other words, allowing science to have epistemological supremacy over other areas of inquiry, such as religion, presents a poor picture of science's role in our lives. The recognition of the nonfoundational character of science is thus vital to recognizing that science may be more subjective and religion may be more objective (Barbour 1997, 93) than first thought. This is a key understanding that must be in place before science and religion can have a conversation as equal partners.

In the light of this epistemological openness, many scholars such as Barbour have defended a philosophical commitment to *critical realism*. In this view, our theories will always give us a partial picture of a reality that exists independently of us. Although our knowledge accumulation about the world may be inherently progressive, we will never achieve a perfect understanding. This idea resonates well with the notion that neither science nor religion possesses a "god's-eye view" of our world. In Polkinghornes's opinion, "No naïve objectivity is involved in either discipline; both science and theology speak of entities not directly observable by us" (1996, 14). Barbour advocates a

> critical realism holding that both communities make cognitive claims about realities beyond the human world. We cannot remain content with a plurality of unrelated languages if they are languages about the *same world*. If we seek a coherent interpretation of all experience, we cannot avoid the search for a unified world view. (1997, 89, emphasis added)

Clearly, Barbour's advocacy of Dialogue is also motivated by a desire for a holistic account of our human experience. Polkinghorne also offers the following: "As a passionate believer in the ultimate integrity and unity of all knowledge, I wish to extend my [critical] realist stance beyond science to encompass, among many other fields of inquiry, theological reflection on our encounter with the divine" (1998, 110).

Barbour warns, however, that it is too easy in this debate to "dwell on similarities and pass over differences. Although science is indeed a more theory-laden enterprise than the positivists had recognized, it is clearly more objective than religion" (1997, 95). There is also the problem of many different religious viewpoints (1997, 151–61). Additionally, one can point to progress in our scientific understanding of the natural world more readily than can be done in our religious understanding. Still, examples of progress in religion do exist; Austin cites the following as evidence for this assertion: "People used to justify slavery, genocide, racism, sexism, and nationalism on religious grounds to a greater extent than they do today" (2000, 169).

Methodological Parallels

One way to begin the Dialogue is to compare the methodologies of science and religion, looking for commonalities. In spite of the inherent problems posed above, there is value in this activity, according to Barbour. He argues that this process is "likely to encourage attention to substantive issues" (1997, 95). In the view of Polkinghorne, this would involve a "methodological and philosophical revaluation of science, rejecting the poverty of positivism and drawing out science's kinship with other forms of rational enquiry" (1998, 77). In the spirit of critical realism, he suggests the following criteria as being common to both science and religion:

1. Knowledge gathering is usually done little by little.
2. Methodologies are uncertain.
3. The relationship between experiment and theory is complex (in theology it is the relationship between belief and understanding).
4. Epistemologies are not universal.
5. The social factor plays a large role.
6. It is based on experience. (1998, 104–24)

Barbour is influenced by the ideas presented in Thomas Kuhn's book, *The Structure of Scientific Revolutions*. He sees strong parallels between science and religion through the interpretive lens of a Kuhnian paradigm, which he defines as a "cluster of conceptual, metaphysical, and methodological presuppositions embodied in a tradition of scientific work" (1997, 93). Religious communities can also be thought of as sharing a common paradigm where

> the interpretation of the data (such as religious experience and historical events) is even more paradigm-dependent than in the case of science. There is a greater use of *ad hoc* assumptions to reconcile apparent anomalies, so religious paradigms are even more resistant to falsification. (1997, 93–94)

Kuhn's argument that paradigm choice is affected by more than purely rational factors seems particularly apt in the case of religion. Barbour also points out that successful paradigms lead to periods of "normal" research in both science and religion, and that more "revolutionary" thinking appears in periods of crisis in both disciplines (1997, 125–30). Of course the determination of whether a change in thinking is substantial enough to warrant consideration as a new paradigm is a matter of considerable debate. Nevertheless, Catholic theologian Hans Kung has identified five major paradigm shifts in Christian thinking through history: Greek Alexandrian, Latin Augustinian, Medieval Thomistic, Reformation and Modern-Critical (cited in Barbour 1997, 129). In fact, Kung argues that in response to a current "crisis" in theology and culture, we may be on the cusp of a new religious paradigm—one that is more ecumenical and religiously tolerant than ever before (Kung and Tracy 1989, 439–52).

Kuhn has been criticized for presenting a model of theory selection in science that seems to emphasize irrational factors over rational ones. Barbour, however, argues that selection criteria do exist and can also be applied to the assessment of religious beliefs with only slight modifications. These criteria are:

1. Agreement with Data—Does the theory (belief) faithfully represent the data (personal experiences and scriptural interpretations) that is available (considering that theories are often underdetermined by the data)?
2. Coherence—Is the theory (belief) conceptually connected and supported by other theories (beliefs)?
3. Scope—Is the theory (belief) comprehensive and widely applicable? Does it unify previously separate domains of knowledge?
4. Fertility—Does the theory (belief) contribute to a fruitful and successful research program? In the case of religion, is it inspirational, enlightening and capable of effecting personal transformation? (1997, 109–13)

Kuhn's ideas about theory development have also been criticized for emphasizing discontinuity over continuity. This is one of the reasons Nancey Murphy prefers the ideas of Imre Lakatos in relating science to religion over Kuhn's model. She argues that certain religious doctrines can be seen as Lakatosian research programs that can be surrounded by a protective belt of peripheral beliefs that can be adjusted from time to time (Murphy 1990, 184–88). Despite this protection, the research program can be set aside if it proves to be *degenerative* rather than *progressive*. Since competing programs can coexist at the same time, there is no radical paradigm shift, as Kuhn envisions. The data for theological research programs could come from scriptural interpretations and the practical experiences of the religious community (1990, 188).

Murphy is also influenced by the ideas of Willard Quine, who developed a holistic view of knowledge that pictures our understandings of the world as connected in a web of beliefs (Murphy 1996a, 107). As a philosopher of religion, she is anxious to see "where theology fits in the web of beliefs, and how it is interwoven with scientific beliefs" (1996a, 112). It is understood that beliefs near the centre of the web are more secure from revision than those near the edge. Thus it is advantageous to pursue as many connections as possible between science and religion to strengthen the web. In fact, Murphy makes the strong claim that "theology differs only in degree from science—[though] science can be confirmed by data that are more precise than the data supporting theology" (1996b, 151). And in a move that pushes her in the direction of Integration, she points out that each "theological belief is tied to a number of other beliefs—some theological, some experiential, and (ideally) some scientific. When one support is lost, or when an inconsistency arises, there will always be a number of ways to revise and repair the web" (1996a, 119).

In spite of all these comparisons, Barbour admits that these methodological discussions can become rather abstract and therefore "of more interest to philosophers of science and philosophers of religion than to scientists or theologians and religious believers" (1997, 95). He also acknowledges that there are some features of religious practice that are seemingly absent in science: "the role of story and ritual; the noncognitive functions of religious models in evoking attitudes and encouraging personal transformation; the type of personal involvement characteristic of religious faith; and the idea of revelation in historical events" (1997, 136). Nevertheless, there are gains in pursuing this discussion. Wesley Wildman (1996, 53) puts it best:

> Building methodological bridges between science and theology amounts to trying to figure out how it can be that the same human beings, using the same rational capacity in the same existential context, can engage in activities that, on the face of things, appear to be so different. It is an attempt to understand the unity of our own rationality.

Presuppositions and Limit Questions

Science and religion can perhaps strengthen each other by challenging and maybe even correcting the presuppositions of the other domain. In the words of Pope John Paul II: "Science can purify religion from error and superstition; religion can purify science from idolatry and false absolutes. Each can draw the other into a wider world, a world in which both can flourish" (cited in Barbour 2000, 17). If this process results in a reformulation of either scientific theories or religious beliefs, then we are moving out of the Dialogue mode and into an Integration mode, according to Barbour (1997, 92–93). But it is possible that a mutual dialogue may expose false beliefs and unwarranted scientific assumptions.

Certainly the philosophical assumptions of the scientific materialists mentioned earlier in this article can be challenged in this manner. The success of modern Western science has led some of these people to believe that science will be able to purchase our salvation and that science alone produces meaningful knowledge (a view sometimes referred to as *scientism*). But Polkinghorne argues that science has "purchased its success by the modesty of its exploratory and explanatory ambitions" (1996, 3). There is also a distinct problem when scientists produce popular books for consumption by nonscientists. The difference between science as it is practiced and science as it is portrayed in some of this literature is often striking. These works often contain unsubstantiated metaphysical pronouncements that an unsuspecting reader might assume are supported by credible scientific data.

Midgley is critical of some of these eccentric metaphysical speculations in her book *Science as Salvation*. In her opinion, "Recent attempts to make traditional materialism consistent have . . . often resulted in making it romantic, superstitious and irrationalistic" (1992, 15). Stahl, Campbell, Petry and Diver arrive at the same ironic conclusion when they assert that "a great part of the myth of science that scientists fail to recognize, or perhaps fail to acknowledge, is that in their efforts to escape from metaphysics they are entrenching themselves as firmly in speculative dogma as any religion ever has" (2002, 28). Thus we have an argument that there is a certain religious element in science that somewhat mirrors the discussion of the scientific side of religion earlier in this section. In fact, Stahl, Campbell, Petry and Driver have organized their entire book *Webs of Reality* based on this premise. They take a critical look at science through the interpretive framework that Max Weber's categories of religious thought provide. These are: soteriology (ideas about salvation), saintliness, magical causation, theodicy (ideas about suffering and death) and mystery (2002, ix–xii). The result is a strong argument for a religious side to scientific endeavours that is often implicit but in some cases even rather explicit.

Barbour defines *limit questions* as "ontological questions raised by the scientific enterprise as a whole but not answered by the methods of science" (1997, 90). In his opinion, "Religious traditions can suggest possible answers to these questions . . . without violating the integrity of science" (2000, 52). Teleological questions (regarding meaning and purpose) such as "Why does the world exist in the first place?" have an implicitly religious nature to them. Many theologians would contend that the rationality of our universe reflects the rationality of its Creator.

What may be a more meaningful approach to Dialogue for the average person may occur in the *ethics* of scientific advances. A recent study by Moore, Jensen, Hsu and Hatch in the United States shows that Americans "have serious concerns about science-related issues" and their views on these issues are "strongly influenced by religion" (2003, 85). Gaon and Norris argue "critical assessment of science is possible for non-experts because at the basis of science is a set of norms, beliefs and values that are contestable by non-scientists" (2001, 187). It thus seems possible and perhaps necessary that nonscientists begin critiquing working scientists on the implications and purposes of their work rather than the actual substance of it. Freeman Dyson (1993) and James Brown (2001) are both concerned that science no longer functions for all people; it is becoming rather undemocratic in their view. Religious insights that incorporate ideas of justice and equality would be of assistance in correcting this trend. In a manner that blends ethical concerns and limit questions, Holmes Rolston believes that

> science does need religion to keep science humane, not only in the pragmatic sense but in the principled and deeply metaphysical sense of keeping science meaningful . . . religion pushes science toward questions of ultimacy, as well as of value, and it can keep science from being blinkered, or . . . religion can keep science deep. (1996, 81)

It seems obvious that scholars who promote Dialogue between science and religion are anxious to show that the relationship between the two disciplines can be a mutually enriching one without significantly effecting the unique quality of each field. In fact, the work described above is useful in helping one understand what the *nature* of science and religion are while acknowledging that nice, neat boundaries between these two fields of inquiry simply do not exist. As Langdon Gilkey once said, "Not all that we know is science, lest there be no possibility of science" (cited in Polkinghorne 1996, 4). Other scholars with a more integrative philosophy argue that some reformulation of key ideas in these fields is necessary in light of these discussions. The next category of Integration investigates some of this exciting work.

Integration

The degree of Integration between science and religion that one is comfortable with is clearly affected by the other three positions. For those adhering to a Conflict modality, no amount of integration is desirable unless one of the disciplines can be subsumed into the other. Scholars that prefer the Independence position would like to see science and religion remain distinct. The Dialogue category holds a range of positions that is somewhat dependent on the degree of commonality that one sees between the two fields of inquiry. For someone like Nancey Murphy, who sees a high degree of similarity between scientific and theological development, a great deal of integration is not only possible but also desirable. Others are not so sure or are concerned, like Wolterstorff that in matters under dispute, "religion [always] has to give" (1996a, 103). There are also those whose categories cannot be pinned down to any of these four categories and whose allegiances depend rather on the context of each situation (there will be more on this in the next section).

Scholars in the Integration position essentially seek to answer the difficult question: "How can we think and act scientifically and theologically, critically and worshipfully, technologically and ethically at the same time?" (Wildman 1996, 42). Polkinghorne rightfully points out that one of the key issues is "the extent to which taking science seriously requires us to modify orthodox belief" (1996, 25). He typifies his own position as one of *consonance* (science tends to constrain and restrict theological thought, but in a mutually interactive and consistent way). He also describes Barbour's position as one of *assimilation* (a more substantial merging of the two disciplines that may put the autonomy of theology at risk) (Wildman 1996, 6–7; 81–84). Barbour seems to concur with this assessment because he believes that a more systematic integration between theological content and scientific content is indeed possible and desirable (1997, 98). As the discussion becomes more abstract, however, a noticeable move away from religion to theology, and thus the applicability to the average believer comes in doubt. Nevertheless, Barbour sees three distinct examples of integration: natural theology, theology of nature and a systematic synthesis.

Natural Theology

This position is usually referred to as the design argument. In this view, God's existence can be deduced (even proved, according to some) by appealing to examples of apparent design in nature that have been scientifically discovered. These arguments are quite old and perhaps reached their most influential point in the writings of William Paley in the early 19th century. He was the proponent of the famous "watchmaker" argument that posited examples of intricate design in nature, such as the eye, as evidence of a designer who must have created them (Barbour 2000, 28–29). The criticisms of this approach are also old: Scottish philosopher David Hume argued that what appears to be design imposed by an external entity could really be a manifestation of natural processes that are innate to an organism. Thus the argument of design could really be an argument from ignorance. He also indicated that evidence of design does not necessarily point to the theistic vision of God (Barbour 2000, 28).

The exaltation of design in nature has also been criticized by modern scholars in light of our knowledge of the extensive cosmological, geological and biological evolution of our world. It is difficult to scientifically conclude that the purposive nature of God's design was to bring about humanity when our presence on this planet has only been a small fragment of its entire history. Science writer Timothy Ferris calls this view "woefully anthropocentric" (1997, 305). Biologists also point out that what might be considered examples of design in organisms may simply be the results of random evolutionary processes. Many religious scholars have responded by arguing that design is "not in the particular structures of individual organisms but in the properties of matter and the laws of nature through which the evolutionary processes could produce such organisms. It is in the design of the total process that God's wisdom is evident" (Barbour 1997, 99). This is a good example of the type of reformulation that Barbour sees as indicative of the Integration position.

For those with religious inclinations, the design argument will always be an attractive one. It has recently received a significant boost from the cosmological arena with many scientists pointing to a seemingly "fine-tuned" universe. Polkinghorne is one of those arguing for a new and cautious approach using the anthropic principle, while being critical of the "old-style natural theology" of Paley (Polkinghorne 1998, 10–11). According to Polkinghorne, "the endowment of matter with anthropic potentiality has no human analogy. It is a creative act of a specially divine character" (1998, 11). To those who might argue that this constitutes a proof of God, he asserts that this "theistic conclusion is not *logically coercive*, but it can claim serious consideration as an *intellectually satisfying* understanding of what would otherwise be unintelligible good fortune" (1998, 10, emphasis added).

Interestingly, the "old-style natural theology" is being reintroduced through a group that calls themselves intelligent design theorists. They believe that evolutionary processes are incapable of producing the kind of biological diversity and complexity that we see in nature and thus God has created discontinuously throughout the development of life on this planet. Scientists have criticized this position for not faithfully portraying a robust understanding of evolutionary processes, and theologians have criticized it for being another version of the god-of-the-gaps argument (Barbour 2000, 96–99). In the words of Charles Coulson: "When we come to the scientifically unknown, our correct policy is not to rejoice because we have found God; it is to become better scientists" (cited in Brush 2000, 120).

Theology of Nature

In the words of Barbour, this position "starts from a religious tradition based on religious experience and historical revelation. But it holds that some traditional doctrines need to be reformulated in the light of current science" (1997, 100). We saw how this occurred to the design argument in the last section, even though one might not assign doctrinal status to that idea. Scientific findings and theories have particular relevance to doctrines related to creation, human nature and God's role in this world, according to Barbour and many of his colleagues. Polkinghorne points out one example of a doctrine that has been modified for some time: the doctrine of the Fall, or original sin. He believes that an "Augustinian notion of decay from an original paradisal state, brought about by a single disastrous ancestral act, is one that cannot be made consonant with what we know about the history of the Earth" (1996, 83).

The potential for controversy is, of course, great in this type of endeavour, and thus Barbour cautions against using speculative theories and advises using well-established science (1997, 101). Rolston opines that the "religion that is married to science today is a widow tomorrow, while the religion that is divorced from science today leaves no offspring tomorrow" (1996, 64). But even the use of reasonably well-established scientific theories is no guarantee of harmony because the ongoing creation-versus-evolution debate amply attests. Also, the speculative nature of certain Integration theories at times seems to challenge the credibility of overlapping the domains of science and religion.

One of the areas where scientific and theological concerns overlap is in the question of God's action in a world of seemingly regular natural processes. Barbour devotes a whole chapter to this issue in his most recent work (2000). Hovering constantly in the background of this debate is the awareness of pain and suffering in a world that God is believed to be actively involved in. In traditional theories going back to Thomas Aquinas, God is believed to be the primary cause of events and science studies the secondary causes in nature that are on an entirely different level (Barbour 2000, 159–60). Van Till defends this view by asserting that "God's creative action, operating at a level different from creaturely action, undergirds *all* that occurs" (2001, 161, emphasis in the original). Noting that this argument still does not explain the "causal joint" connecting God directly to creation, Polkinghorne suggests that God's action may consist of an input of "active information" into potentially chaotic and complex systems in nature (Barbour 2000, 166–67). In this manner, God can exert an influence without interfering in natural causation. Murphy sees God as radically self-limiting His own power to allow for human free will. This position also contains a response to questions of theodicy by suggesting that "suffering and disorder are necessary byproducts of a noncoercive creative process that aims at the development of free and intelligent beings" (Murphy 1996a, 169).

A related issue that scientific advances have shed light on is the understanding of human nature. The body/soul dualism that has been an important component of some religious traditions apparently needs adjustment due to developments in the neurosciences that show the seat of human consciousness to be the physical human brain. In this case, biblical scholarship has supported this movement by showing that the body/soul notion is largely an extrabiblical import into theology. It is Austin's opinion that "Plato's dualistic understanding of humans as body and soul, imported to a stubborn place in Christian theology by Augustine, and made more intransigent by Descartes' wedding of it to a modern scientific worldview, is being whittled away" (2000, 136). As in the previous paragraph, theories abound regarding the "true" nature of humanity, but Barbour offers the final comment: "I believe that both recent theology and recent science support a view of the person as a multilevel psychosomatic unity who is at the same time a biological organism and a responsible self" (2000, 149).

Stahl, Campbell, Petry and Diver are critical of some of the integrative practices in the theology of nature. It is their opinion that if "we see science as its content, religion can never be more than added on, and its legitimacy will always be suspect. Science will always be the active partner in the dialogue, and religion can do little more than listen" (2002, 68). They see that science needs to be perceived as what scientists do rather than a body of certifiable truths that most non-experts simply have to accept at face value. In this scenario, religious insights can be implemented "before the dust settles" (especially in ethical matters) and thus contribute in a more significant way. The payoff for Stahl, Campbell, Petry and Diver is that when viewed this way, "science becomes less of an abstraction, and scientists cease being mythic heroes. Instead, when science becomes the practice of real people, we have a much more solid basis for partnership and dialogue" (2002, 68).

Wolterstorff echoes some of these concerns in his book *Reason within the Bounds of Religion*. He also sees no reason why religious insights should be left out of scientific theorizing, only to be incorporated in the final analysis.

This is because he views the theory-selection process as involving not only data and theory but also what he calls *control beliefs*—ideas about what kind of theories are acceptable (1984, 63–70). In light of the Kuhnian notion that theories are often underdetermined by the data, Wolterstorff argues that

> the Christian scholar ought to allow the belief-content of his authentic Christian commitment to function as control within his devising and weighing of theories. For he like everyone else ought to seek consistency, wholeness, and integrity in the body of his beliefs and commitments. (1984, 76)

This may seem to be an argument for giving religion the upper hand, but he later adds that "such activities will forever bear within them the potential for inducing, and for *justifiably* inducing, revisions in our views as to what constitutes authentic commitment, and thus, revisions in our actual commitment" (1984, 91–2, emphasis in the original). He thus envisions a rather dialectical process occurring between science and religion.

Systematic Synthesis

According to Barbour, a "more systematic integration can occur if both science and religion contribute to a coherent worldview elaborated in a comprehensive metaphysics" (2000, 34). The most common manifestation of this is process theology, which is based on the ideas of Alfred North Whitehead. In this view, God transcends nature and yet is immanent in all events in a manner that never determines the actual outcome. God is thus not viewed as an omnipotent being but rather a persuasive one, a move that partially resolves some of the issues regarding divine action and the presence of pain and suffering in our world (Barbour 2000, 34–36).

This position has many critics. Polkinghorne argues that in "reacting against a God seen as a dominating Cosmic Tyrant, process theologians appear to have settled for a Marginal Persuader . . . [who] is too much in thrall to his creation to be the Ground of hope" (1996, 33). He is also critical of this line of thinking on scientific grounds (1996, 28–29). Denis Lamoureux believes that, although process theology may be "intellectually titillating for intellectuals," it is decidedly "irrelevant in [the] pews" (2004, 49). Barbour himself asserts that "neither science nor religion should be equated with a metaphysical system. There are dangers if either scientific or religious ideas are distorted to fit a preconceived synthesis that claims to encompass all reality" (2000, 37). Nevertheless, relinquishing the idea of a deterministic God who controls events and has prior knowledge of everything that happens seems to invite a move toward process theology.

Criticisms of Barbour's Typology

One of the criticisms of Barbour's approach is his determination to place people in one of his four categories. In a sense, Barbour might be accused of being a "compulsive categorizer!" He does admit, however, that his "attempts to categorize may itself reflect a Western bias" (2000, 6). In many cases, his choices for who belongs in each category seems to make sense, but consider the following argumentation he uses to categorize Willem Drees:

> Drees's religious naturalism does not conflict with science (indeed it is closely related to science), but it does conflict with (or remain agnostic about) most of "the heritage of religious traditions" on which he wishes to build. . . . But Drees is not agnostic about naturalism, which he defends as a metaphysical position rather than simply as a philosophy that might be functional to human life. With some reluctance, then, I would have to classify him . . . under the heading of Conflict. (2000, 159)

Barbour's approach also seems to suggest a natural progression from Conflict through Independence that finally leads to a Dialogue or Integration stance. This notion has been challenged and criticized by Brooke and Cantor (1998). They claim it is basically an essentialist thesis and represents a distinctly ahistorical way of looking at the science–religion relationship. They consider the case of St George Jackson Mivart:

> He perceived conflict between the Darwinians' overstated commitment to natural selection and his understanding of the human condition in which mental and moral attributes were important but could not be explained by natural selection. Likewise he used an independence strategy when

> arguing that the Galileo affair should teach us that science is for scientists and theology for theologians. . . . Yet he also conceived a form of dialogue when arguing that both science and religion are rational activities; he insisted that neither scientists nor theologians should forsake their critical faculties. Finally, much of his own research was empowered by specific integrationist strategies. Thus he perceived the world framed by the divine architect and he directed his research to elucidating archetypes. (1998, 276)

Brooke and Cantor go on to argue that Barbour's approach does not capture the dynamic and complex nature of one's understandings of science and religion. They maintain that "in opposition to the essentialist program . . . the individual must be treated as an active agent who deploys different strategies creatively" (1998, 276). Stahl, Campbell, Petry and Diver offer the following: "Barbour presents us with boundaries but does not let us watch how those boundaries were constructed. But unless we understand the dynamics and trajectories of a debate, we cannot fully comprehend it" (2002, 6).

Can "Progress" Be Claimed?

It would be tempting to simply see progress in this debate in the movement away from the claim that science and religion are irreconcilable. In fact, Barbour's typology has been tremendously important in recognizing that credible and viable intellectual positions exist other than Conflict, regardless of the sometimes abstract nature of the debate. The fact that scientists and theologians see this as a fruitful field and sometimes work together in exploring it is evidence of progress. As examples of "bridge-building" are becoming more common, even some agnostic scientists are exploring the implications of religious thinking for scientific endeavours. Steven Jay Gould tells of an interesting incident where he, a Jewish agnostic, tried to reassure some Catholic priests that evolution could be consistent with their religious beliefs (2001b, 738).

The defence of critical realism by Barbour and his colleagues is also a key component of a rapprochement between science and religion. There is certainly irony contained in the contention that progress can be marked by what one does not know. The old saw, however, is probably true: Not everyone can be right but it is possible for everyone to be wrong. The following statement by Barbour exemplifies this approach:

> All models are limited and partial, and none gives a complete or adequate picture of reality. The world is diverse, and differing aspects of it may be better represented by one model than another. . . . The pursuit of coherence must not lead us to neglect such differences. In addition, the use of diverse models can keep us from the idolatry that occurs when we take any one model . . . too literally. (2000, 180)

Ironically, this assertion also applies, of course, to Barbour's own typology. Elsewhere he defends a "multileveled view of reality in which differing (epistemological) levels of analysis are taken to refer to differing (ontological) levels of events and processes in the world" (2000, 109). Thus a certain amount of epistemological and ontological pluralism is required before science and religion can offer mutually consistent accounts of our world. Alan Padgett argues that classical realism is rather naïve and lacks an appropriate amount of humility, while antirealism is too anthropocentric in asserting that humans can construct their own reality (2002, 187). Neither position is consistent with theistic religious beliefs or science. Padgett goes on to claim that our version of realism should be *dialectical*; it will only be through serious debate and the highlighting of differences that significant progress in relating science and religion will take place (2002, 184–91).

Educational Implications

What is certainly being argued for here is a tolerant and humble attitude from scientists and science educators alike. One could definitely teach science without recognizing the importance of other ways of knowing, such as religious insights, but that would inevitably leave a rather narrow conception of science. It has often been argued, however, that the Independence position protects science teachers from interference from creationists, among others, and that a narrowly bounded view of science is simply the best political and practical solution. The National Academy of Sciences released the following statement in 1981: "Religion and science are mutually exclusive realms of human thought whose presentation in the same context leads to misunderstanding of both scientific theory and religious belief."

But is a type of religious orientation already being implemented in science education? The most common complaint from many religious people is that science education is unduly influenced by scientific materialism. This argument was significantly reinforced by the explicitly materialistic statement from the National Association of Biology Teachers (NABT) in 1995:

> The diversity of life on earth is the outcome of evolution: an *unsupervised, impersonal,* unpredictable, and natural process of temporal descent with genetic modification that is affected by natural selection, chance, historical contingencies, and changing environments. (quoted in Cobern 2000, 239, emphasis added)

The NABT later dropped the italicized words after being made aware of the religious nature of the statement. Since then, NABT member Eugenie Scott has been beating the Independence drum and even speaking to many religious groups on the merits of distinguishing between *methodological naturalism* ("normal" scientific research) and *philosophical naturalism* (the metaphysical view of scientific materialism), but in some ways the damage was already done. This blunder was unfortunate because it convinced many religious people that science teaching in the public schools is overtly tainted by the views of scientific materialism and that evolutionary theory really is atheistic in nature.

The concern that something akin to *scientism* is being taught in our schools has received support from educational theorists like William Cobern. He refers to it as the "*myth of school science*. The myth is a scientistic view roughly embracing classical realism, philosophical materialism, strict objectivity, and hypothetico-deductive method" (2000, 233, emphasis in the original). Each of these themes comes under serious challenge from a modern philosophical understanding of science. Olson and Lang refer to scientism as the "weed well fertilized in the garden of science education" (2004, 545). To them, part of the problem is that "the very image in textbooks of scientists at work (often detached from history and from culture) takes on the character of the 'lives of saints' and the science itself the 'aura of catechism'" (2004, 546).

Cobern and some of his colleagues are arguing for a more holistic science education. More and more educators are acknowledging that "this whole contains the social, humanistic, aesthetic, and *spiritual* elements constituting a subjectively personal relationship between a passionate, dependent, and intuitive self and others" (Kozoll and Osborne 2004, 174, emphasis added). Warren Nord claims: "One purpose of a liberal education is to put students in a position to make 'all things considered' judgements, rather than to accept uncritically the conventional wisdom of any discipline, science included" (1999, 33). Critical thinking is part of the dialectical process in the dialogue between science and religion.

There is also the possibility that opening up science to a wider view will facilitate conceptual change. Cobern argues that "conceptual change should become more plausible for students when they have been invited to a discourse on what are the important questions of life . . . and what does science have to contribute to the common human quest for a meaningful life (1996, 579). Elsewhere he points out that "one should not assume an authoritarian stance and discount student knowledge and belief. Rather, teachers should promote discussions about the reasons one has for believing and thinking the things that one does" (Cobern 2000, 237). A sensitive teacher can conduct such discussions in a climate of mutual respect and tolerance with the help of some excellent pedagogical advice from Oulton, Dillon and Grace (2004). They believe that approaches to class discussions should do the following:

1. Focus on the nature of controversy and controversial issues; that is, that people disagree and have different worldviews, value and limitations of science, political understanding, power, and so on.
2. Motivate pupils to recognize the notion that a person's stance on an issue will be affected by their worldview.
3. Emphasize the importance of teachers and learners reflecting critically on their own stance and recognize the need to avoid the prejudice that comes from a lack of critical reflection.

4. Give people the skills and abilities to identify bias for themselves, encouraging them to take a critical stance toward claims of neutrality, a lack of bias and a balanced view.
5. Promote open-mindedness, a thirst for more information and more sources of information and a willingness to change one's view as appropriate, and avoid strategies that encourage pupils to actually make up their minds on an issue too hastily.
6. Motivate teachers, as much as possible, to share their views with pupils and make explicit the way in which they arrive at their own stance on an issue. (2004, 420)

Of these recommendations, the last one is certainly the most controversial because of the teacher's position of authority in the classroom. Oulton, Dillon and Grace argue that this is mitigated by teachers' frank acknowledgement of their own biases and presuppositions. They also point out that "perfect balance is probably impossible to achieve. Teachers have to make subjective judgements about what information to present, and differing views may not be easily accessible" (2004, 416). In some cases, teachers may need to present a more neutral position in certain dichotomies (creation versus evolution, for example) to give students another "schematization" that may "bear fruit" when conflicts arise. In other cases, it might be worthwhile to have students argue a point of view opposite their own and have the teacher remain neutral.

Cobern also recommends that teachers remember the following points:

1. All epistemologies are grounded worldview presuppositions. (2000, 237)

We need to remember as teachers that "people simply do not hold beliefs for no reason. It is not helpful to suggest that blind belief is belief merely supported by appeals to authority since all of us make use of authority" (2004, 234). Because it is generally the religious worldviews that cause the most problems for students, it would be helpful for preservice teachers to take a course in science and religion as part of their teacher training. This would help teachers understand where some views (such as anti-evolutionism) originate and possibly help them discover their own "baggage" as well. This would hopefully inspire humility about our own tentatively held knowledge. Understanding the fallibility of our own convictions should help us appreciate Cobern's second point:

2. There is no single set of presuppositions that adequately describes all of science. Science can be—and is—supported from a number of presuppositional bases. (2000, 238)

Cobern advises that, instead of worrying about placing boundaries around science, "good science instruction should help students see the variation under the umbrella we generally call science" (2000, 238). Science is a complex affair inextricably linked to the realm of human affairs with different disciplines and traditions. There may even be some pedagogical shrewdness in acknowledging other paths to knowledge beside science. As Sherry Southerland claims,

> The goal of such instruction [for conceptual change] is not to change students' religious beliefs or persuade them to accept evolutionary theory (although we must acknowledge that both sophisticated epistemological beliefs and dispositions do have a strong bearing on a learner's acceptance of evolution). Instead, the goal of such instruction is to help students understand how science does not provide the only answers important in their lives. This, in turn, decreases potential aversion to concepts and may help to avoid the negative emotions that can impede instruction related to evolution, allowing for intentional level constructs to be invoked. (2003, 28)

But even with a tolerant view of epistemological variations, we still recognize Cobern's third point:

3. Although presuppositions are underdetermined, they can be rational and their relative merits are certainly debatable. (Cobern 2000, 239)

Cobern claims that "pluralism in epistemology is a fact of life. . . . On the other hand, the fact of pluralism does not imply that all members of this plurality are equal" (2000, 239). Recently, Richard Reed also challenged the notion that a careful separation of methodological naturalism and philosophical naturalism guarantees religious neutrality when he claimed that, "according to science, there are some things it is likely that God did *not* do. . . . What science says [however] does not rule out the possibility of God—it does not imply [either] materialism or atheism" (2002, 22, emphasis added). It is important to note that teaching something like evolution fully and accurately can be significantly different than teaching it dogmatically. This leads to the fourth point:

4. The science curriculum should not antagonize needed allies by insisting on presuppositional purity. (Cobern 2000, 240)

Presuppositional purity in science is a rather elusive goal, and if we come to a point in our careers where we think that we have attained it, we could end up teaching in the manner Mano Singham portrays in the following statement:

> We who teach introductory physics have to acknowledge, if we are honest with ourselves, that our teaching methods are primarily those of propaganda. We appeal—without demonstration—to evidence that supports our position. . . . All of this is designed to demonstrate the inevitability of the ideas we currently hold, so that if students reject what we say, they are declaring themselves to be unreasoning and illogical, unworthy of being considered as modern, thinking people. (2000b, 54)

In conclusion, it is fair to state that this is a tall order for science educators. This vision requires that teachers be philosophically sophisticated and religiously astute. But the reward of having an improved view of how science operates in our lives is worth the effort. The final words are from Cobern:

> Acknowledging in the science classroom that all knowledge systems are grounded in presuppositions would re-introduce a valuable discussion on the nature and meaning of science knowledge itself. It would force more instructional time on the nature of knowledge, reasoning, evidence, and commitments. This cannot be done, however, without acknowledging students' *other* beliefs and *other* beliefs held by scientists and science teachers. Rather than fearing such a situation as an unpalatable intrusion on the science classroom, it should be welcomed as an opportunity to discuss how reason operates in different disciplines and in different areas of life. (2000, 241, emphasis in the original)

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Albert Einstein and Mileva Maric: A Centenary Overview

Wytze Brouwer

The United Nations General Assembly officially designated 2005 the World Year of Physics. Exactly 100 years ago, Albert Einstein published his groundbreaking papers on Brownian motion, the photoelectric effect and the special theory of relativity. Each of these papers was influential on the development of physics and on people's understanding of nature. In 1905, surprisingly, many scientists were still not convinced of the existence of atoms, even though Dalton's model was already almost 100 years old. The leading chemist of the time, Wilhelm Ostwald, did not believe that atoms were more than a mathematical fiction until he read Einstein's paper on Brownian motion.

The quantum nature of energy had been suggested by Max Planck in 1900 to explain the energy carried by radiation, but Planck was not yet convinced that quantum processes existed in nature. Was it just a trick to make calculation easier? Einstein's paper on the photoelectric effect helped convince scientists that quantum processes are everywhere, and real. The paper won Einstein the Nobel Prize in 1921 after previously being recommended for the Nobel Prize for this and for his special theory of relativity every year but two since 1910.

His most famous paper, "On the Electrodynamics of Moving Bodies," fundamentally changed people's view of the universe and provided the nuclear age with its fundamental reason for success: $E = mc^2$

In the following three fictitious interviews, I will present an overview of Einstein's own thinking about his research, as well as his views on society, nuclear disarmament and the need for international laws and institutions. In recent years, many of Einstein's nonscientific papers have come to light, including thousands of letters of correspondence. Among these is a set of letters between Einstein and his first wife, Mileva Maric. Mileva and Albert both had dreams of being scientists and of being involved in science together for the rest of their lives. The fictitious interview with Mileva throws some light on how those dreams ended, leaving Mileva with poor health and bitter memories, along with the responsibility of looking after their two sons, Hans Albert and Eduard.

Albert Einstein: His Scientific Work

Albert Einstein was born in Ulm, Germany, on March 14, 1879, and died in Princeton, New Jersey, on April 18, 1955. He is probably the only 20th-century physicist that could be compared to Isaac Newton in intellectual stature. Although he won a Nobel Prize in physics in 1921 for the photoelectric effect, he could have won it for special relativity, general relativity or a host of other topics. In fact, Einstein had been nominated 10 times before he was finally awarded the prize. Every area of physics has been influenced by Einstein.

As his life progressed, he became more and more involved in politics. When 92 leading German scientists signed a manifesto pledging their support for the German war effort in 1915, Einstein helped circulate another petition urging scientists to help bring a peaceful end to the war. The last official act of his life was to sign, in 1955, what was to become known as the Einstein–Russell Manifesto, urging nuclear disarmament and renouncing war as a means of settling international conflicts.

The fictional interviews with Einstein are conducted from the point of view of a high school teacher who wants to present physics to his students in a somewhat broader social context than was common in the 1950s.

Teacher: Professor Einstein, Jeremy Bernstein states in his biography of you that there was no precedent in your family history for any scientific or intellectual achievement (Bernstein 1973, 19).

Einstein: I think that is a bit unkind to my parents and relatives. My father owned an electrical shop until 1894 and although he was a rather unsuccessful inventor, it shows an intellectual attitude at a time when creativity certainly was not encouraged. My mother, on the other hand, was musical, and music and mathematics often go hand in hand, as Pythagoras would say.

Teacher: Were you interested in science when you were young?

Einstein: Nothing in my early formal education inclined me toward science, but I remember three incidents from my early life that had a great influence on me. I remember receiving a compass from my father on my fifth birthday. I spent many days playing with that compass and magnets. Also, I received a book on Euclid's geometry from my uncle Jacob on my eleventh birthday. I spent many hours reading this book and working through the theorems. And when I was 12, one of our Thursday evening dinner guests, Max Talmey, brought me a book on popular science, which I also enjoyed greatly.

Teacher: Did you enjoy school in your early years?

Einstein: No. In fact, I hated school. The teachers at the Catholic school and the gymnasium were like staff sergeants, discouraging creativity and emphasizing drillwork. I remember remarking later in a public speech I once gave: "It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry. . . . It is a very grave mistake to think that this enjoyment of seeing and searching can be promoted by coercion and a sense of duty" (Bernstein 1973, 69).

Teacher: How would you revolutionize schools to make sure creativity and intellectual development are not stifled?

Einstein: It is relatively simple to keep schools free from coercion and fear. "Give in to the power of the teacher the fewest possible coercive measures, so that the only source of the pupil's respect for the teacher is the human and intellectual qualities of the latter" (Einstein 1954, 69).

Teacher: Dr Einstein, rumour has it that you were expelled from the gymnasium as "a bad influence on other students."

Einstein: That is correct. My parents had moved to Milan in 1894. I was very lonely and somewhat rebellious, and asking too many questions in school. It's just as well that I left Germany at that time and applied for entrance to the Zurich Polytechnic Institute.

Teacher: Did you actually fail your mathematics entrance exam?

Einstein: No, no. That's a rumour that seems to have gotten about somehow. I did well in mathematics and physics but rather poorly in languages and biology, and also history. Fortunately, I was referred to a school in Aarau, Switzerland, which was progressive. The school even had science laboratories and allowed students freedom for individual experimentation.

Teacher: Tell us about your experiences at the Polytechnic Institute.

Einstein: There is not really much to tell. I was unhappy with the system of lectures and courses at the Polytechnic Institute. If it had not been for Marcel Grossmann, who was a meticulous note taker, I might never have passed the course exams. In fact, one of my teachers was Hermann Minkowski, who wrote some beautiful papers on special relativity 10 years later. He was quite surprised that the initial work was done by "that same Einstein that was in my class. He was always such a lazy dog" (Hoffmann 1972, 84). The experience at the Polytechnic Institute had such a deleterious effect on me that I found the consideration of any scientific problems distasteful to me for an entire year.

Teacher: Did you consider teaching at a university as a possible career at that time?

Einstein: Yes, I did, but first I needed my PhD. That meant that a professor had to take me on as an assistant, but no one wanted me. My father even wrote a letter to the famous Professor Ostwald, but to no avail. So I took some short-term teaching positions until the father of my good friend Marcel Grossmann obtained a position for me at the Berne patent office.

Teacher: It must have been difficult for you to work at the patent office and to work on physics in your spare time.

Einstein: Actually, the work at the patent office was quite interesting. It required the kind of puzzle solving that stimulates one's intellectual powers. In some ways, the six years I spent at the patent office were among the happiest of my life—I had a regular job and eight hours of leisure a day, plus a Sunday, all of which could be devoted to physics.

Teacher: In Berne you met frequently with Maurice Solovine and Konrad Habicht in what you called the Olympia Academy to discuss philosophy and literature. Was that useful to you?

Einstein: The physics curriculum at the universities is probably far too narrow. Many of the fundamental questions of philosophy have to do with the nature of being; with space, time and matter; and with ways of knowing about nature. Every scientist or science teacher should be familiar with these concepts, which have a great influence on science. Moreover, it gave us a chance to bounce our ideas off each other, a necessary exercise in what was, intellectually, a somewhat lonely place.

Teacher: Was the relativity paper in 1905 your first published paper?

Einstein: No, I worked on several topics during those years. I published some papers on capillarity, kinetic theory, thermodynamics and other topics in the *Annalen Der Physik*. However, my PhD thesis on "A New Determination of Molecular Dimensions," in which, among other things, I calculated the probable size of a sugar molecule, was rejected in 1903. My first thesis had been rejected in 1901. I almost decided to forget about the PhD, but I resubmitted this latter thesis in 1905 with one sentence added, and it was finally accepted.

Teacher: So, 1905 was, in essence, a good year for you.

Einstein: Yes, I suppose it was. Three of the papers I published that year—on Brownian motion, the photo-electric effect and the electrodynamics of moving bodies—certainly had some influence on physics.

Teacher: Is it true that when you were 16 years old you thought about what a light wave would look like if you were moving beside it at the same speed? I ask this because my 16-year-old high school physics students often ask difficult and strange questions that I cannot even begin to answer.

Einstein: I think every successful scientist, despite his intensive training, must keep the relatively unspoiled, naïve outlook of the 16-year-old, who is not afraid to ask embarrassing questions that the science of his day does not consider important anymore. My questions about light waves probably indicated some concern of mine about space and time that required considerable time and effort to bring to fruition.

Teacher: Was it the result of the Michelson–Morley experiments that led to your theory of special relativity?

Einstein: Much has been written about that question (Holton 1969, 133–97), but my memory is probably not a reliable guide anymore (Ogawa 1979, 73–81). Certainly the Michelson result influenced my work indirectly through the papers of Lorentz and Poincare. However, I have always felt that the main influence that paper had on me was philosophical. In the special relativity paper, I reflect on the effects of a magnetic field on a conductor (Einstein 1905, 891). As you are aware, moving a magnet past a conductor sets up an electric field that acts on the charges to set up a current. Moving the conductor through the field of the magnet exerts a Lorentz force on the charges, and a current of the same magnitude results. The effects are identical—should the causes be different? If the cause is the same in both cases, then only the relative motion of the magnet and the conductor is a physically meaningful quantity. Hence the axiom that the laws of physics must be valid in all reference frames that are moving with constant velocity with respect to each other follows from philosophical considerations.

Teacher: Did your life change suddenly after your fundamental papers in 1905?

Einstein: You can get some indication of the influence of my work from the fact that when I applied for a position as privatdozent at the University of Berne in 1907, I included a copy of my special relativity paper. My application for the position was refused and the paper returned with the comment “Incomprehensible!” I learned later that Wilhelm Wien, Max Planck and a professor Witkowski from Krakow were impressed by the paper. However, it wasn’t until 1909 that I finally got an academic position at the University of Zurich. I remember notifying Mr Haller, the director of the patent office, of my resignation and of my appointment in Zurich. Mr Haller said, “Now, now, Mr Einstein, don’t play any more of your silly jokes. Nobody would believe such nonsense.”

Teacher: So the year of your first academic position coincided with the year of your first honorary doctorate at the University of Geneva. In 1913, you were offered an academic position at the Kaiser Wilhelm Institute in Berlin.

Einstein: Yes, in the summer of 1913, Max Planck and Walther Nernst came to see me in Zurich and offered me an attractive position in Berlin plus election to the Royal Prussian Academy of Sciences (Hoffmann 1972, 100). It allowed me to work with the best physicist in the world at that time. In the flattering recommendation written by Planck and some others, they suggested that I “should not be judged too severely for occasionally losing sight of [my] objectives in [my] logical reasoning as is the case in [my] theory of light quanta” (Hoffmann 1972, 94).

Teacher: Was it in Berlin that you worked primarily on the general theory of relativity?

Einstein: I had already started working on the equivalence between gravitation and accelerating frames of reference in Zurich and Prague. In fact, in 1912, I predicted a value for the bending of light past the sun that was half the value I predicted in 1916. My good friend Freundlich led a 1914 expedition to the Ukraine to measure the deflection of light in a total eclipse. Because of the war, Freundlich became a prisoner of war instead. Fortunately, with the great assistance of David Hilbert, I completed the general theory in 1916, and Eddington’s expedition of 1919 fully bore out the new prediction of the deflection of starlight.

Teacher: In our interview tomorrow, I would like to talk more about your views on war and peace. My last question today relates to the research you were working on in your latter years. Is it true that most physicists felt that your quest for a unified field theory was a waste of time?

Einstein: My dear friend, there are fashions in physics that come and go as the clothing fashions do. With people like Hermann Weyl and others, I pursued the unification of electromagnetic and gravitational forces and tried to incorporate them into the geometric structure of spacetime. Most physicists had other more-necessary problems to solve, but I have no doubt that a future generation of physicists will return to the problem of the unification of the basic interactions of nature.

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Albert Einstein: Humanitarian

The next day at 11 in the morning, our physics teacher arrives at Einstein’s house and is escorted to Einstein’s study. Although Einstein is not supposed to smoke, he is enjoying a pipe, and Ms Dukas brings them both a cup of coffee. The teacher fiddles with his tape recorder, takes a pad of paper from his briefcase and questions Einstein again.

Teacher: Professor Einstein, last night as I was typing up our interview from yesterday, it struck me that I had forgotten a couple of questions that might be important to my colleagues. Do you mind if I ask you a few more questions about physics?

Einstein: I don’t mind at all, although I have a suspicion as to what type of question might pop into your head late at night.

Teacher: The first question has to do with the cosmological term you introduced to modify the gravitational field equations, which you developed in 1915, in order to derive from them a static universe solution.

Einstein: Ah, yes. Everyone of my biographers has pointed out that I should have been satisfied with the original field equations, which appear to predict universes that are expanding or contracting rather than remaining static, as the evidence in 1917 appeared to suggest. When Friedmann's expanding universe solutions were found to fit well with Professor Hubble's observations, I decided that the whole business of the cosmological term was a mistake and I refused to have anything to do with it after that time (Pais 1982; Bernstein 1973, 128–30).

And your other embarrassing question?

Teacher: It has to do with quantum mechanics. Is it true that you have not accepted the current view of physicists that the basic laws of physics are probabilistic, not deterministic?

Einstein: Quantum mechanics has been a fruitful theory, and in 1927 I was already convinced that quantum mechanics undoubtedly contained part of the ultimate truth (Pais 1982, 448). Yet it seemed to me that a theory should do more than just give energy level transition probabilities for electrons in an atom; it should describe the electron orbits in the atom or in cloud chambers.

Initially, I attempted to show that quantum mechanics was inconsistent and that the uncertainty principle could be circumvented. However, all of these attempts failed. Finally, with Boris Podolsky and Nathan Rosen, we designed an experiment that at least showed that certain properties of atoms had an objective existence even prior to the measurement of these properties, and that quantum mechanics is therefore incomplete. I believe that the wave function, therefore, does not describe a state that is a single system; it relates rather to many systems, in the sense of statistical mechanics (Einstein 1954, 308–09).

Teacher: Clearly your mistrust of quantum mechanics must have something to do with your vision of reality.

Einstein: I think that every physicist must be a realist in so far as he or she seeks to describe a world independent of the acts of perception. Although strict objectivity and causality fail us in quantum mechanics, I believe the last word has not been spoken.

"May the spirit of Newton give us the power to restore unison between physical reality and the profoundest characteristic of Newton's teaching—*strict causality*" (Pais 1982, 15, emphasis added).

Teacher: You refer to yourself as a realist, Professor Einstein. That surprises me. I would have thought the term idealist would describe you more accurately.

Einstein: In actuality, philosophers of science often consider physicists as unscrupulous opportunists. A physicist is a realist with respect to the external world, but he is also an idealist in how he considers concepts and theories to be the free inventions of the human spirit. He is also a positivist in how he considers that his concepts and theories are only justified to the extent to which they correspond to sensory experience, and he is perhaps even a Platonist or Pythagorean in how he considers elegance and logical simplicity to be indispensable tools of his research (Pais 1982, 13).

Teacher: Well, that takes care of my questions on your views of science and of nature.

Your work has had a great influence on society as a whole. Have you ever wondered if it was worthwhile, given the technological implications of your work?

Einstein: I have occasionally expressed myself as wishing I had been a cobbler instead of a physicist, now that I know the uses to which physics and physicists were put, but such feelings have never lasted very long. To find a thought that lets us penetrate a little deeper into the eternal mystery of nature, and to have experienced the recognition, sympathy, and help of the best minds of his time, is almost more happiness than a man can bear (Hoffmann 1972, 253).

Teacher: Do you think that you developed the theoretical groundwork for the atomic bomb?

Einstein: First of all, it is never easy to foresee the ultimate consequences of one's research. Second, any scientific accomplishment inevitably contains consequences for good and evil. Unfortunately, it sometimes seems as if "all our technological progress—our very civilization—is like an axe in the hand of a pathological criminal" (Dukas and Hoffmann 1979, 88). We have not learned the moral lessons that help us cope with our modern technology.

Teacher: You were a pacifist most of your life, yet you did, together with Dr Leo Szilard, send a letter to President Roosevelt, warning him of the possibility that Germany might develop an atomic bomb, and that the United States should set up a research program to develop the atom bomb before the Germans.

Einstein: Actually, Eugene Wigner and Szilard came to see me while I was vacationing on Long Island—I think Edward Teller also came once—and we drafted a letter urging quick action from the administration (Hoffmann 1972, 205–06).

Early in the 1930s, I made a decision that military resistance was necessary to save Europe, and perhaps the world, from a barbarous, totalitarian Germany. As I wrote to some conscientious objectors in Belgium: "I hope most sincerely that the time will once more come when refusal of military service will again be an effective method of serving the cause of progress" (Bernstein 1973, 181; Hoffmann 1972, 170).

Szilard came to see me again in March 1945 and we urged President Roosevelt not to use the atomic bomb against a civilian target in Japan. However, it is doubtful that President Roosevelt ever saw the letter.

Teacher: Since then, you've always argued for nuclear disarmament and international control of atomic energy.

Einstein: Yes, I've been quite distressed by the current paranoia in the United States. It almost seems that, having defeated the Germans, the Americans are intent on taking their place (Bernstein 1973, 183). They are suffering under the dangerous illusion that censorship and secrecy can prevent knowledge about nuclear weapons from spreading to other nations. The only real secret was already revealed at Hiroshima. Once it is shown that nuclear weapons can be made, it is only a matter of time before other nations follow. The only hope we have in the nuclear age is to form an international system of government that will resolve future conflicts by international law.

Teacher: Isn't it impractical to expect nations to give up their right to settle differences by war and allow a world parliament to resolve disputes for them?

Einstein: Is it really a sign of unpardonable naiveté to suggest that those in power should decide that future conflicts must be settled by constitutional means, rather than by the senseless sacrifice of great numbers of lives (Ferris 1983)?

Teacher: But are you afraid of the absolute power that a world government could yield?

Einstein: Such a world parliament should consist of representatives elected from all parts of the world, and its power should be restricted by constitutional means. Because it will be the only organization with an international army, there will be some danger of the abuse of this power. But I fear even more the coming of another war that could annihilate humanity.

Teacher: Professor Einstein, if you were to look back over your life, what would you choose as the most important thing you have done for humanity?

Einstein: My dear friend, you ask the impossible! In my life I have been able to think a little bit about the secrets of nature and I have been honoured out of all proportion to my accomplishments. I have lived in a time that is distinguished by wonderful achievements in the fields of scientific understanding and the technical implications of these insights. But humanity must realize that knowledge and skills alone cannot lead it to a happy and dignified life. Humanity needs to learn to place the proclaimers of high moral standards and values above the discoverers of objective truth. What these blessed men have given us, we must guard and try to keep alive with all our strength if humanity is not to lose its dignity, the security of its existence and its joy in living (Dukas and Hoffmann 1979, 70–71).

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Mileva Maric and Albert Einstein: Unfulfilled Dreams

Mileva Maric was born just before Christmas 1875, in Kac, Serbia, which was then part of Hungary but later belonged to Yugoslavia. She was an intelligent child but not strong physically. She had a limp that caused her to be teased as a child.

Mileva's father, Milos, was especially supportive of Mileva and managed to get her admitted to the Royal Classical High School (for boys only), which focused on the physical sciences.

Mileva graduated with highest honours. She desperately wanted to continue her studies but few universities at that time admitted girls. The University of Zurich had admitted women students since 1865, so Mileva went to Switzerland and finished the Swiss-equivalent of high school by 1896. She entered the faculty of medicine, but after one term she switched to the Zurich Polytechnic University to study mathematics and physics. Her goal was to at least become a high school physics teacher. There were six students in her class, the youngest was a 17-year-old German student named Albert Einstein.

Teacher: Mileva, how would you describe your first meetings with Albert?

Mileva: During the first year, the six of us were in many in classes and labs together and I quickly saw that Albert had a deep interest in basic physics. He would sometimes be impatient with the slow pace of lectures, but we both enjoyed Professor Weber's classes immensely. We also discovered that we shared an interest in music, and he sometimes accompanied my piano playing on the violin. We also went on some hikes together with other students. However, I decided to leave Zurich after one year to continue my studies in Heidelberg.

Teacher: Why did you leave Zurich?

Mileva: I'm not really sure of the reasons. I went home to visit my family during the summer and I remember telling my parents about this interesting young student. My father gave me some tobacco to give to Albert, but since I was in Heidelberg, I couldn't give it to him personally. But I had no time for romance. I remember writing that there was no point in falling in love, given the state of the world at that time (Renn and Schulmann 1992, Letter 1). I do remember receiving a four-page letter from Albert in October of 1897.

Teacher: But you did return to Zurich later that year.

Mileva: Yes, even though I enjoyed my stay in Heidelberg initially, especially the physics lectures of Professor Lenard. But Albert kept writing to me, wanting me to return to Zurich. I finally decided to return to the Polytechnic Institute in April of 1898, and Albert lent me his notebooks and those of Marcel Grossmann and helped me catch up in my studies.

Teacher: Did your romance with Einstein progress during that year?

Mileva: Yes, I suppose it did. Our goals in life, our interests and even our emotions were so similar that we enjoyed each other's company a lot. I remember Albert writing to me once when he was visiting his parents—he said he had described me to his family and they teased him quite a bit.

Teacher: Did Albert's family object to your relationship?

Mileva: Yes, that became evident much later when they realized how serious Albert was about me. When his mother objected so strongly that I became discouraged, Albert wrote to me: "Have courage little witch. I can hardly wait to be able to hug you and squeeze you and live with you again" (Renn and Schulmann 1992, Letter 17). He would comfort me by promising that we would have a gypsy household in which we would both pursue physics problems together.

Teacher: Did you work on physics research together?

Mileva: That is a hard question to answer. My own feelings have gone back and forth on that issue. As long as Albert was happy and a member of our family, I was so proud of his achievements and not jealous, but when he began to distance himself from me and the children, it began to feel as if Albert had gotten the pearl from the oyster and I was left with the shell, as I wrote to my good friend Helena Savic in 1910.

Teacher: But isn't it true that Albert himself referred to the work on relativity as "our work"?

Mileva: At various times he did refer to our work together. For example, in 1901, when Albert was away visiting Michel Besso in Milan, he wrote: "I'll be so happy and proud when we are together and can bring our work on relative motion to a successful conclusion. When I see other people, I can really appreciate how special you are" (Renn and Schulmann 1992, Letter 25). On the other hand, even when we had just gotten to know each other in 1899, Albert was already convinced that electrodynamics had to be presented in a simpler way than it was in the old textbooks (Renn and Schulmann 1992, Letter 1).

Teacher: But you and Albert had extensive discussions about electrodynamics and other physics problems, correct?

Mileva: What made those days so wonderful is that Albert loved to discuss physics problems with me and with his other friends. In almost every letter, after a few brief endearments he would write about the progress he was making on these problems. In one letter, written around 1901, he wrote that he was appointing me his dear little scientist, and even after we were married he told a friend that he needed me because I solved all the mathematical problems for him. In those days, my own dreams of being a scientist and working with Albert had not yet disappeared.

Teacher: Is there a time when you felt that you would not achieve your youthful dreams of becoming a scientist?

Mileva: That again is a difficult question to answer. I failed my final examinations twice in 1901, the last time three months before our baby girl Lieserl was born. It goes to show that being a woman could be a serious handicap to a career in science; we are biologically prevented from devoting as much time as men to scientific studies. Other factors included being unhappy about Albert's parents' disapproval of our relationship, and neither of us finding a suitable position for several years.

Teacher: Did you and Albert decide to give Lieserl up for adoption?

Mileva: That's what people assumed, but it wasn't true. We left Lieserl with my parents for the first year. Even Albert was quite excited about having a daughter. He wrote to me when I was with my parents that he didn't want to give Lieserl up and asked me if my father could arrange for Lieserl to be with us in Switzerland (Renn and Schulmann 1992, Letter 45). Unfortunately, Lieserl developed scarlet fever when she was about a year old and, although we thought she would recover, she died later in 1903. I often wondered if I could have looked after Lieserl better, or if I should have taken her with me immediately to Switzerland, but we could not yet afford to get married, and we didn't have a suitable home.

Teacher: You and Albert did get married in 1903. Was it still a difficult time for you?

Mileva: No, Albert had just gotten a permanent job as a patent analyst in Bern and his father, on his deathbed, had finally given Albert his blessing to get married. It was a wonderful time for both of us. I remember writing Helena Savic, that I was, if possible, even more attached to my dear treasure than I was in our Zurich days (Popovic 2003, 83). I looked forward eagerly to his daily return from the patent office, and it was a pleasure to see him work hard at his physics research in the evening. And from time to time he asked me to check his mathematics because he was often in such a hurry that he would make some simple errors. We often met with friends on the weekends and accompanied each other musically.

Teacher: Was Albert as happy as you?

Mileva: Oh, yes. Albert even added a postscript to one of my letters to Helena and wrote: "Well, now I am a married man, and am living a very pleasant, cozy life with my wife. She takes excellent care of everything, cooks well, and is always cheerful."

Teacher: The year 1905 has always been regarded as Einstein's miracle year. Was it a great year for you, too?

Mileva: Oh, yes. I remember feeling proud of Albert, that all of his papers were accepted. However, it still took several years before the world seemed to take notice of them. I remember Albert being excited when Professor Planck sent one of his students to the patent office in Bern to talk to "this young Einstein." I do remember writing to Helena, however, that when I was sitting in our little apartment in Bern, I often used to dream of "sitting in Zurich in a certain room and am living my most wonderful days" (Popovic 2003, 89).

Teacher: I notice in your letters to Helena that around 1909 you begin to exclusively refer to Albert as "my husband."

Mileva: I hadn't noticed that. I just remember still being happy with my two children, Albert and Eduard. They were both wonderful boys, bright and talented—except that Eduard (Tete) was often sick and we had to be careful with him. My husband, I mean Albert, was extremely busy and becoming quite famous. I remember writing to Helena that I was happy for his success, but I hoped and wished that fame would not have a harmful effect on his humanity (Popovic 2003, 98). [Note: Tete was born in 1910]

Teacher: There are stories of Albert enjoying the company of other women. Did you find that his interest in other women hurt your marriage?

Mileva: I don't really want to talk about that. For the first six or seven years of our marriage, Albert seemed quite happy with his family life. I was also happy, even though my dreams of a student life had faded away, and my time taken up by caring for my family. I did feel jealous when my husband's fame made other women idolize him and flirt with him. Men are such weaklings at those times. But in 1912, Albert visited Berlin to meet with Max Planck and the other physicists, and he also met his cousin Elsa again. She was divorced already, and it didn't take me long to notice that she was strongly attracted to him, and she kept writing to him. Albert once wrote to her to tell her to stop writing, but she started again after a year. If we had stayed in Zurich, I think we could have remained a happy family.

Teacher: Why did Albert move from Zurich to Berlin?

Mileva: Ach, we first moved from Zurich to Prague and spent a year there. It was not a happy time for me because Germans in Prague looked down on Slavic people. I was very happy that we moved back to Zurich after one year. But then Planck and Nernst visited Albert and offered him a high position in Berlin, where Elsa was and the rest of Albert's family. We moved to Berlin, but it was quickly obvious that our marriage was at an end. Albert spent half his time at Elsa's, and I finally decided that I could not be happy in Berlin and took the boys back to Zurich.

Teacher: Was it hard for Albert to part from the boys and from you?

Mileva: I remember standing at the train, and all four of us were crying. I remember thinking, "Why is this happening to us? Why can't we be happy together?" But Albert mostly cried because the boys were going so far away. He had made it clear that he could not live in the same house as me unless I gave him complete freedom.

Teacher: Did Albert ask you for a divorce immediately?

Mileva: No, he assured me that he did not want a divorce and that he had no interest in marrying anyone else. But his family put lots of pressure on him to marry Elsa, so he did ask me for a divorce a few years later. I refused, and he seemed quite content with my refusal. They were difficult years for me and the children. Tete and I were often sick and because of the war we did not get much money from Germany. I had to do a lot of tutoring when I could, to make ends meet.

Teacher: You eventually divorced Albert in 1919.

Mileva: Yes. After the war ended, Albert's family continued pressuring him to marry—to regularize the relationship with Elsa so that it would be easier for Elsa's daughters to find husbands. I was tired of fighting at that time, and it wasn't good for the boys to have these tensions continue, so I finally agreed.

Teacher: Is it true that Einstein promised you the proceeds from the Nobel Prize if and when he ever won it?

Mileva: Yes. He had been recommended for a Nobel Prize before and it was only a matter of time before he would win one. I agreed because it would give me, Tete and Albert (as our son Hans Albert was usually called) some security in difficult times.

Teacher: This has been interpreted by some biographers as an admission by Albert that you made great contributions to his 1905 work on relativity and other subjects.

Mileva: I don't think Einstein intended people to make that interpretation. I did help with the mathematics at times, and we did have wonderful discussions about the topics, but I never did physics of the level of the Nobel Prize. I think Einstein wanted his boys to have a secure future and did not want to have to worry about sending us money from year to year. He had a high-enough salary in Berlin at that time, so he and his cousin did not have to worry about money either.

Teacher: Do you think that Einstein and Elsa had a happy marriage?

Mileva: No. I think Elsa was often unhappy. Einstein kept having affairs and didn't even try to hide them. I wrote to Helene Savic sometime in the early 1920s that I no longer had any feelings for Albert Einstein. In some ways, relations between us got even more cordial for several years around this time when Einstein came to visit the boys or take them on hikes. But our lives became more separated, and after he emigrated to the United States we never saw him again.

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The Past and the Future of Elementary Science Curriculum in Alberta

Anita Kamal

Introduction

Once it is accepted that we will educate our children and that this responsibility should be assumed by society as a whole, the question arises: who decides what to include in the curriculum? Of course this task has been delegated to experts from all disciplines, not only the discipline of education. But in final analysis, in a democratic society, it is us—the parents and the older generation—who come to this task politically, determined to do the best for our children, bringing our predispositions and, dare I say, prejudices (of which we may be completely unaware) into our decisions. Pratt, quoted in Tomkins (1986, 441), sums this up as follows:

> In a process that [is] essentially political, rational, arguments for change [are] of little avail. This suggest[s] that curriculum questions [have] some kind of deep psychic significance. A possible explanation [is] that people who [feel] that they had been relatively successful in life, the middle-class who [are] the most vocal critics of the schools, ascribe their success in part to their education. Accordingly they [seek] an education for their children as similar as possible to what they experienced a generation earlier. Support for curriculum change would suggest that their own schooling had in some sense been deficient. Hence their continued devotion to fractions and Euclidean theorems, Shakespeare learned by rote, predicates and subordinate clauses, lists of historical dates and outline maps of Europe . . . concerns relating to the liberal vis-à-vis the practical in the curriculum, and indeed to the very meaning of these terms, and to the socializing vis-à-vis the educating role of schools, [have] engaged policy-makers for more than a century. Throughout that period, the basic structure of schooling, curricula and teaching [have] remained remarkably stable.

As I dig through all things curricular, I am astonished at how Pratt's words are constantly reaffirmed. This paper is my exploration of the elementary science curriculum in Alberta, and I hope to develop it further. I was intrigued and took a closer look at this field after teaching elementary science for more than five years in the late 1990s. At the same time, I was also teaching biology at the junior high and high school levels, which threw my dilemmas more sharply into focus. Coming from a secondary science background, I found the elementary science curriculum a challenge—incoherent, fractured and without a holistic structure.

Curriculum, and the various disciplines and social factors that influence its development, is, of course, a large and complex area of research. Historic and contemporary political and economic forces, evolutions in developmental psychology, behavioral sciences and curriculum theory, as well as teacher training, have been and continue to be the major influences affecting changes. These factors interdigitate, affecting societal responses, which are reflected in educational curricula. Likewise, curriculum affects pedagogic practice, and evaluation and assessment philosophies and practices. Such a sweep is too broad for the scope of this paper. Here I survey the trends that have emerged in the elementary science curriculum in Alberta since the early 1920s and identify and discuss aspects of this curriculum that I believe need to be addressed and recontextualized. Such a historical re-evaluation may give direction for the future development of this curriculum so that it is more in line with current philosophical and epistemological thinking in the field of science education (Roth et al 2001, introduction).

To understand the directives that currently shape the elementary science curriculum in Alberta, we must continually remind ourselves of the various pressures, especially American and British, that have historically influenced and continue to influence developments in Canadian curricula (Tomkins 1986).

I believe that the elementary science curriculum needs serious revision. In considering the possibilities for these changes, I ask the following:

1. What was the elementary science curriculum in Alberta like in the past, and what societal forces brought it about?
2. What shape, content and thrust should the Alberta elementary science curriculum have?
3. What can we learn from the past about mistakes to be avoided and directions to explore?

Historical Context of the Alberta Elementary Science Curriculum

The 80 years of curriculum development in Alberta since the 1920s has produced an astonishing variety of ideas and innovations, often from within the field of curriculum itself, and influenced always by the social, scientific, political and economic spirit of the times (Tomkins 1986, chapter 10).

Alberta emerged from territorial status to become a province in 1905, but continued to use the program of studies it had inherited from its territorial days, which had been in place since 1892 (Tkach 1977, 175). Curriculum writing in the prairie provinces at this time consisted of simply selecting textbooks written and produced in Ontario (Tomkins 1986, 236). Legislators, preoccupied with the flood of homesteaders and the rapid growth of towns and cities, were not concerned with an education system that seemed satisfactory (Tkach 1977, 176). Nevertheless, a "belief that existing programs failed to give pupils a practical understanding . . . and the conviction that the quality of instructions . . . was sub-standard" led to demands for change (Tkach 1977, 483). However, the committee drawn up in 1910 to survey the curriculum, only recommended revisions to the organization of schools rather than changes to the curriculum itself.

Canada was, as is today, influenced by American and British educational theories. By 1915, the American term *progressive education* was heard and discussed in education circles, especially in western Canada. The same ideas under the title of *new education* were also coming to define education in Britain. Peter Sandiford, critiquing the traditionalist curriculum across Canada in 1915, found a curriculum "[of] remarkable uniformity," "seldom suggestive," "almost invariably prescriptive" and "frequently restrictive." Rarely was the curriculum "fitted to local conditions" (Tomkins 1986, 132).

The progressive ideas influencing educational thinking on both sides of the Atlantic were brought to public notice in 1916 with the publication of John Dewey's *Democracy and Education,* followed in 1918 by W H Kilpatrick's *The Project Method*, which demonstrated the practical applications of Dewey's philosophy (Tomkins 1986, 133). The project method is described as "a wonderfully purposeful activity," proceeding in a social environment that is "consonant with the child's own goals [that] would enhance learning through . . . positive reinforcement . . . and intended to serve Dewey's social purpose by creating a school environment more nearly typical of life itself than that of the traditional curriculum" (Tomkins 1986, 190–1).

The 1918 revision of the Alberta curriculum, although not containing substantive changes in program content from those of the 1892/1912 curricula, already saw the inclusion of this new philosophical thinking, "attention [being] paid to psychological considerations" (Tkach 1977, 272), with the injunction that "the skilful teacher will never lose sight of the fact that, while it may be necessary to adapt this outline to the ability and power of the pupil, the progress of the pupil should never be determined by the scope of the work herein assigned for each school year" (Tkach 1977, 273; and quoted in J T Ross, *Course of Studies for the Elementary Schools* 1918). This new program encouraged teachers to take individual differences into account, and an effort was made to incorporate this into the curriculum (Tkach 1977, 273). "The new course must be flexible and easily adaptable to the varying needs of the children of all parts of the Province" (Alberta Department of Education 1922, 6). The introduction to the elementary science course of study states:

> The chief criticisms of the old course centered around the quantity of material included, and the lack of specific direction. At first glance it may appear that the present course is open to the former objection. Such, however, is not the case. The committee is able to present a course closely related to the child's pre-school experience, having its basis in his every-day environment. (Alberta Department of Education 1922, 26)

The document goes on to encompass and expound on Dewey's pragmatic and progressivist philosophy, both as explanation and justification to the teacher, in the curriculum guide under the heading "Why Is Elementary Science Included in the Course of Studies?" and the thinking reflects concerns similar to those of today:

> Man cannot live unto himself alone. . . . His whole being is defined in terms of his environment. He must respect the laws which govern the world about him. To disregard them is to invite discomfort, inconvenience, loss, and even destruction. Narrow experience, limited knowledge, and faulty judgments lead to poor adjustments of the individual to his environment, and cater to ignorance and superstition. (Alberta Department of Education 1922, 27)

Under the heading "Method" (of instruction), the following advice is given:

> Free and informal discussion with the children on the various topics is suggested. The teacher should guide the discussion, encouraging the class to talk freely of their experiences and habits. They should be encouraged to ask questions as well as to answer them. (Alberta Department of Education 1922, 33)

The project method spawned a variety of project-centred, progressive curricula. Alberta, leader of educational innovation, introduced these into the school system following the 1922 curricular revisions. The Dalton Plan, for example, "was given a five year trial in Edmonton beginning in 1924" (Tomkins 1986, 191).

In the latter half of the 1920s, Alberta educators made "a systematic effort to create a theoretical base that would undergird curriculum change" (Tomkins 1986, 191). Two able and active educators, Fred McNally and Hubert Newland, in association with social reconstructionists like George Counts in America, "argued that school should take an overtly political stance and promote the building of a new social order" (Counts 1997; Tomkins 1986, 191).

The pressure for change in the elementary curriculum came from both the reconstructionists and the lay public, including two influential political groups, the United Farmers of Alberta and the Alberta Social Credit Party, both of which endorsed a more liberal and inclusive education (Tkach 1977, 382–84). This demand led to the incorporation of the project method into the Alberta curriculum under what was known as "experience education" (as it was known in the United States) or the enterprise method (which was similar in nature but developed in Britain). "A decade of discussion and limited experimentation" (Tomkins 1986, 194) came to fruition. In his 1934 annual report, the Deputy Minister of Education stated:

> The greatness of the Province will ultimately be determined by the type of education we provide . . . and the creating of an atmosphere within our schools that will serve well childhood, youth and manhood. . . . Education is not a means [to] livelihood it is a means to life. Our objectives have possibly been based too much upon the need for obtaining a living. . . . Mental attainments, subjects taught, and methods employed are means rather than ends. . . . Education is not a forced growth in the classroom . . . but is rather a self-developed process, a living of life in wholsomeness and fullness, and the process is continuous and lifelong (Tkach 1977, 385).

References to the enterprise method first appeared in the 1936 *Programme of Studies for the Elementary School*. "The name 'enterprise' [was] chosen to designate the 'doing or activity' [because] it has a stricter meaning than the more familiar 'project.' An enterprise is a definite undertaking" (Alberta Department of Education 1936, 288).

"The program incorporated the educational principles of some of the foremost curricularists of the time" (Tkach 1977, 387), and was supported by a formal announcement from the department of education that in the fall term of 1936, the "traditional school" would be replaced by the "progressive school" (Tkach 1977, 380). The major points of the philosophical base of this program, "in opposition to the traditionalist premise that "education is but a means of preparation for life . . . was founded on the belief that education is life" (Tkach 1977, 381). The major points may be summarized as follows:

1. Learning is not something that a child gets, but something that he does.
2. The school must respond meaningfully and purposefully to the child's call for things to do.
3. The natural way that children learn in their play life may be adopted by the school and redirected to educational objectives.
4. School learning embraces more than the knowledge and skills of traditional school subjects to include attitudes, ideals, abilities and so on.
5. The school program must provide for instruction in both the ways of life and how to live a normal life within the school.
6. The teacher will watch carefully and patiently for the learning outcomes of social activities and experiences.
7. It is both feasible and desirable to correlate many different learning units and consolidate them into studies or social activities (Tomkins 1986, 194).

School reorganization at this time brought about the rearrangement of the classes from the two-tier system of schooling to the current three-tier system. Grades 1–6 were designated as elementary school, Grades 7–9 as junior high school and Grades 10–12 as senior high school. Elementary school was further subdivided into two parts: Division I, comprised of Grades 1–3, and Division II, comprised of Grades 4–6.

The Alberta model of enterprise spread across Canada, and the province's curriculum revisions "between 1936 and 1940 have been called the high water mark in the acceptance of progressive education . . . in all of Canada" (Tomkins 1986, 194). Peter Sandiford regarded these changes as the "first major curriculum change in the province," but as Tkach notes, difficult political and economic conditions were the catalyst that spurred people to again consider change (Tkach 1977, 382).

The golden age of progressivism started to unravel, and even Dewey himself turned against the (mis)interpretations of his thinking, declaring it too child-centerd and unstructured (Tomkins 1986, 191). The curricular philosophies of the rational humanists—Franklin Bobbitt and Ralph Tyler—which invoked the use of the scientific method for constructing curricula and assessment tools, were becoming extremely influential in North America. The ideas and methods continue to influence curriculum, today reincarnated in Bloom's *Taxonomy of Educational Objectives* (1956). However, the 'enterprise' method, carried the seeds of its own destruction. The 1940 Programme of Studies for the Elementary School begins with the following paragraph:

> While no attempt has been made to set out a specific outline of organized subject matter in the field of Elementary Science, it must nevertheless be recognized that the present world is unintelligible to one who is ignorant of science and of its contribution to our modern world. Outlines of subject in logical detail tend to hamper rather than further the integration process . . . Elementary–science material will be employed in the enterprises as a *natural* part of a major socialized activity. Children do not come to school to learn Science *per se*.
>
> The enterprise method is one of the best illustrations of the scientific method in thinking. It is the scientific method, consisting essentially of a problem with a purpose. (Alberta Department of Education 1936, 57)

These statements gave almost total discretion about matter and method to the teacher but no direction. Many teachers felt threatened by, yet pressured to pursue, this radical method "at the instigation of a group of theorists" (Tomkins 1986, 196). Many of the enterprises became empty "show pieces" with little educational value. Indeed, a falling away of support for this radical program was beginning to be felt throughout the education system in Alberta. Two of the greatest obstacles to its success were a lack of proper teacher preparation in subject content and methodology, and a seriously inadequate supply of the materials and library resources required to support such a program. Then, as now, the education system was underfunded, but sufficient pressure, again coming from the public, forced curriculum revisions in 1940, including "a withdrawal of [the] new report card which [had] discarded grades, examinations, marks, passing or promotion" (Tomkins 1986, 196). To reassure the public, it was pointed out that the curriculum was made in Alberta especially for Alberta students and was not a foreign import. This was not completely true, and references to "enterprise" continued to appear in the curriculum until 1957.

Up to this point, teachers had not been given much direction beyond lists of suggested topics. Demand arose for the creation of structure so that the elementary science program would have a shape, a coherence and a firm foundation. A subcommittee to survey teachers' needs was struck in 1952 and came back with the following list of problems that teachers felt needed to be addressed:

- Lack of specific direction for developing scientific concepts at each grade level
- Lack of direction for incorporating the existing approaches:
  - Integrated teaching/learning, which was the enterprise method
  - Incidental/opportunistic learning
  - Parallel activities that took place in separate periods

Elementary science, health and social studies, continued to be combined until 1957. The programme of studies for 1940 stated:

> There should be no separation of science from health and social studies in the elementary grades. Elementary science material should be introduced as a natural part of a major socialized activity, and should make its contribution to general educational objectives in intimate relationship to other areas of learning. (Tkach 1977, 445)

The short list of only two major concept areas from the 1936 revisions—Living Things, and the Earth and the Universe—was extended with the addition of the Energy and Machines concept area. This change was included in the 1957 programme of studies. It can therefore be said that there was no great change in the elementary science curriculum in Alberta from 1936 until 1957, the year that the Russians launched Sputnik and the world entered the Space Age.

Although subject-centred curriculum reform had already begun (Tomkins 1986, 291), the western world, especially the United States (which was trying to understand the Russian coup in science and technology, and decided how best to address it), decided that educational expectations and standards had to be raised immediately (Tomkins 1986, 291).

> If Americans were to regain their superiority in the fields of "pure" and "applied" sciences, they would have to renounce the philosophy of education that they had adopted [since] the turn of the century . . . the progressive philosophy of education . . . which [had] sabotaged one of the principal objectives of schooling . . . academic excellence." (Tkach 1977, 460)

It was believed that social problems and the progressivist emphasis on group dynamics had de-emphasized the importance of basic skills and the traditional academic curriculum (Tkach 1977, 460). A meeting of leading scientists and educational psychologists was convened at Wood's Hole, Massachusetts, in 1959 to address the crisis in education. It was decided that children should be educated and trained to become "little scientists"—to think like scientists and problem solve like scientists. A modernistic, positivist, elitist and exclusionary system based on process skills was created (Tomkins 1986, 291). Jerome Bruner was one of the foremost educators to push for this new education in his book *The Process of Education*, which appeared in 1960. His theory had two aspects: presentation of hard-fact content, coupled with discovery or inquiry learning. This approach "was attractive because it promised to restore academic rigor to schooling and offered a solution to the problem of the knowledge explosion by reducing the complexity and clutter of unlimited quantities of information. The irony was that discovery/inquiry sounded very similar to the progressivist project/enterprise method" (Tomkins 1986, 291). The situation was considered so dire that funding to develop this program was provided to the American education system by the defense department. Specialized programs at the secondary level in biology (Biological Science Curriculum Studies, or BSCS), physics (Physical Science Curriculum Studies, or PSCS) and chemistry (Chemical Education Materials Study, or CHEM Study) were developed in the United Sates, and in the United Kingdom through the Nuffield Foundation. (These were not only used in local schools but were also widely sought throughout the developing world.)

Canadian educators were also concerned with the state of science education, especially at the elementary level, recognizing that it was "years behind the times and the content and methods of instruction were totally inadequate (Tkach 1977, 463). Northrop Frye went on to express concern about such a rigid and structured approach and the lack of consideration for what the true goals of education should be (Tomkins 1986, 292–93).

These external international pressures in part led to the 1963 changes in the elementary science curriculum. The objectives of elementary science (generalizations, problem solving, scientific attitude, interest and appreciation, store of knowledge and conservation) are not only listed (National Science Teachers Association 1963, 7–10), but each discussed at some length. This was also the first document to discuss the evaluation of the students, the teacher, the science done in the classroom and the school science program itself (p 14–15). The program had new sections dealing with space in the three major concept areas of Living World, Earth and the Universe, and Energy and Machines, mainly at the Grade 6 level (Tkach 1977, 464–74).

A clear and coherent structure of this new science program is presented in the 1968 *Alberta Program of Studies for Elementary Science* (Alberta Department of Education 1968, see Appendix 1). The two fundamental areas of emphasis of this program were

- the development and use of inquiry skills, and
- the development of basic science concepts.

This was to be accomplished within six major conceptual schemes, including matter, energy, life and the universe, and change and conservation in the interactions in and between these spheres (p 33). There were no further changes until 1990, when science was divided into science inquiry and problem solving through technology. Also in 1990, both the high school and elementary curriculum formally recognized technology's influence on society. This was done in high school through a science–technology–society (STS) component and in elementary curriculum by emphasizing problem solving through technology (Alberta Department of Education 1990; 1996, A4). No further changes to the elementary science curriculum have been made to the present (2003).

Organization of Topics within the Concept of Elementary Science in the Alberta Curriculum

While not discussing this topic at length, it is useful to see what topics have been included in elementary science over time, consider them from a historical perspective and consider the philosophical and political suasions that brought them about. I have compiled two sections (Appendix 1): Language Used in the Curriculum Writing, and Goals of Elementary Schooling, which I quote at length from the contemporary Alberta government publications, and which give an overview of elementary science.

In 1922, elementary science included nature study, geography and health (physiology and hygiene). Agriculture was included in the upper two grades (Alberta Department of Education 1922, 26).

In the 1936 curriculum, elementary science was only combined with health education; the two subjects were considered complementary. This was also the year when enterprise as a radical, hands-on program was introduced (Alberta Department of Education 1936, 144).

The 1940 curriculum designated the program of studies for elementary school as an "activity programme," and it was divided into two parts: subjects (reading, language, arithmetic, physical education, art and music) and integrated sequence (social studies, elementary science and health). Elementary science, health and social studies were further integrated under the general theme of basic human needs. The enterprise program continued (Alberta Department of Learning 1940, 27).

In 1963, science became a discipline in its own right. Material about space travel was included in the Grades 4–6 curriculum. The enterprise method continued (National Science Teachers Association 1963, 5).

A major revision occurred in 1960. The program was put onto a more scientific footing, emphasizing inquiry skills and the development of basic science concepts

> A modern science program emphasizes inductive modes of inquiry . . . contrasted with much science teaching in the elementary school, which has science as dogma. . . . The difference stems from ones' definition and view of science. . . . [If] science is regarded as an active process for acquiring

> knowledge about the world, curricula must be designed to bring the learner into a direct encounter with this process. (Alberta Department of Education 1968, 4)

Another change came in 1980/1983 (the program was formally revised in 1980)—the program was set up on a core–elective format. The core component (taking 60–70 per cent of time) consisted of skills, concepts and attitudes that all students must learn. The elective component allowed teachers to choose from a list of topics, components that would enhance learning for their particular students (Alberta Department of Education 1982, C1).

In 1990, the science program was divided into two parts: science inquiry and problem solving through technology—recognizing for the first time that technology, being an integral part of society, should be recognized in the curriculum. STS was also formally introduced into the senior high curriculum. Although the elementary curriculum has undergone revision in other areas, elementary science has not been changed in any substantive way since 1990, and the same curriculum is still in place in 2003.

This brief overview shows how stable and resistant to change the science curriculum has been through all the philosophical changes of the last 80 years.

Language Used in the Curriculum Writing

Important changes to the curriculum can be traced from 1922 to the present through the language used to present the curriculum. The move has been from a generalized language that implies a moral good to a depersonalized imperative. The overtone that learning is a moral good, both for the individual and society, is emphasized through the use of conditional verbs (such as *should*). More recently, the language has become more detached and imperative when emphasizing the expected outcomes for the individual learner, for society and for work, resulting in a switch to the imperative verb *will* (see Appendix 1). The tone has shifted from the question "What should students learn?" to "How should intended learnings be stated?" in an attempt, in the interests of efficiency and accountability, to make the objectives of classroom, school, district and province congruent (Tomkins 1986, 311).

The objectives have become more tightly defined. Skills and attitudes have become more numerous and specific.

Goals of Elementary Schooling in Alberta

The goals and aims of elementary education, as they have been articulated over the 80 years in this overview, have also changed. These changes are also recorded in the language used, the emphases made to the teacher, the learner and the reader, and the inferences that each one is directed to draw. To illustrate, consider the goals as published in the current program of studies.

Program of Studies for Elementary Schools

Program Foundations

Under this umbrella heading is the subheading Alberta's Learning System, below which appear the topic headings Vision, Mission and Goals (a footnote explains that this entire section is taken from Alberta Learning's *2001–2004 Business Plan*.

Goals

"The goals for Alberta's learning system outline government's ongoing aims and directions over the long term. To maintain a high-functioning society and prosperous economy, Alberta's learning system must

1. provide quality programs that are responsive, flexible, accessible and affordable;
2. enable learners to demonstrate high standards;
3. prepare learners for lifelong learning, work and citizenship;
4. develop and maintain effective relationships with partners; and
5. operate responsively and responsibly.

These five goals support government's core business of people, prosperity and preservation, and related goals."

The language here is impersonal, and references to direct human contact are absent. The goals are described in language that is so vague and general that it is practically meaningless. What is a "learning system"? What exactly is meant by "ongoing aims over the long term," and "high-functioning society"?

The imperatives are given that Alberta's learning system must "provide quality programs that are responsive [and] "flexible," and that "enable learners to demonstrate high standards." None of these descriptors are defined or explained. And what exactly is meant by the imperatives that "Alberta's learning system must . . . develop and maintain effective relationships with partners"? Who might these partners be? What might their interest in education be? And what is the meaning of the final sentence? If these are the goals of Alberta Education, then they must be seriously questioned by everybody in education or concerned with education.

Summary of Trends in Education in North America Since 1920

Each generation believes that it is faced with different political and economic problems than those faced by previous generations, yet a backward glance at the trends, tensions and pressures in the emergence of the elementary sciences curriculum in Alberta shows that the project of education is conservative; changes come slowly. Politics, together with economics, may have a stronger influence on education than educational theorists and philosophers.

Three educational perspectives have influenced curriculum development over the last 80 years: the progressivists, the behaviouralists and those in-between. Two opposing views of the child and of curriculum arose in the 1920s and 1930s and still influence educational thinking today, certainly in North America. On one side, the progressivists, philosophically aligned with Dewey and Kilpatrick, emphasized a child-centred, experiential, project-oriented method of learning. The contrary position was presented in Franklin Bobbitt's famous *How to Make a Curriculum*, published in 1924, and resulted in the minute objectification of every step in the learning processes (Bobbitt 1997). This notion was reincarnated in the 1960s in Bloom's *Taxonomy of Educational Objectives*, based on classifying and measuring overt behaviours. Skinnarian behavioural modification and Piaget's idea of stages in child development are still applied in early childhood education under the rubric of developmentally appropriate practice (DAP), which states that children need to reach certain maturation levels before learning certain concepts. The middle ground in curriculum writing—the ends justifying the means—was taken up by Ralph Tyler in his *Basic Principles of Curriculum and Instruction* (1949), a seminal work that still influences curriculum writing and lesson planning.

Russia's launch of Sputnik caused a paradigm shift in the perception of and relationship to the self, the other and the universe. The educational response in general was narrow and backward looking. For the next 15 years in most western countries, students struggled while being formed into "little scientists," not for their own benefit or their own understanding, growth or development, but for political imperatives. Jerome Bruner's *The Process of Education* (1960) influenced a generation of students on both sides of the Atlantic, spawning such science programs as BSCS, PSCS and CHEM study in the United States and the Nuffield Foundation programs in the United Kingdom, which were widely sought by governments around the world, especially from the developing world, as they scrambled to stay abreast in the knowledge race.

The 1968 Hall-Denis Report from Ontario, *Living and Learning*, suggested in flowery language that the truth of learning was powerfully liberating ("the truth shall make you free"). However, the question is, whose truth (Tomkins 1986, 302)? Thomas Kuhn had just published the first edition of *The Structure of Scientific Revolutions* in 1962, in which he showed that by historical precedent there is no set scientific method (the premise on which school science programs were based), that science proceeds in leaps or paradigm shifts as old theories are abandoned and new ones come into vogue, and that knowledge is socially created instead of discovered by individual scientists. Paul Feyerabend held similar anarchistic views, which he published in 1975 in the now-famous *Against Method* (Chalmers 1999). Truths were partial and changeable, and answers were always contextual and contingent. Knowledge was no longer fixed but socially constructed. Feyerabend declared that method was dead and that all form of knowing, including witchcraft, have equal validity. Philosophically, he had moved science from an isolated and solitary world (*I*) to a shared world (*we*); practically, we were in the cold, calculating and selfish world of Thatcher and Reagan (the world of *me*). It was the beginning of globalization.

The failure of progressivim and scientism, which influenced not only school science but also other subject areas in the curriculum, provoked a flurry of books, from Bloom's *The Closing of the American Mind* to Postman's *Amusing Ourselves to Death*, that addressed the problem and voiced the dangers of losing academic rigour in curriculum and of drowning in the soma of media pap.

This coincided with the globalizing moves of multinational and transnational corporations, the economic and political philosophy, and the fallout that we are currently experiencing. Nation states lost their power to control policy directions to economic interests, thereby coming under the political influence of multinationals, the World Trade Organization (WTO) and the International Monetary Fund (IMF). Politics became expedient as workers were groomed to fulfill the needs of mobile job markets and as nation states fell under constraints imposed by the WTO and the IMF. In the Caribbean and Latin America, "under the Structural Adjustment Policies of the IMF and World Bank, spending in the poorest 37 countries declined 25 per cent between 1984 and 1994. Costa Rica . . . once had the highest literacy rate in the Caribbean, due largely to a public education drive. . . . In 1981 the government was given an IMF loan on condition that education expenditures be cut" (Smith 2002, 63). Mexico has suffered even more severely—the public education system is being dismantled and industry–school partnerships are creating an education that serves the needs of industry. Educators in a province like Alberta, which is heavily dependent on the export of energy, especially to the United States, must be aware of these trends. The Alberta government is moving rapidly to privatize much of the public sector, including healthcare and education. The language of the curriculum (the "bittification" of the curriculum), at least in science, is turning it once more into a training ground for future workers. The curriculum language employs the same time-and-motion and quality-control techniques that Bobbitt used 80 years ago. Are we destined for another round of vocational education? The previous programs had flaws and problems, including not providing authentic work experiences (Tomkins 1986, 301–2). The current economic policies are increasing the disparity between the poor and the middle class, educationally as well as financially (Tomkins 1986, 282). How can this gap be narrowed? Questions must be asked—not only "What is the future of education in Alberta?" but "What should the future of education in Alberta be?"

Future Directions for Elementary Science in Alberta?

My personal involvement teaching elementary science for Grades 4–6 led me to ask many important questions. They rise from Spencer's phrase, "What knowledge is of most worth?", which can also be rephrased as "Whose knowledge is of most worth?" and "For whom is this knowledge of most worth?" My elementary teaching experience was not in a regular elementary classroom, but in a school that had specialist subject teachers teaching only their specialty. Here are my questions:

1. Should children in elementary school be taught science at all?
2. Who should teach science—only the teacher or members from the community as well, including professionals? How much liaison and partnering should there be between the school and any part of the outside community?
3. In what ways can and do business partnerships with schools affect curriculum? What are the dangers?
4. What exactly should be taught and why? For example, why do elementary children have to learn the parts of an airplane, and how the ailerons move and how the plane reacts in each case? Why do problem solving skills have to be taught in the framework of solving crime? Has education sunk to the lowest common denominator of entertainment? Children should be interested in the subject, but, without sounding moralistic or patronizing, there must be better things than crime to use as an educational vehicle.
5. What are the pros and cons of teaching the disciplines (life sciences, physical sciences and earth sciences) separately or at the same time?
6. Is it better to give a lot of time (a term or a school year) to a particular subject on the grounds that it gives a more holistic view of that particular aspect of science, allows for an unhurried development of the subject (depth not breadth), and allows for the

digressions of interest that will arise from time to time, or is it better, as now, to have short units devoted to relatively unrelated topics that give some breadth but little depth?

7. Should the elementary curriculum include science, technology and society (STS) and science, technology, society and environment (STSE) components? STS has been used as a vehicle for teaching and learning within context for at least 30 years. This method is aimed at involving both students and teachers in discussing and planning directions and topics of study, which integrates real-life situations and experiences into the classroom (National Science Teachers Association 1993; Yager and Roy 1993; Zoller 1993).
8. What training should an elementary teacher who is certificated to teach science be required to have? This has been a problem right from the beginning. Normal schools were only closed in Alberta in 1946, when a university-degree program was finally put in place (Tomkins 1986, 245–420). Currently in Alberta, an education student fulfilling Alberta Education requirements only needs a half-course in science to be qualified to teach science. I am told that more than 90 per cent of these students also take an elementary science methods course voluntarily. Is this a satisfactory state of affairs? What could and should be done?
9. If STS is already being put into the curriculum (as the "problem solving through technology" emphasis indicates), do teachers have adequate training to cover this aspect of teaching the elementary science program (Benson 1996)?
10. What are the pros and cons of the following spiral programs?
    - An elementary curriculum that is composed of two complete cycles: Grades 1–3 and Grades 4–6, repeating each component (life sciences, physical sciences and earth sciences) at increased levels of difficulty, one year each
    - Same as above, but with the sequence repeated every year (one component per semester)
11. Should science and technology be taught in parallel? The United Kingdom elementary program teaches design and technology separately from (pure?) science, as well as a third parallel strand of information and communication technology.
12. Should elementary children be taught by subject specialists because
    - a specialist teacher knows the subject much better that a generalist and can therefore anticipate problems and solutions, and give more insightful explanations and experiences to the students;
    - it is good for children to meet with several people on a daily basis and not be reliant on the knowledge and perspective of only one adult in the classroom;
    - team teaching works well for the elementary grades; and
    - we should be wary of the status quo?

All of these questions need to be answered, and although their range is wide and demands several research papers, they all pertain to curriculum. Curriculum can be defined as all the experiences that a learner encounters. Curriculum is indeed lived.

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Appendix 1

This appendix consists of verbatim quotes from the identified documents.

I: Language Used in the Curriculum Writing

1922

(*Course of Studies for the Elementary Schools of Alberta: Part II* 1922, 28)

The Aims in Elementary Science

- The child must be made conscious, early in his career, that he is part of a great system, into which he must fit . . .
- He should be made to feel a personal responsibility to his neighbor and to his environment . . .
- An attitude of reverence should be developed, and a soul-appreciation of the charm of nature born . . .
- A definite store of information should be acquired which would have utilitarian value "in a social way, in his reading, and in his interpretation of life situations . . .
- These data will serve the additional end of being of immediate value in establishing bases upon which to build the superstructure of science in later years . . .
- It is fair to expect that the work in elementary science should lead to the formation of certain scientific habits; for example the habit of looking for things, the habit of withholding judgment until a broad basis of experience or data has been secured, the habit of in experimentation and investigation, and frame of mind which will tolerate nothing but truth.
- Elementary science may be said to have, in the final analysis, an ethical end

1936

(*Programme of Studies for the Elementary School: Grades I to VI 1936*, 145–46)

Elementary Science: Aim and Procedure

1. The aim of this course is to help the child orientate himself [*sic*] amidst the natural phenomena of his environment. The objective for the child is scientific understanding. In the traditional approach to elementary science through "nature study," the motivation of "wonder" led to the nature myth, personification and anthropomorphism, rather than to intelligent enquiry and a scientific attitude. It did little to establish in the child's mind the

broad principle of cause and effect, which, as civilization advances, replaces belief in magic, astrology, and superstition. *In this course, the child begins to attain scientific understanding through his own observations, activities, and attempts to solve problems*.

2. As the children solve problems, and in so doing arrive at the notion of cause and effect, they will also learn that *man's conception of truth changes.* Once man believed that a fact is a fact for all time; but now man knows that what appears to be a fact today may be modified by the discoveries of tomorrow. Hence the teacher will not suggest to the pupils that his words are infallible. He will co-operate with his pupils, helping them to realize that their solution of a problem may be modified in the light of more evidence. He will accustom the pupils to compare their conclusions with the conclusions of others who have worked on the same problem; and to examine, when authorities are referred to, *whether the authorities used the scientific method and stated their evidence*.
3. The scientific method—For the elementary school, the scientific method is the method of solving problems by experiment, there are seven steps in an experiment, whether it is used as a group activity, an individual activity, or a class demonstration. They are as follows:
    1. Problem
    2. Apparatus or materials
    3. Method or procedure
    4. Observation or results
    5. Conclusion
    6. Verification
    7. Application

[Note: Points 1–7 are accompanied by explanatory notes which I have omitted.]

1962

(*Program of Studies for Elementary Schools of Alberta* 1962, 24)

Objectives

Science is a method of discovering new facts and seeing new relationships, solving problems and satisfying curiosity. As the child proceeds through elementary school, science should help him [*sic*]

1. know some generalizations or science principles that he can use in solving problems in his environment,
2. grow in ability to solve problems effectively,
3. develop a scientific attitude and think critically,
4. develop an interest in an appreciation for the world in which he lives,
5. build an ever increasing store of useful scientific knowledge and
6. develop an ever-broadening appreciation of the need for conservation.

1968

(*Program of Studies for Elementary School of Alberta* 1968, 33)

Objectives of Science

The new elementary school science program has two fundamental but inseparable objectives. By emphasizing the development and use of inquiry skills as tools of investigation, the program is designed to enable the student to become and dynamic investigator of science. To have the student develop basic science concepts is a second aim. A number of concepts, that is abstract ideas generalized from particular experiences, are to be developed under each of the six major conceptual schemes which provide a framework and structure for the program at each grade level.

1. Objectives: Skills

As a result of science instruction, the elementary school pupil should

a. develop the ability to inquire, i.e. ability to think and investigate science through the use of process skills (behaviours) such as observing, classifying, communicating and inferring.
b. demonstrate manipulative skills in the use of apparatus in order to conduct investigations.

2. Objectives: Attitudes

Much of the spirit and meaning of science is transmitted to students from the teacher. The teacher must create conditions of learning that will enable the student to

a. demonstrate a growing curiosity and interest,
b. demonstrate intellectual honesty,
c. be open-minded,
d. look for cause-effect relationships and
e. suspend judgement when data is inadequate.

3. Objectives: Concepts

As the student proceeds through the elementary school science program, he [*sic*] should develop an increasing body of scientific information in the form of concepts.

1982

(*Program of Studies for Elementary Schools* 1982, B1).

Science: Goals and Objectives

The elementary science program is designed to contribute to the achievement of the overall objectives for science in Alberta.

1. To develop the ability to inquire and investigate through the use of science process skills.
2. To promote the assimilation of scientific knowledge.
3. To develop attitudes, interests, values, appreciations, and adjustments similar to those which are recognized as appropriate to the scientific endeavour.
4. To develop an awareness and understanding of the environment with positive attitudes and behaviours toward its use.
5. To develop an awareness of the role of science in the causes and resolution of some current social problems.
6. To promote awareness of the humanistic implications of science.
7. To promote an understanding of the role that science has in the development of societies and the impact of society on science.
8. To contribute to the development of vocational knowledge and skill.

1990/1996/2001/2002

(*Program of Studies: Elementary Schools* 1990/1996/2001/2002, B1–B33)

Learner Expectations

II: Goals of Elementary Schooling

1922

(*Course of Studies for the Elementary Schools of Alberta: Part II* 1922, 5–6)

It is the function of the curriculum to put children in possession of their great intellectual heritage. This can be best interpreted to the child when it is regarded as a summary of the sole solutions of its various problems which the race has devised up to the present moment. It must however do more than this. Not only must the child be made acquainted with the steps by which we have won our present position, but it must be assisted to an intelligent participation in the various activities inevitable to our present social organization . . . conscious curriculum making implies the intentional selection of materials and activities which together, will result in desirable changes in behaviour and the development of wholesome attitudes and ideals. Such is the point of view from which the course has been written. The Minister of Education adds:

> The Department . . . must determine the subjects which are of most worth to Alberta boys and girls. It must plan a course which will make any other than thorough work and development of habits of industry impossible, no matter what subjects have to be sacrificed . . . the curriculum must be made to contribute its full share to the development of character, tight attitude and good citizenship in Alberta youth.

1940

(*Programme of Studies for the Elementary School (Grades I to VI)* 1940, 3)

Aims and Objectives of the Elementary School

1. To facilitate the child's progressive orientation in the life of which he is a part
2. To provide an environment that sustains growth and development
3. To promote social adjustment
4. To develop desirable attitudes, ideals and appreciations
5. To develop necessary skills, and to impart information
6. To promote health, both physical and mental
7. To supply objectives and activities suitable for children's leisure

1965

(*Program of Studies for Elememtary Schools of Alberta* 1965, 4–5)

Objectives of Education

The major purpose of elementary education is to foster the fullest development of each child's potentialities. Direction for this development is provided by the behavioural goals listed below:

I: Abilities and Skills

Each child should increase his capabilities to

1. communicate with others orally and in writing;
2. listen;
3. read;
4. find, organize and use information;
5. use numbers and mathematical processes effectively;

6. solve problems of a social and scientific nature;
7. express himself through artistic media;
8. maintain health;
9. function as a wise purchaser and consumer; and
10. maintain concentrated efforts in accordance with native ability and natural maturation.

II: Understandings

Each child should learn to recognize the significance of

1. the social life of expanding communities,
2. the interdependence of all forms of life,
3. the effects of environment on human life,
4. man's increasing knowledge of social development and social control,
5. man's increasing control over nature,
6. the contributions of the past to the present,
7. democracy as a way of life and
8. responsibilities inherent in a democratic way of life.

III: Attitudes

Through suitable experiences each child should be helped to develop:

1. Self-respect—marked by control, discipline and direction through his own initiative
2. Creativeness—marked by personal expression that becomes unique and revealing
3. Scientific viewpoint—marked by the power to delimit problems, search for data, weigh evidence, form conclusions, and above all to evaluate his judgment in the light of subsequent events
4. Co-operation—marked by consideration for the rights and feelings of others and a willingness to share
5. Responsibility—marked by readiness to carry tasks to completion, to behave honestly with himself and with others, and to accept the consequences of his own actions
6. Social concern—marked by earnest effort to implement whatever desirable ends his group may seek
7. Reverence—marked by a conviction of Deity, and a regard for His supreme handiwork, mankind

IV: Appreciations

Through suitable experiences each child should acquire an appreciation of

1. the dignity, worth and possibilities in the individual, reflected in a high standard of conduct for himself, and a high regard for other people and their values and beliefs;
2. the dignity, value and achievements of work in science, in religion, in philosophy, in art, in literature, in craftsmanship, in honest labour everywhere; and
3. the manifestations and beauties of nature—both in the natural state and as revealed through science.

1975

(*Program of Studies for Elementary Schools* 1975, 1–3)

Goals of Basic Education

In a world characterized by rapid change, yet counterbalanced by stabilizing influences, education must provide opportunities for students to meet individual and societal needs. This statement of goals is intended to give direction for Grades I–XI which will assist in meeting that dual set of needs.

As the variety among individuals and societies is broad, no attempt is made to place the goals in any order of importance. Such priorities might more appropriately be made at system or school levels. Despite the absence of stated priorities, none of the goals are to be deleted but complementary goals may be added.

In this regard, goals concerning the relationship of people to a deity will have special significance for certain populations. Other goal areas may be of prime interest to other groups. Nevertheless the goals which follow, combined with such complementary goals as may be deemed necessary, form the basis for directing the educational endeavours of schools and school systems.

Finally, subsections under each goal are not meant to be inclusive but indicative of the intent of the goal. [Note: I only list the headings of the 12 areas.]

1. Learn to be a good citizen.
   a. Develop an awareness of civic rights and responsibilities.
   b. Develop an understanding of the Canadian and other forms of government.
   c. Develop feelings of cultural identity and heritage at national and international levels.
   d. Develop an attitude of respect for public and private property.
   e. Develop an understanding of the obligation and responsibilities of Canadian and world citizenship.

2. Learn about and try to understand the changes that take place in the world.
    a. Develop the ability to adjust to the changing demands of Canadian society.
    b. Develop an awareness of and the ability to adjust to a changing social and physical environment.
    c. Develop understanding of the past, identity with the present and the ability to meet the future.
3. Develop skills in communication (listening, speaking, reading, writing, viewing).
    a. Develop skill in understanding the communication of others.
    b. Develop ability in communicating ideas and feelings effectively.
    c. Develop skill in oral and written language.
4. Learn how to organize, analyze, and use information in a critical and objective manner.
    a. Develop ability to organize information into meaningful categories.
    b. Develop ability to apply scientific methods in the pursuit of and analysis of knowledge.
    c. Develop skills of thinking and proceeding logically.
5. Learn to respect and to get along with people of varying beliefs and life styles.
    a. Develop appreciation and respect for the worth and dignity of individuals.
    b. Develop an understanding of functions, responsibilities and achievements of various societal institutions.
    c. Learn to take into account the values of others when making personal choices.
6. Learn about the world of work.
    a. Develop a feeling of pride in achievement and progress.
    b. Develop the ability to use information and counselling services related to career decisions.
    c. Develop skills basic to the world of work.
7. Develop management skills.
    a. Develop an understanding of economic principles and responsibilities.
    b. Develop skills in managing natural, financial and human resources.
8. Develop a desire for learning.
    a. Develop intellectual curiosity and eagerness for lifelong learning.
    b. Develop a positive attitude towards learning.
9. Learn to use leisure time.
    a. Develop interests which will lead to a wise and satisfying use of leisure time.
    b. Develop a positive attitude toward participation in a range of leisure time activities—physical, intellectual and creative.
10. Practice and understand the ideas of health, fitness and safety.
    a. Develop an understanding of good physical and mental health practices.
    b. Establish a good physical fitness program.
    c. Establish sound personal health habits.
11. Appreciate culture and beauty in the world.
    a. Develop creative self-expression through various media including the fine and practical arts.
    b. Develop special talents in the arts.
    c. Cultivate appreciation of beauty in various forms.
12. Develop basic and special knowledge competencies.
    a. Develop understanding and skill in the use of numbers, natural sciences, mathematics and social sciences.
    b. Develop a fund of information and concepts.
    c. Develop special interests and abilities.

1982

(*Program of Studies for elementary Schools* 1982, vi)

Purpose of the Elementary School

All three levels of schooling have a common purpose in that they share responsibility for achieving the goals of schooling and education. At the same time, the mission of each school level differs from the other two in terms of the emphasis given the various goals as well as in the program selected to achieve that mission. For this reason the purpose of elementary schooling can be considered unique. It consists of providing opportunities for students to

- develop an appreciation for learning,
- acquire fundamental learning skills which will enable them to progress to more difficult learnings,
- acquire the requisite social skills which will enable them to function effectively both in school and in the community and
- develop certain desirable attitudes and commitments towards themselves, their peers and the world as they know it . . . these five statements constitute the mission or purpose of the elementary school.

1990/1996/2000/2002

(*Program of Studies: Elementary Schools* 2002, 2)

Program Foundations

Under this umbrella heading is the sub-heading: Alberta's Learning System, below which appear the topic headings Vision, Mission, and Goals, and this whole section is taken from the *Alberta Learning 2001–2004 Business Plan*.

Goals

The goals for Alberta's learning system outline government's ongoing aims and directions over the long term. To maintain a high-functioning society and prosperous economy, Alberta's learning system must

- provide quality programs that are responsive, flexible, accessible and affordable
- enable learners to demonstrate high standards;
- prepare learners for lifelong learning, work and citizenship;
- develop and maintain effective relationships with partner; and
- operate responsively and responsibly.

These five goals support government's core business of people, prosperity and preservation and related goals.

Electricity

Frank Weichman

Introduction

As some of you may know, I go to local schools on occasion with boxes full of science toys and do a show-and-tell about electricity and magnetism. The call comes mostly from Grade 5 teachers when they are ready to present material on simple circuits. My presence is requested, usually through the Edmonton Science Outreach Network, for many reasons. In some cases the teachers feel unsure about the material they have been teaching and would appreciate some reinforcement from an "expert." Some just like to have access to the demonstration material, which I can bring along from our physics department. Some just want their students to meet a real scientist who might be able to interest them in scientific matters.

I have come to realize that students, and sometimes teachers, have little understanding of voltage and current. What are they? Are they dangerous? For example, is 1,000 volts dangerous? The school board limits experiments to what can be done with 1.5-volt batteries. Do they know walking on a carpet in a dry room generates electric sparks that are greater than 1,000 volts?

I will present in this article an analogy that is accessible to students and their teachers, and that will help them understand the basic ideas of voltage, current and resistance. By the end of this article, the use of this and other analogies will become clear, as will the dangers of pushing the analogies too far.

The Ski Hill

Electricity flow is often compared to water flowing through tubes. Pumps are the analogy of choice for the battery. It is difficult to squeeze water through narrow tubing because it has more resistance to flow than wide tubing. I propose a different analogy—that of a ski hill. The ski lift is the battery, the trails and open slopes are the conducting wires, and the skiers are the particles of electricity that flow through the circuits. Follow along with me and see how it helps explain many electricity phenomena, and how it eventually gets us into trouble.

The Battery and the Ski Lift

In the analogy of the ski lift as a battery, what role does voltage play? The height (or "the vertical rise" in skiing terms) of a lift is a valid analogy to the voltage of the battery. For example, a 9-volt battery will have six times the vertical lift of a 1.5-volt battery. However, there are many different-sized 1.5-volt batteries, designated as D, AA or AAA, in order of decreasing physical size of the battery. Where does that fit into the ski-hill analogy? If two lifts have the same vertical rise but are powered by motors of different physical size, the one with the bigger motor will be able to lift more skiers per hour (if you want to pull up more people, you need a bigger motor). Look at it in a different way. Suppose you had a 9-volt battery that was identical in volume to a 1.5-volt battery. According to the ski-hill analogy, the ski-lift equivalent to a 9-volt battery would bring skiers up the hill at six times the height. However, because the motor is the same physical size as the lower lift, it could only take 1/6 the number of skiers in the same elapsed time.

Current

In the analogy, the current in an electrical circuit is the number of skiers moving up or down the hill during a given time interval. This is not as obvious because at a given moment the number of skiers being pulled up may be quite different from the number going down (when the lift opens in the morning, a lift full of skiers is heading up but no one is coming down yet). This is a non-equilibrium situation, and it does have momentary equivalents in electricity flow. A similar situation (lots going up, nothing going down) could occur at lunchtime at if there is a cafeteria partway up the slope. The lunchroom is a storage facility. A capacitor in an electric circuit plays a similar role. It can store electric charge for future release. Before the analogy gets too complicated, let us return to equilibrium situation, with a steady flow up and a steady flow down, and the two being equal. We also still have to clearly define what we meant by "flow."

What factors determine the flow of skiers?

1. The capability of the lift—With no lift, there are no skiers going up and skiing down (except the few cross-country skiers that might climb up the hill and ski down again, but those we will ignore).
2. The number of skiers on the hill—The more skiers, the more "flow." However, if the number of skiers exceeds the lift capacity, the skiers have to line up to wait their turn at the lift.
3. The type of skiers—Are they beginners, snow bunnies or world-class competitors?
4. Steepness of the hill—Good skiers will go faster down a short, steep slope than a long, gentle slope.
5. The conditions on the hill—Is it fast and easy to ski down, or are the trails long and narrow? Is the slope icy, or does the skier have to deal with deep, heavy snow?
6. A special case of conditions on the hill—Suppose the hill is in excellent shape except for a short stretch that everyone has to pass through on the way down. This area will be congested, with rocks, ice or obstructions. Caution prevails and all skiers slow down.

All the above points are valid on a ski hill. What are their counterparts in the electric circuit? I'll go point by point.

1. The lift capacity is stated in numbers of skiers per hour—let's say it's 1,000 skiers per hour. Regardless of the number of skiers or the conditions of the hill, the average flow cannot exceed 1,000 skiers per hour. A battery has a voltage output, which can be compared to the vertical height of the lift, but it also has limitations in current output. Physical size (volume) limits the output current because chemical reactions that produce the current need space and time to separate the charges.If there happens to be a day when there are no skiers (perhaps there's a hockey game on TV, or it's bitter cold), then no matter what the lift might be capable of or how good the snow conditions are, there will be no flow. The lack of skiers is analogous to the electrical insulator in which there are no loose electrical charges to be moved around.
2. Now for the number of skiers. Let's start with one skier. She takes the lift up, skies down, finds that there is no line-up at the lift, goes up again, down again, up again and so on. The flow, in terms of skiers per hour, will be determined by the time it takes for this single skier to make a round trip. If it takes four minutes to go up with the lift and three minutes to ski back down, then the round trip will take seven minutes. The single skier will constitute a flow of 60 minutes per hour / 7 minutes per round = 8.6 skiers (rounds) per hour. If there are 10 skiers on the hill, all with the same skiing skills, then the lift has adequate capacity and the flow becomes 86 skiers per hour. Now, assume that there are 500 equivalent skiers on the hill. Because of the capacity limitations of the ski lift, at 1,000 skiers per hour, each skier can only go up twice each hour and has to wait in the lift line for 23 minutes between runs (or quits in disgust).

Put all this together. The flow of skiers requires a ski lift. The lift has power restrictions that place an upper limit on the number of skiers going up the hill per hour. Next, the model requires a number of skiers willing and able to take to the slopes. Increasing the number of skiers increases the flow, until you reach the carrying capacity of the lift. It also follows that as long as the numbers of skiers stays small, the flow increases if the skiers ski down faster.

Electrical current is the movement of electrical charges instead of skiers. These may be electrons, ions or even nuclear particles. In our analogy, a skier represents a particle carrying a net charge—an ion for example. It is placed in a higher energy state by the battery and makes it down through the rest of the circuit to the lower end of the battery, to be lifted again to repeat the process. In our ski-hill analogy, the number of skiers making the rounds per hour are counted. In an electrical circuit, the charge is counted—some ions might be singly charged and others doubly charged, or even more. We don't care about the size or number of ions, just how much charge they carry along. To fantasize a little further, suppose what really counts toward the flow is the number of daypacks making the rounds instead of the number of skiers. Some skiers carry them, some skiers do not.

Coulomb and ampere are units of measurement that predate detailed knowledge of the particle nature of electron flow. We now know that electrical currents consist of individual particles passing by, just like the skiers and daypacks on the ski hill. It was established in 1900 that each particle carries a charge—positive or negative—in multiples of 1.602×10^{-19} coulombs. Therefore, each coulomb corresponds to approximately $1/1.602 \times 10^{-19} = 6.24 \times 10^{18}$ of these elementary charges. The flow of a one-ampere current through a wire means that 6.24×10^{18} individual charges pass by any section of that wire each second.

3. What are the skiers like? There are experts, intermediates and beginners, with significant speed differences. Research has uncovered that an electrical conductor can have more than one charge carrier. For example, an electrolyte, like the sulphuric acid in a storage battery, can have moving electrons, moving positive ions, moving negative ions and possibly even electrically charged cosmic rays, all making their contribution to the total charge flowing in the circuit. The ease with which the charge carriers can be made to move is given the technical term *mobility*. Mobility and the number of electrons that participate in the conduction process can be measured in all materials of interest for electronics. For example, electrons have been found to move more easily than the comparably massive ions. They therefore have a higher mobility. Copper conducts electricity better than iron because the mobility of electrons in copper is higher than the mobility of electrons in iron, despite there being twice as many electrons per cubic centimetre available for the conduction process in iron than in copper.

   Current flow, then, depends on the voltage of the battery, the number of charge carriers and the mobility of the charge carriers.
4. What about the conditions on the ski hill? Skiing on a wide-open slope is much different than skiing down through the woods. Electrons also move faster (with higher mobility) in solids in which the individual atoms are neatly lined up—the perfect single crystals. Imperfections in the atomic arrangement give rise to *scattering centres*, where the electrons are temporarily bounced off their idealized paths, reducing their average speed.
5. The steepness of the ski slope, in the analogy, is the electric field. The larger the electric field, the greater the force on the electric charges and the faster they are pushed or pulled about. The combination of the strength of the electric field (slope) with mobility (skiing skill) determines the speed of the charge carriers.
6. Congestion points reduce the flow. They may be at the top of the lift before the skiers disperse, in the middle where a gully is the only way down between steep cliffs or near the bottom where skiers must slow down before getting back to the lift. They increase the time the skier requires to get down, which increases the time required for a round trip, and therefore, even if the number of skiers remains the same, decreases the flow rate. A congestion point in the electrical circuit is called a resistor. It limits the flow of the charge carriers.

In a classroom experiment, the battery is the ski lift, the lead wires are the open slopes and the lamp that lights up is the congestion point (the resistor). The resistor is the place in the circuit where the electric flow does the assigned work—lights a lamp, runs a motor or a computer, or heats the coffee pot. It is as if the ski-hill operator lets you go up for free but demands his pound of flesh halfway down.

Some Details

This would not be a physics paper without a few detailed calculations. Skip this segment if you just want to know the results.

On the ski hill there is height, number of skiers and the speed of the skiers. Are the equivalent numbers available for, say, copper wire? Yes. For many metals, copper included, each atom contributes one electron that can move freely under the influence of an electric field. How many electrons, then, would be available for an electrical current in a cubic centimetre of copper? The atomic weight for copper is 63.5 grams per mole. The density of copper metal is 8.96 grams per cubic centimetre. Therefore, one cubic centimetre contains $8.96/63.5 = 0.141$ moles. Each mole contains 6.022×10^{23} atoms, which leads to $0.141 \times 6.022 \times 10^{23} = 8.50 \text{ X } 10^{22}$ atoms per cubic centimetre, and there are just as many free electrons per cubic centimetre.

How fast do they move? This question requires more input. First, we need to know the electrical resistance of the copper. What is the resistance of a length of wire? The handbooks give a λσνγ λιστ of values of a material constant called resistivity, designated by the Greek symbol ρ. For copper $\rho = 1.72 \times 10^{-6}$ ohm-cm. Resistivity is defined as the resistance of a one centimetre cube. The resistance R of other shapes is given by $R = \rho l/A$, where l is the length of the wire and A is its cross-sectional area. A long, thin wire has a greater resistance than a short, squat rod.

I will go step by step through the following calculation, even though there are short cuts. For example, the length and diameter of the wire cancel out in the end.

Quite arbitrarily, let's use a 2-metre long and 0.3-milimetre thick copper wire. Once converted to centimetres, the resistance can be calculated as $R = \rho l/A = (1.72 \times 10^{-6})(200)/(\pi(0.030/2)^2) = 0.487$ ohms. Convert the empirical relationship $V = IR$ to $I = V/R$ and calculate the current I to be $I = 1.5/0.49 = 3.1$ amperes. This is a pretty hefty current, and it would drain the battery quite rapidly—almost making a short circuit.

The current is 3.1 amperes, where each ampere represents 6.24×10^{18} electrons passing by every second, for a total of $(3.1)(6.24 \times 10^{18}) = 19 \text{ X } 10^{18}$ electrons making the rounds each second.

Speed of the Electrons

How is the speed of the electrons calculated? First, another analogy—a freeway and the flow of cars. The problem to be solved is the following: given a certain density of traffic and all cars moving at the same known speed, determine the number of cars passing a milepost in one minute? Let's say there are three solid lines of traffic going west, all the cars are moving at 90 km/hour and in each lane the cars are spaced at a density of 4 cars per 100 m (0.04 cars/m). The cars are moving at 90 km/h, or 1.5 km/min. In 1 minute, all of the cars within a distance of 1.5 km east of the milepost are going to pass by. With 4 cars per 100 m per lane, this equals (40 cars/km)(1.5 km/min)(3 lanes) = 180 cars per minute past the milepost. The flow rate is 180 cars/minute.

Now let's go back to the copper wire. Let N_o be the number of electrons per cubic centimetre (already established to be 8.50×10^{22}). Select a time t. The electrons move at an unknown speed v. Following the highway example, all the electrons at a distance vt "upstream" from our metering point will pass the meter in the time interval t. The volume of that segment of wire is the distance multiplied by the cross-sectional area of wire—vtA—and the number of electrons in this segment will be $(vtA)N_o = (vt\pi(0.030/2)^2)(8.50 \times 10^{22})$. This is the number of electrons passing the meter in time t. The current (or the electron flow) is the number passing by per second, that is, $I = (vt\pi(0.030/2)^2)(8.50 \times 10^{22})/t = (v)(\pi(0.030/2)^2)(8.50 \times 10^{22}) = (v)(6.0 \times 10^{19})$. Written completely in symbols the electron flow is AvN_o and the electrical current is $I = qAvN_o$. We know that 3.1 amperes is a current of 19×10^{18} electrons per second, therefore $v = (19 \times 10^{18})/(6.0 \times 10^{19}) = 0.32$ cm/s. Slow, isn't it?

The mobility (the speed for a given strength of electric field) can also be calculated. Applying 1.5 V over a wire 200 cm long produces an electric field of $1.5/200 = 7.5 \times 10^{-3}$ V/cm. The mobility of the electron in copper, then, is $(0.32)/(7.5 \times 10^{-3}) = 43$(cm/s)/(V/cm). For the record, electrons have a much higher mobility in semiconductors. The mobility of electrons in silicon is 1,450(cm/s)/(V/cm), and in the semiconductor indium antimonide it has been measured at 77,000 (cm/s)/(V/cm). All these figures are for the materials at room temperature. In most materials, the mobility of electrons increases as the temperature drops.

Does It Make Sense So Far?

An electron speed of 0.32 cm/s should surprise you. Lights go on at the “flick of a switch,” and we have learned long ago that electrical signals move at something close to the speed of light. What is wrong? Is anything wrong? The short answer is that nothing is wrong. The individual electrons do move slowly, but, as we saw in the ski-lift analogy, it is not necessary for a given electron to make the complete round. At the ski hill, as one person gets on the lift at the bottom, another gets off the lift at the top, well before the newcomer gets to the top. On the macroscopic scale, such as household electrical circuits, electricity acts like an incompressible fluid. A push at one place is instantaneously felt in the entire circuit. On the microscopic scale, the speed of the individual electrons becomes important, and the incompressible-fluid principle is no longer applicable (this has applications for computer chips).

Test your knowledge of the laws of physics with the following problem, adapted from the book *Real-Life Problems for Introductory General Physics*.[1] Why do building codes require that we have such thick copper wires in the walls of our homes?

Problem 1

In northern climates, automobiles sprout external electrical connectors in the winter and cars parked on the street appear to be connected by umbilical cords to the nearest house. Although some car owners go so far as to install electrically heated seats, most are satisfied with an electrical heater in the engine block to keep the oil flowing freely.

A standard version of such a block heater consumes power at a rate of 800 W at the 120 V of the electrical outlets in the house.

1. Calculate the resistance of the block heater.
2. Calculate the electrical current in the heater when it is used at 120 V.
3. Many cars are parked on the street and require extension cords to reach from the house electrical outlet to the block heater. A distance of 25 m is not uncommon. The choice at the hardware store is between a cable made from #16 wire, which should be just about adequate in cold weather for the required wattage, and a cable made from #14 wire, which is recommended for the purpose but costs considerably more. Calculate the resistance of a 25 m length of #16 copper wire and the resistance of a 25 m length of #14 copper wire. The handbooks[1] quote the resistance of #16 copper wire as 13.17 Ω/km and the resistance of #14 copper wire as 8.29 Ω/km.
4. What is the cross-sectional area and diameter of the #14 and #16 wires? To make the wires flexible, they are usually made of multiple, parallel strands of thinner wire.
5. Calculate the current through the #16 cable when it is used to connect the block heater to the 120-V outlet. Remember that an electrical cable must have at least two wires. Calculate the total resistance—cable plus block heater—first. The third wire in high quality extension cords is for safety. It is called the ground wire. It does not play a role in the circuit under normal operating conditions.
6. Will the engine block still get its 800 W at the end of the #16 cord? Calculate the heat energy dissipated in the block heater and in the cord leading to the car. If the voltage at the outlet in the house is 120 V, what will the voltage be at the contacts for the block heater?
7. Repeat the calculations for parts 5 and 6 for the #14 wire cable. Note the effectiveness of the block heater when used with extension cords having a greater or lesser diameter.
8. Back to the original question: because the electrical power enters the house from an external cable and is then distributed to the many outlets in the house, why should the distributing wires be as thick as possible?

Solution 1

1. Power $P = V^2/R$. With $P = 800$ W and $V = 120$ V, it follows that $R_{bh} = V^2/P = 120^2/800 = 18.0\ \Omega$.
2. Power $P = IV$. With $P = 800$ W and $V = 120$ V, it follows that $I = P/V = 800/120 = 6.67$ A.
3. At 12.14 Ω/km, the wire will have a resistance of $R_c = (13.17 \times 10^{-3})(25) = 0.329\ \Omega$. At 7.63 Ω/km, the wire will have a resistance of $R_C = (8.29 \times 10^{-3})(25) = 0.207\ \Omega$.
4. Use $R = \rho l/A$. The value of R was calculated in part 3, the length l is also known and the resistivity Ω of copper is 1.72×10^{-6} Ωcm. Substitution of the values leads to $A = 1.29 \times 10^{-2}\ \text{cm}^2$ for #16 wire and $A = 2.07 \times 10^{-2}\ \text{cm}^2$ for #14 wire. The diameters will be 1.24 mm and 1.63 mm respectively.

5. The total resistance of the cable and the block heater is 0.329 Ω + 0.329 Ω + 0.329 Ω + 18.0 Ω = 18.66 Ω, which implies a current of $I = V/(R_{bh} + R_c)$= 120/18.66 = 6.43 A.
6. A lower current through the block heater means less heating power. The power delivered to the block heater is $P = I^2R_{bh}$ = $6.43^2(18.0)$ = 744 W. The power dissipated as heat in the extension cord is $P = I^2R_c$ = $6.43^2(0.658)$ = 27.2 W. The voltage at the contacts for the block heater is $V = IR_{bh}$ = 6.43(18.0) = 116 V. [Note: 744 + 27.2 = 771 W, which is less than 800 W.]
7. There are two wires in a series for a total distance of 50 m. At 8.29 Ω/km, the cable will have a resistance of R_c = 0.414 Ω. The total resistance of the cable and the block heater is 18.41 Ω, which implies a current of $I = V/(R_{bh} + R_c)$ = 120/18.41 = 6.52 A. The power delivered to the block heater is $P = I^2R_{bh}$ = $6.52^2(18.0)$ = 764 W. The power dissipated as heat in the extension cord is $P = I^2R_c$ = $6.52^2(0.414)$ = 17.6 W. The voltage at the contacts for the block heater is $V = IR_{bh}$ = 6.52(18.0) = 117.3 V. As a general principle, the thicker the wires, the lower the resistance of the cable, the higher the current in the circuit and, finally, the more heat created where it is needed—in the block heater. [Note: 764 + 17.6 = 782 W is still less than 800 W.]
8. There are two reasons for using thick copper wiring in the house. The first is to ensure that you get the highest possible voltage at the electrical outlets of the house, regardless of the power drawn from the outlet. The second is that the wires will heat up whenever current is drawn. The thicker the wire, the less it heats up, which reduces the danger of fires.

Comments on the Problem and Its Solutions

Working on the problem will have reminded you how to use the equation $V = IR$ and how resistivity relates to resistance. More practically, you will realize that, although thin wires are cheap, they won't always do. Even a good electrical conductor like copper is not at constant potential when currents are flowing through it. The voltage drops significantly over a length of copper conductor, degrading the power that can be delivered to the intended user. The copper conductor will also generate heat, which can become dangerous.

In the main text we have looked in detail at copper as a conducting material. We have estimated that the number of electrons that are free to move in the electrical conduction process are 8.50×10^{22} per cubic centimetre, and there are experimental methods to confirm this number. Knowing the resistivity of copper, we then determine the mobility of the electrons to be 43(cm/s)/(V/cm). Now try your skill at the following problems.

Problem 2

Silicon, the workhorse for the semiconductor industry, can be manufactured to have a wide range of electrons free to move in the electrical conduction process. The minimum is 10^{10} per cubic centimetre and a practical maximum is 10^{18} per cubic centimetre. The mobility of electrons in silicon is 1,450(cm/s)/(V/cm).[2] Predict the range of resistivities of silicon as compared to copper.

Solution 2

The easiest way to approach this problem is to use proportions. We have used the resistivity ρ of copper as 1.72×10^{-6} Ωcm. It is associated with a mobility of 43(cm/s)/(V/cm). If its mobility was boosted to 1,450(cm/s)/(V/cm), an increase of a factor of 34, the resistivity should drop by that factor of 34 to 5.10×10^{-8} Ωcm. Counteracting the increase in speed of the electrons is the decrease in their number, from 8.50×10^{22} to 10^{10}, representing a factor of 8.50×10^{12}. That decease in numbers causes an increase in the resistivity by that same factor, from 5.10×10^{-8} Ωcm to 4.3×10^{5} Ωcm. The lowest resistivity silicon, at 10^{18} conduction electrons per cubic centimetre, will, accordingly, have a resistivity 10^{8} times less, 4.3×10^{-3} Ωcm. Copper is therefore still a better conductor than low resistivity silicon by more than a factor of 1,000.

Comments on the Problem and Its Solutions

One of the characteristics of semiconductors is that their resistivity can be accurately controlled over many orders of magnitude. Silicon is the best understood and most widely used semiconductor.

What Else?

Much of my research work has been on measuring the mobilities and carrier concentrations in semiconductors. Of particular interest to me has been the influence of light on electrical conduction. A large numbers of insulators become electrically conducting when they are illuminated. When the lights are turned off, these materials become insulators again. This phenomenon is called *photoconductivity* and is used in light sensors. A related phenomenon is the emission of *cold* light when a current flows through certain materials. This has led to the creation of light-emitting diodes and laser pointers. Where might these fit into our ski-hill model?

For many insulators, the lack of current is due to a lack of charge carriers (electrons), not poor mobility for the electrons. As well, incident light can temporarily break some of the chemical bonds, releasing electrons. These electrons can then flow through the circuit until caught again to re-establish the bonds. What kind of jolt could increase the number of skiers on our ski hill? A contest? An advertising campaign? Closing the cafeteria halfway up the hill? A simpler analogy is that ski hills shut down in the dark, but floodlights keep them going.

Among the materials that change their electrical resistance in the presence of light are silicon—the mainstay of the computer industry—some diamonds, cadmium sulphide, gallium arsenide and my personal favourite, cuprous oxide.

Try another problem to see how photoconductivity works.

Problem 3

It was stated in Problem 2 that silicon can be made with only 10^{10} electrons per cubic centimetre free to move in the electrical conduction process. Suppose now that we have photons of just the right wavelength to each shake loose an extra electron from a stable bond to help conduct electricity. The extra electrons stay loose for one microsecond before being trapped in the chemical bond again. How many photons per second would be required to cut the resistance of a piece of silicon of one cubic centimetre in half? Assume that each incident photon shakes loose an electron.

How far might one of these light-generated electrons travel before it is recaptured?

Solution 3

To decrease the resistance by a factor of two, the number of conduction electrons must be increased by a factor of two. Therefore, an average of 10^{10} additional electrons per cubic centimetre must be maintained. If these electrons only live (are free) for one microsecond, 10^{10} electrons per cubic centimetre per 10^{-6} seconds, or 10^{16} electrons per second, must be generated. This requires a light intensity of 10^{16} photons per second.

We have a time, 10^{-6} seconds, but to find the distance we need a speed. Speed is determined by electric field and mobility, $v = \mu E$. The mobilitly μ is known for silicon, but a value for the electrical field, E, must be selected. For copper, a few volts per metre already gives excessive currents. Silicon, a much-higher resistivity material, can tolerate much higher voltages before heating up. 100 V/cm is quite acceptable. In that case, $v = \mu E = (1450)(100) = 1.5 \times 10^5$ cm/s. The distance of travel is then $(1.5 \times 10^5)(10^{-6}) = 0.15$ cm.

Comments on the Problem and Its Solutions

The lifetime of the light-generated electrons is extremely important in determining the change in resistance. A slowly responding semiconductor like lead sulphide, which is a widely used light detector, needs fewer photons for the same number of generated electrons because the electrons live longer. The drawback is that this material is not as sensitive to quick changes in conditions. It would be useless in optical communication (fiber optic networks), in which light is made to flicker at nanosecond rates.

Back to the Story

The increase in the number of charge carriers due to light is, in actuality, due to external-energy input. A single photon, if it has enough energy, breaks a bond and releases an electron. Light is given off while electrons are making the rounds because of a process in which electrons suddenly lose energy, giving it off in the form of a photon. To understand this, let's go back to the ski-hill analogy. A skier sliding down the slopes continuously loses potential energy. What if, on the other hand, there are small cliffs or a ski jump? Here, energy is lost in sudden steps. This is analogous to what happens in an insulator. The electron is ripped loose from its moorings and now, while passing a similar spot of a broken bond, gets trapped and loses potential energy. This energy, in turn, can be emitted as a photon. Be careful with this analogy; it is just an imaginary picture of what might happen in the material. In fact, the electron jump takes place where two different materials are joined in the circuit, such as where the copper lead wires connect to the insulating material.

The above-described phenomenon of light emission is called electro-luminescence. Gallium arsenide, gallium nitride and silicon carbide are used in devices based on this principle.

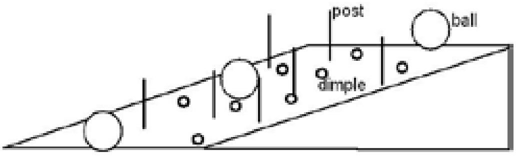
Does the Rest Make Sense?

Think of batteries, lead wires and light-bulb circuits. What happens if the polarity of a battery is reversed? If the current is reversed, the light bulb is just as bright as before. It is independent of the direction of the current. What would happen in the ski-hill analogy if the direction of the lift were reversed—that is, it only took skiers down, not up? Regardless of the number of skiers in the area, the slopes would quite soon be empty (with the exception of a few cross-country diehards) and the cafeterias at the bottom of the hill will be crowded, followed by the exodus from the parking lots. The ski-hill model at best describes a circuit with a rectifier: one-way current only. The ski slope acts as a one-way street because the majority of skiers are unwilling or unable to go uphill.

Can the Model Be Tweaked?

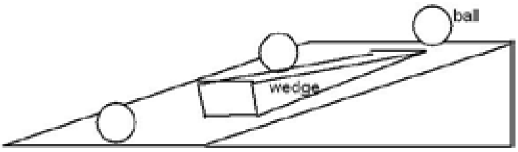
It seems a shame that the model fits many aspects of an electrical circuit but then, in the end, looks like nonsense after all. Has the entire effort been in vain? All models can be no more than an approximation of the real world. If the model helps us visualize at least part of what goes on, it can help us understand, but we must be conscious that we are dealing with a model, not reality, and that it can only carry us a limited distance.

After finding some of the failures, the model can be tweaked to closer fit reality. Let's try a pinball machine. A flat board or table top with a good-sized rim. The board can be tilted at angle and there is a mechanism for lifting balls from the low end to the high end. Somewhat randomly distributed on the board are posts that scatter the ball as it rolls from the high side to the low side. The tilting mechanism, together with the lift for the balls, substitutes for the ski lift, which in turn was the analogy for the battery. The balls have been substituted for the skiers, and the randomly distributed posts are the trees and other hazards on the ski hill. The size and weight of the balls can parallel the mobility concept. Why is this model better than the ski-hill model? Reversing the battery tilts the board the other way, presumably with the associated reversal of the lifting mechanism.



What about the influence of light? Put some shallow dimples on the board in which the balls can get stuck. Small, locally applied energy, such as a puff of air, can knock the ball loose, and it can get caught again at a later time in the same dimple or another one.

Light emission can be modelled by a wedge. The ball easily rolls up one side but falls down steeply on the other side, releasing a burst of energy. Putting enough of these wedges side by side produces an asymmetry. The steep side of the wedges allows the ball to roll at only one direction of tilt. A barrier has been introduced. Light could be emitted at this barrier when the polarity is one way, and no light will be emitted (and no current will pass) when the polarity is reversed. This is a reasonable model for the electronic device called the rectifying diode, and, with the correct material, it is also a model for the light-emitting diode.



The idea can be taken another step further. If the board is tilted enough, even with its dimples and wedges, and even in the blocking direction, the balls could jump the barrier and allow current to pass. Electronic diodes have a maximum blocking capability as well. Once the safe level is breached, breakdown occurs, usually burning out the device in the process.

Conclusions So Far

Models, such as the ski hill for an electric circuit, can be useful for visualizing many attributes of a phenomenon. They are good teaching tools, but it takes a solid, fundamental understanding of the real phenomenon to come up with a valid model. The better you understand, the more sophisticated and reasonable the model becomes.

There are at least two difficulties with models. First, it is virtually impossible for someone with a poor understanding to make up a model that will be useful as an educational tool. Second, trouble arises when you pursue some of the details with numerical calculations. The three problems in this article happen to work well. The speed of the electron in copper seems a bit low, but still acceptable.

As a practicing scientist and researcher on the optical and electronic properties of semiconducting materials, I kept finding far too many logical holes in my arguments as I was writing this article.

What happens if we dig a little deeper by applying more algebra and the basic laws of mechanics to our imagined analogies.

Some More Problems to Contemplate

There is an interesting difference between the starting assumptions of mechanics and those of electricity. Mechanics starts with the assumption that friction is non-existent, and if it does exist, it is considered a minor, complicating factor. The beginning equation is $F = ma$. Electricity works the other way around by assuming that friction is there from the start. Friction is called resistance, and the equation $V = IR$ is, for the student, the electrical equivalent of $F = ma$. There are materials, called superconductors, that have zero resistance. This can be difficult to accept because we have been indoctrinated with $V = IR$, which makes superconductivity and zero resistance seem counter intuitive.

$F = ma$ holds for electrons in a solid where the mean free path (the distance an electron travels between collisions) is large. It also holds for electrons in a vacuum, as long as the electron's speed does not become excessive.

How then do we get from "acceleration proportional to force" to "speed proportional to force"? The following attempts this using the principles of the model we have used.

Problem 4

On average, electrons travel a distance l between collisions and accelerate freely between collisions. The acceleration will be proportional to the electric field strength E, which is given by the voltage V/d, the length of the wire over which the voltage is applied. Furthermore, let N_o be the number of electrons per cubic centimetre and A be the cross-section of the wire. Derive an expression for I, the current in the wire as a function of applied voltage.

Solution 4

From the text, the equation is $I = qAvN_o$. The average electron speed v will depend on the applied voltage and requires analysis.

The force on an electron is given by $F = qE = qV/d$. The acceleration in the space between collisions will be $a = F/m = qV/dm$. Given this acceleration, what is the average speed over the distance l ? Recall from mechanics that $l = at^2/2$. The variables l and a are known, allowing us to solve for $t^2 = 2l/a$ and $t = (2l/a)^{1/2}$. The average speed v is l/t, which is $v = l/(2l/a)^{1/2} = (lq/2md)^{1/2}V^{1/2}$. Finally, $I = qAvN_o = qAN_o(lq/2md)^{1/2}V^{1/2}$.

Comments on the Problem and Its Solutions

Does this expression make sense? Some of it does, but some of it does not. Increase A, q, N_o, l and V, and the current increases, as it should. Increase the mass of the electron m or the length of the wire d, and the current decreases, also as it should. What does not make sense is that, although experiments show the current to be proportional to the voltage, as per Ohm's law, the model has shown it to be proportional to the square root of the applied voltage. This is another serious failure of the model, which requires a bit more tweaking.

Problem 5

Problem 4 started with the idea that electrons, on the average, travel a distance l between collisions and accelerate freely between collisions. Try a mathematically simpler assumption next. Let us postulate that an electron spends a specific average time τ between collisions instead of a specific average distance l.

The acceleration will still be proportional to the electric field strength E, which is given by the voltage V/d, the length of the wire over which the voltage is applied. N_o is still the number of electrons per cubic centimetre and A is still the cross-section of the wire. Again, derive an expression for I, the current in the wire as a function of applied voltage.

Solution 5

From the text, the equation is $I = qAvN_o$. The average electron speed v must now be maintained under the new conditions.

The force on an electron is, as before, given by $F = qE = qV/d$. The acceleration during the time between collisions is $a = F/m = qV/dm$. Given this acceleration, what will be the average speed v over that time τ?

$v = a\tau/2 = (qV/dm)\tau/2$, φρομ ωηιχη φολλοωσ $I = (q^2AN_o\tau/2dm)V$.

Comments on the Problem and Its Solutions

Does this new expression make sense? Increase one or all of A, q, N_o, τ and V, and the current increases, as it should. Increase the mass of the electron m or the length of the wire d, and the current decreases, as it should. What also makes sense is that the current is directly proportional to V, as required by the experiments and Ohm's law. But did the assumption make sense?

Another Step

Compare $I = (q^2AN_o\tau/2dm)V$ as derived from $I = (1/R)V$—an altered version of Ohm's law. Identify the resistance of the wire as $q^2AN_o\tau/2dm = 1/R$ and, from $R = 2dm/q^2AN_o\tau = \rho d/A$, isolate the resistivity $\rho = 2m/q^2N_o\tau$. As shown earlier, the number of electrons in copper is known, as is their mass and charge, so it is possible to estimate the time τ between collisions: $\rho = 1.72 \times 10^{-6}$ ohm-cm, $q = 1.602 \times 10^{-19}$ coulombs, $N_o = 8.50 \times 10^{22}$ electrons/cm^3 and, from the handbooks, $m = 9.1 \times 10^{-31}$ kg. With these, calculate for $\tau = 4.9 \times 10^{-10}$ seconds. This time interval is short, to say the least.

Put that lifetime of $\tau = 4.9 \times 10^{-14}$ seconds into context. Return to the formula $v = a\tau/2 = (qV/dm)\tau/2$, using $v = [(1.602 \times 10^{-19}$ coulombs)(1.5 V)/(200 cm)(9.1 $\times 10^{-31}$ kg)](4.9 $\times 10^{-10}$ seconds)/2 = 0.32 cm/s. This is the same speed found much earlier in this article. The length that a typical electron travels in the average time between collisions is $d = v\tau = (0.32)(4.9 \times 10^{-10}) = 1.6 \times 10^{-10}$ cm. How does that number compare to atomic dimensions? The size of an atom is around 10^{-10} m, about 60 times the 1.6×10^{-10} cm that the electron travels.

The original idea that electrons slow down as they bounce off atoms that block their way can't be true. The other bothersome aspect is that the specific average time between collisions makes little or no sense. If the electrons really slow down by hitting randomly placed barriers (the atoms), then the faster the electron moves under the influence of the electric field (force), the sooner it will reach the next barrier. But the experimental evidence, according to Ohm's law, only works for specific average time rather than specific average distance between collisions. More tweaking of models is required, as well as the use of experimental evidence that resistivity decreases with decreasing temperature, thereby increasing the time between collisions. This will lead to the current theory of electrical conduction, which involves the presence of high frequency vibrations in the solid. Much like photons that carry electromagnetic energy, the electrical conduction process can best be explained by the existence of a new set of particles—phonons—that carry vibrational mechanical energy. These phonons bounce into the conduction electrons, much like how gas molecules bounce against dust particles in Brownian motion, inhibiting the electron's movement. Yet even greater sophistication is needed to include all the possible natural vibrations in the solid to get full agreement between theory and experiment. It even goes the other way around—the electrical measurements can be used to identify the types of vibrations that can exist in the solid.

Final Conclusion

How much do you need to know? How correct do you want to be? Can you ever really be correct? Let's look at the questions one at a time, because it all depends.

How much do the students in your class need to know? Primarily, they need to know that Ohm's law is an experimental fact, that batteries drive the current and that different materials need different amounts of push to make the current go. Students also need to relate the new material to previous experience. The ski-hill analogy may provide enough experience to make Ohm's law and simple circuits seem reasonable.

How much do you as a teacher need to know? You should ideally be a trained physicist so that you really know what you are talking about. But would anyone be helped if you started your presentations with the phonon theory of condensed matter? Or, for that matter, would a condensed matter physicist be able to teach Ohm's law and simple circuits in a manner that would make sense to the students? Here is my recommendation: be able to deal with an analogy that is appropriate to the level of teaching, but emphasize that the analogy is just a way of thinking about how nature operates, and realize that the analogy breaks down if and when you take it too far.

How correct do you want to be? Analogies are like fairy tales. Fairy tales play a useful role in teaching morals, but the fairy tale remains a fairy tale, and both the audience and teller know it. Analogies have enough resemblance to real life that they have a predictive power that can be tested. It is great fun, when you have bright students, to help them dig around to find the holes in the analogy and then to tweak it.

Can you ever really be correct? The answer is simple: never. As the precision and sophistication of experiments improves, there will always be refinements in the theory, but that is the job of the specialist in that field of research and it will have little influence on the old tried-and-true subjects you are asked to teach.

Notes

1. Real-Life Problems for Introductory General Physics[1] (Weichman, F P Hendriks Publishing, 2000, p 99)

2. Weast, R C, ed. 1968. *Handbook of Chemistry and Physics*, 49th ed. Cleveland, OH: Chemical Rubber Company, F131.

3. Madelung, O, ed. 1991. Semiconductors: Group IV Elements and III–V Compounds. Berlin: Springer-Verlag, 18.

Approaches to Reciprocal Teaching in Science Education: A Questions-Based Approach

Dr Thelma Gunn and Dr Lance Grigg

Introduction

The skills students need to comprehend, remember and learn from science texts are numerous and difficult to acquire. Many science teachers know that understanding the material in a science text requires specific knowledge, skills and strategies that are obtained through extensive instruction and practice. In light of such difficulties, it is important that teachers are made aware of research that focuses on optimum text processing. This is especially true for expository text processing in science teaching.

This article outlines an important but often ignored questioning strategy designed to help students process science texts. It describes current research about and features of the generic-question-stem technique as it occurs in reciprocal teaching. This approach has typically been conducted with lecture and/or lesson comprehension as well as in group settings. Guided generic question stems are better at enabling students to make meaning out of expository texts than single word questions or unguided questions (Gunn 2000). Science teachers can thereby greatly improve learners' acquisition, utilization and maintenance of text-derived knowledge, and comprehension skills and strategies.

Generic Stem Questioning: Setting Things Up

Being able to read and comprehend text is a well-recognized goal of instructional practice. Research findings indicate that word-recognition processes must be accurate and automatic for text comprehension to occur (see, for example, Adams 1990). Put more simply, text comprehension is contingent on the basic decoding skills of the reader. Fortunately, a great deal of research concerning orthographic, morphemic and phonologic processing has been conducted, enabling a clearer understanding of the complexities involved in word processing (see, for example, Adams 1990; Stanovich 1986; 1989). This research has also enabled the development of instructional models that target reading development and reading recovery.

Word recognition, however, is only one of many reading-comprehension processes. Mental representations of text, text coherence and topic familiarity all contribute to comprehension (Beck, McKeown, Sinatra and Loxterman 1991; Just and Carpenter 1987; Spires and Donley 1998; van Dijk and Kintsch 1983).

Students' ability to comprehend a piece of text can be impeded if one or more of these components aren't in place, no matter what their technical skills are. For example, understanding a science text requires both a textbase and a situation model. The textbase model encompasses those elements and relations that are derived from the text itself (McNamara and Kintsch 1996). The situation model involves meaning making. It is a representation of the situation depicted in the text—events, actions, scientific characters and so on) (Zwaan 1996). It is constructed using the textbase, as well as the reader's prior knowledge and experience.

Various sources contribute to the building of a situation model, including knowledge about language, the world and the specific communicative situation, and personal experiences

(McNamara and Kintsch 1996). These sources help transform isolated memories into something that better reflects the reader's knowledge and experience (McNamara and Kintsch 1996, 252).

An approach that can help science students understand what is in a text and how to make meaning or sense of it would, therefore, be useful for science teachers. One approach is generic stem questioning—questioning techniques that can be personalized, administered to large groups, and used individually or cooperatively.

Alison King is the primary proponent of and author of writings on generic question stems. She has successfully demonstrated using this approach with adolescents in lecture and lesson comprehension settings. This approach involves the development of questions using generic stems. The stems are not so much guidelines as structures upon which questions are constructed. Their purpose is to assist in constructing internal and external connections within the material being studied and the students' prior knowledge. Internal connections involve organizing selected information from the presented material into a coherent whole, and external connections link some or all of the newly acquired information to prior knowledge structures (Mayer 1989; 1992). After students create questions, they are to discuss them within small groups.

By employing generic question stems, coherency can be easily achievable at both the local and global levels, helping students better understand science texts. Generic question stems are partially completed sentences that cue the subject to create internal and external connections (Mayer 1989; 1992) by way of question generation. The following are examples of generic stem questions:

- How is ____ associated with, or related to what we have learned or read before?
- Are ____ and ____ related in any way? Explain.
- What do you think might occur if ____?
- What information do we already have about ____?
- How does it apply to ____?
- Are there any differences between ____ and ____? Explain.
- ____ appears to be a problem because ____. What are some possible solutions?
- The author states that ____. Explain why this statement is true or false.
- Compare ____ and ____ in regards to ____. Explain your answer.

Reciprocal Teaching

Generic question stems work well within a teaching strategy known as reciprocal teaching (Brown and Palincsar 1989; Palincsar and Brown 1984). Reciprocal teaching is a step-by-step model that has had considerable success across all learning domains, including reading, mathematics, writing instruction and science. The model consists of four critical strategies: questioning, clarifying, summarizing and predicting. These strategies are acquired and practised in an environment of cooperative learning, expert scaffolding and guided instruction. This is a very useful approach for social studies education.

Each strategy has a specific purpose. For instance, question construction leads to a greater integration of text; clarification assists the instructor, the group and the learner to monitor not only their own comprehension levels but the comprehension of others as well; summation promotes further analysis and self-evaluation of the learner's knowledge, skills and strategies; and prediction activates prior knowledge (Derry, 1990; Lysynchuk, Pressley and Vye 1990).

Students were trained to develop questions that incorporated *who*, *what*, *where*, *when*, *why* and *how*. These prompts are referred to as signal words (Rosenshine, Meister and Chapman 1996) and have been successful in improving social studies text comprehension.

Empirically, reciprocal teaching improve reading comprehension scores as well as metacognitive awareness (Palincsar and Brown 1984; Lysynchuk, Pressley and Vye 1990). Thus, it has succeeded in decontextualizing vital knowledge, skills and strategies, which are required across the domains.

Reciprocal Peer Questioning

The link between generic stem questioning and reciprocal teaching occurs in an activity known as reciprocal peer questioning (King 1989; 1990a; 1990b; 1991a; 1991b; 1992a; 1992b; 1994a; 1994b; King and Rosenshine 1993). Reciprocal peer questioning focuses on the construction of questions and responses, and the integration of schematic structures with new knowledge, skills and strategies, and is useful for science teachers.

Reciprocal peer questioning begins with explicit instruction on the use of question generation using generic question stems. Generic question stems require the learner to complete skeletal question outlines. They require the learner to make connections both within the text and to his or her prior knowledge.

Following question generation, each learner independently generates two or three questions relevant to the material being studied. Individually or through small, cooperative groups, the learners take turns posing their questions to each other. As with reciprocal teaching, feedback is provided by the instructor and/or peer group.

According to King (1990a; 1990b; 1991a; 1991b; 1992a; 1992b), this model produces significantly higher achievement scores than discussion alone, questioning and responding without guidance, and independent study. Learners are required to activate and use prior knowledge, generate higher-level meaningful questions and to monitor one's own knowledge, skills and strategies. This makes reciprocal peer questioning and generic question stems promising approaches toward the development of cognition, metacognition and knowledge construction.

Applications to Science Teaching

How might this work in a science classroom? To prepare, first identify a text that you want your students to study in-depth, such as an article on understanding animal behaviour. Next, break down that text into four parts. Each part must have enough information in it to allow students to visualize what that part of the text is describing, summarize it and formulate generic stem questions about it—two paragraphs could be adequate for each part. Make enough photocopies for the entire class, and tell them they will be doing what every good reader does—visualizing, summarizing and questioning.

Read the first part of the text aloud to the class, asking them to visualize the material, or create an image of what the author is saying. Encourage the students to ask questions like, "What scene is being described?", "What does it look like?", "What animals are in it?" and "What are they doing?" After reading the text, ask the students to open their eyes and draw what they have visualized.

Next, ask the students to summarize in two or three words what has been said and drawn. A good strategy is to get the students to imagine they are describing the scene to their friends or parents, but they can only use two or three words, so those words have to be powerful. Write some of their responses on the board so that everyone can see them. Last, ask the students to formulate four to six generic stem questions based on the material they have read and heard. For example, they might ask:

- What do you think might occur if a mammal developed outside of its mothers body? What dangers would there be for the baby's survival?
- What information do we already have about reptiles and mammals? How do these differences apply to physical characteristics?
- Are there any differences between learned and instinctive behaviour? Explain.
- The death of a mother appears to be a problem because of her role as a nurturer and teacher. What are some possible solutions for the baby's survival if the mother dies early?
- The author states that "mammals are the only animals that have hair or fur." Explain why this statement is true or false.
- Compare incisors and canines with premolars and molars in regards to eating. Explain your answer.

Students can brainstorm by themselves and then gather questions from one another in a cooperative-learning setting. These questions can be placed on the board for other groups to see. They can also be used for authentic approaches to peer assessment, teacher-directed assessment, homework assignments and so on.

Go through the rest of the text in the same way.

Conclusions

Reciprocal teaching and reciprocal peer questioning using generic question stems are useful strategies for encouraging students to process science texts more effectively, but sadly, they are not often used. Because generic stem questions are not subject-specific, they are applicable to a broad range of science texts. This article hopefully exposes teachers to a way of engaging students in text comprehension that combines a set of basic strategies in a creative manner. It is also anticipated that teachers will take this material further, highlighting its limitations and building on them.

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