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The Renewal of Case Studies in Science Education

ARTHUR STINNER[1], BARBARA A. MCMILLAN[1], DON METZ[2],
JANA M. JILEK[3] and STEPHEN KLASSEN[2]
[1]*Department of Curriculum, Teaching, and Learning, Faculty of Education, The University of Manitoba, Winnipeg, MB, Canada R3T 2N2;* [2]*The University of Winnipeg, Winnipeg, MB, Canada R3B 2E9;* [3]*Electrical/Electronics Technology Department, Red River College, Winnipeg, MB, Canada R3H 0J9*

Abstract. Our objective in this paper is to clarify the contextual approach in science education and to suggest appropriate uses of history in the science classroom from early years through post secondary education. We present a description of the variety of approaches by which teachers and educators may include the history of science in science instruction. This is followed by five sections in which historical approaches appropriate for early years, middle years, senior years, college, and university level learning are discussed.

1. Introduction

Three years ago we received from the Social Sciences and Humanities Research Council of Canada (SSHRC) what may be considered a sizable grant in education circles to convene two international seminars promoting the inclusion of the history and philosophy of science (HPS) in science education. That this grant was awarded with some hesitation is attested to by the comment made in the accompanying letter, placed at the end of the usual congratulatory remarks: "The general feeling of the committee, however, was that there is no evidence that the inclusion of history in science education is effective in teaching science". It may be relevant to mention that there were no scientists or science educators among members of the awarding committee.

Research has shown that incorporation of HPS into science instruction is effective in leading students to a better understanding of the nature of science (Irwin 2000; Solomon et al. 1996; Brush 1989). However, science educator Lederman (1998) sounds a cautionary note, pointing out that not all studies of the effect of history of science on understanding the nature of science have positive results (for example, Dickinson et al. (1999), show little impact). Lederman (1998) points out that studies where the nature of science objectives have been made explicit in the instruction are the ones that have been more successful (Jones 1969; Ogunniyi 1983; Olstad 1969). There are also research studies that indicate positive results in employing history of science to encourage student conceptual change (Seroglou et al. 1998; Sneider & Ohadi 1998; Wandersee 1985). A study by Galili and Hazan is possibly unique in demonstrating a clear improvement in students' content understanding as a result of the generous incorporation of historical models into instruction (Galili & Hazan 2000). Although these initial studies are encouraging, they are not conclusive, due to their small number and the absence of replication. Allchin et al. (1999) found that students' attitudes towards, and understanding of science were shown to improve when using history-based laboratories, as compared to the usual lecture teaching techniques. Finally, the historical thematic approach lends itself to curriculum organization and design and has been used fruitfully in reforming first-year college courses and textbooks (Holbrow et al. 1995).

The comment made by the SSHRC award committee, of course, did not surprise us. Even science teachers think that, although the occasional inclusion of history in the science classroom may foster a positive attitude and may add "cultural information or human interest" (Monk & Osborne 1997, p. 406), it is not expected to improve students' conceptual understanding of science. For most science teachers the teaching of science is a textbook-centered presentation of the finished products of science. Conceptual development is considered important, but preparing students for examinations based on the curriculum content takes precedence over everything else. Science teachers point out that scientists generally believe that knowledge of HPS is irrelevant for the practice of their scientific specialization (Brush 1974).

Monk and Osborne, referring to Reichenbach's distinction between *the contexts of historical discovery* and of *epistemological justification*, summarized this state of affairs well:

> In the former, ideas are tentative, if not speculative, and described in language that is interpretive and figurative, often using new metaphors. Most science teachers view their task as being very much concerned with the transmission of the products of "the context of epistemological justification" – that is, on the narrow focus of "what we know" rather than "how we know". . . . (1997, p. 406)

They go on to argue that teachers view science as an established body of knowledge and techniques that require minimal justification. Physics teachers, for example, when teaching Newton's laws, present these laws as if they were self-evident and came full-blown to the mind of the great man, shortly after the apple fell on his head. The laws are then illustrated by experiments such as "verifying Newton's second law of motion" (Stinner 1994b).

Unfortunately, the context of epistemological justification is presented to students by using a limited aspect of only one of the two components of this context, namely the *methodological*. The other component, the *interpretive*, is almost never mentioned. The methodological component "is concerned with the generation of appropriate hypotheses for testing, the identification and control of relevant variables (fair testing), the collection of reliable data, the use of basic statistical models, reliability, and validity of measurement (Monk & Osborne 1997, p. 408). However, in actual classroom practice, due to the limitation placed on teachers by time, curriculum, and the extent of their own content knowledge of science, the methodological component is seriously under-represented.

Applying the conventional "science processes" approach then must be seen as necessarily leading to an inductive-empirical picture of science. The idea that there is a specifiable scientific method that guarantees the discovery of scientific laws seems plausible to both teachers and students. Duschl (1994), however, pointed out that scientific ideas that we present to children are the products of creative scientific thinking of a culture in a given time. This creative scientific thinking cannot be captured by the application of the certain rules imbedded in a specifiable method. Therefore, it is necessary to present carefully chosen episodes from the HPS integrally used in the teaching of science, in order to illustrate the creativity, the intellectual struggle involved, the difficulty of communicating with and persuading others, and the necessity of reaching an agreement about definitions, principles, laws and theories. An example of the folding together of the contexts of discovery and justification in just such a way can be found in Matthews' (2000) exposition of the history, philosophy, and science of pendulum motion.

Our objective in this paper is to present arguments for contextual and historical approaches for the teaching of science from early years through post secondary education. We will describe the development of vignettes, science stories, historical case studies, scientific narratives, and thematic approaches to help teachers become more effective in the science classroom. This will be followed by five sections in which historical approaches appropriate for early years, middle years, senior years, college, and university level are discussed.

1.1. THE "STORY-LINE" APPROACH TO THE TEACHING OF SCIENCE

Several writers and science education researchers have recommended and elaborated the notion of using a "story line" approach to the teaching of science. Arons (1989) believes the best way to attract students' attention as well as organize a science course is by way of a "story line". He outlines in some detail the historical settings of important discoveries and events. Arons is referring to what are essentially good science stories that have intrinsic interest and show connections not to be found in textbooks. He argues that these stories seem to be excellent small versions of Conant's (1957) *case histories* "that can be infused into introductory courses, without seriously affecting the amount of physics being covered" (Arons, 1989).

Wandersee has been using Egan's *Story Form* in developing what he calls *Historical Vignettes* to enhance the teaching of science to young students. He uses "carefully chosen examples from the history of science ... tailored to the interests of the science students ...", (Wandersee 1990). It seems that these writers to a lesser or greater extent recommend a "story-line" organization of a science topic that resembles our original contextual approach (Stinner 1989; Stinner &Williams 1993; Stinner 1994b). In this approach, we described what we called the large context problem (LCP) that was originally developed in response to the discovery that significant engagement by students could be achieved by a well developed context with one unifying idea that was capable of capturing the students' imagination. We have developed a set of guidelines that are suitable for designing LCPs as well as historical case studies. These guidelines, used by students for writing LCPs as well as historical units, such as vignettes and case studies, are given in Table 1. This approach can be used for all modes of presentation, from historical vignettes to large scale case studies (see below).

Teachers know that telling a story (at any level) is a powerful tool for engaging students (Ellis 2000; Cresswell 1997; Roach & Wandersee 1993). Telling a coherent story, with a beginning, a middle, and a provisional end, may be the best way for learning, remembering and re-telling of ideas (Kenealy 1989). Kenealy reminds us that "In fact, most people will impose coherence on a set of random sentences in an attempt to create a context for what they are reading or hearing" (Kenealy 1989, p. 210).

2. The Units of Historical Presentations in Science

Before discussing the nature of contextual teaching in science for the various grade levels, we will briefly outline what we call "the units of historical presentation". This is not an exhaustive list but includes most approaches used in placing science in context and in the presentation of history. In designing these units our pre-service teachers use the guidelines given in Table 1.

Vignettes. The smallest unit of presentation is the historical vignette, developed and discussed in great detail by Wandersee (1992). He argues that introducing a well-crafted and well-chosen vignette into the classroom connects the concepts and ideas under study with the interests of the student. Vignettes should also "serve as motivation and encouragement for students to read more about science and scientists" (Wandersee 1992, p. 21). Case Studies. Case studies are historical contexts with one unifying idea, designed according to the guidelines for writing a large context problem (LCP), shown in Table 1. Students form groups of three and make a commitment for planning a case study. Each group is asked to present the case study in three parts, one part prepared by each student:

1. *Historical context:* Student one presents the scientific ideas of the historical period and show how they are connected to the topic.
2. *The experiment(s) and the main ideas:* Main ideas and/or empirical support for what is central to the case study is presented by student two, assisted by his/her colleagues. If possible, these demonstrations should also involve the students in the audience.
3. *Implications for scientific literacy and the teaching of science:* Student three responds to the following questions: where do the concepts fit in the science curriculum? How would one present these concepts/ideas/experiments in the classroom? What are the diverse connections of the concepts under discussion?

Table I. Guidelines for designing historical case studies

1. Map out a context with one unifying central idea that is deemed important in science *and* is likely to capture the imagination of the student.
2. Provide the student with experiences that can be related to his/her everyday world as well as being simply and effectively explained by scientists' science but *at a level that "makes sense" to the student.*
3. Invent a "story line" (may be historical) that will dramatize and highlight the main idea. Identify an important event associated with a person or persons and find binary opposites, or conflicting characters or events (Egan 1986) that may be appropriate to include in the story.
4. Ensure that the major ideas, concepts and problems of the topic are generated by the context naturally; that it will include those the student would learn piece-meal in a conventional textbook approach.
5. Secure the path from romance to precision to generalization (Whitehead 1985). This is best accomplished by showing the student that
   a. problem situations come out of the context and are intrinsically interesting;
   b. that concepts are diversely connected, within the setting of the story as well as with present-day science and technology;
   c. there is room for individual extension and generalization of ideas, problems and conclusions.
6. Map out and design the context, ideally in cooperation with students, where you as the teacher assumes the role of the research- leader and the student becomes part of an on-going research program.
7. Resolve the conflict that was generated by the context and find connections between the ideas and concepts discussed with the corresponding ones of today.

Confrontations. We are inclined to think of modern science as having resolved most issues. Quite the contrary is true; science in the 20th century is fraught with confrontations, some completely or partly resolved, and others still raging. Sometimes there are many competing theories seeking to lay the foundations of a new discipline, as in the case of the eighteenth-century science of electricity and Lavoisier's new chemistry and the alchemists, but mostly scientific confrontation is the squaring off between two rival theories.

Thematic narratives. This approach identifies general themes that transcend the boundaries of individual scientific disciplines and may have interdisciplinary and humanistic connections. For example, the thematic couple of atomism and continuum "played an important role in shaping the conceptual structure of early twentieth-century biology and science" (Jordan 1989). Other themes could be conservation, time, regularity and evolution. These themes transcend individual disciplines and often link major activities in the various disciplines and touch on humanistic activities. It is often convenient to connect several small case studies to produce a continuous narrative with an underlying theme.

Dialogues. Galileo used the dialogue format in his books in order to dramatise his science. To make his "new science" more accessible to the general reader he wrote the text in Italian rather than in the conventional Latin. Galileo's approach has been "rediscovered" by several science educators (Lockhead & Dufresne 1989; Raman 1980): "The method I discovered recently was to present the relevant information and ideas in the form of a dialogue in which the original scientists are made to speak of their ideas and theories" (Raman 1980, p. 580). The following dialogues have been developed and presented in class by students: Copernicus and the Aristotelians; A creationist confronts an evolutionist; Priestley and Lavoisier discuss the relative merits of phlogiston and oxygen theories in explaining combustion and 'calcination'.

Dramatization. The role of the scientist in society has been a subject for playwrights for hundreds of years, many modern plays have been written about science and scientists in modern society (Brecht: *The Life of Galileo*; Golding: *The Physicists*; Kipphard: *In the Matter of J. Oppenheimer*. Recently the play *Copenhagen* that is essentially a dialogue between Heisenberg and Bohr in 1941 has been playing to capacity audiences in Europe and North America. Duveen and Solomon (1994) have written and used such plays as The Great Evolution Trial to encourage students to role-play in the classroom.

In our science history classes we have developed dramas (as amateur playwrights, of course) for the purpose of presenting them in a science classroom. They have been quite successful in the University setting: *The Trial of Galileo*; *The public debate between science and the Church of England:* Darwin (actually, his "bulldog" Huxley) confronts Bishop Wilberforce; *The Age-of-the-Earth debate* (A debate set in 1872, with Kelvin, Huxley, Lyell, and Helmholtz representing the disciplines of physics, biology, geology, and cosmology).

3. Remarks about Contextual Teaching: From Early Years to University

We believe that a science curriculum should be humanistic, context-based, and well connected to a sound theoretical structure (Stinner 1994a). It should contain a sequence of theoretical and empirical experiences involving contextual teaching, science stories, thematic teaching, and popular science literature teaching. For early years (K-grade 4) one would like to see a program of simple science stories that deal with the child's conceptions of the world. We want to recognize, respect and build on children's early conceptions, using motivating contexts that involve an exciting story-line and employ a number of first hand experiences. These activities should be guided by a sound conceptual development model. The model should assume that teachers will neither challenge children's "common sense" science with scientist's science, nor attempt to impose scientific understanding on children. Rather, teachers help children to build domain-specific knowledge and effective scientific reasoning by means of scaffolded instruction that is carefully attuned to children's prior experience and thinking (see Fraser & Tobin 1998; Glynn & Duit 1995; McGilly 1994; Minstrell & van Zee 2000; among others). Ways to guide conceptual development of children between the ages of six and ten involve experiences that enable restructuring of conceptual models through first-hand investigations that make public what is observed and inferred (cf. Gallas (1994), talking, writing, dancing, drawing, and singing understanding of the world). These exploration, practice, and application activities are one part of a sequence of carefully designed lessons that build on examples, analogy, themes, theories, or models inaccessible to young children through everyday experiences or common sense reasoning.

It is hoped that the science stories will be connected to a program of activities like those suggested for an early introduction to physics by Osborne and Monk (Osborne 1984; Monk 1994). These activities would involve air tables to study motion qualitatively, watching and discussing objects falling in air and in a vacuum, learning that words have different meanings in different contexts, discussing images and passages from stories and films and discussing, after experience makes obvious, the need for clear definitions in science.

For middle years these early stories and contextual activities could be followed by science stories based on history, and by contexts based on students' experiences and on contemporary issues that students are interested in. The science of the Greeks, because it is essentially high-grade thinking based on unaided observation, seems especially well suited for teaching science in the middle years.

In the senior years case studies can be introduced that discuss one main idea and/or experiment as well as those that discuss science *thematically*. Many science teachers, of course, already use, at least implicitly, such themes as the corpuscular nature of matter, the notion of conservation, and the wave-particle duality of matter. The criterion of selectivity here should be based on how well known the outcome of the story is. Physics teachers interested in using history of science know that telling the story of Galileo and the inclined plane often fails to make an impact if the description of the motion has already been learned from a textbook.

Contextual settings, including science stories, of course, can also deal with the relationship between science and technology and society. Clearly, STS themes that are now very popular can easily be accommodated by the contextual teaching discussed here. Indeed, students at the University of Manitoba and the University of Winnipeg have developed LCPs based on such themes as *Nuclear Energy*, *The Flood of the Century*, *Food Processing and Irradiation*, and *Genetic Engineering*. STS issues will emphasize the added dimension of the relationship between science, technology and society. However, we must try to make the context for STS teaching interesting and appropriate for the student, roughly as suggested by the guidelines for writing LCPs and science stories.

For the college and first year university science classroom we need large scale discussions, extensive well crafted contexts that do not shy away from detail and mathematical complexity.

4. Proper Insertion of Modes of Presentation

Finally, we comment on the proper insertion of these various modes of presentation in the science classroom for all levels. Monk and Osborne (1997) present a sound and well-argued pedagogical model that allows the insertion of the HPS alongside each major idea or concept discussed in the science classroom. They point out that we cannot rely on textbooks to incorporate significant HPS, and that the prevalent model for the incorporation of HPS in science education has been the occasional addition to supplement and "humanize" the text book-centred science taught. On the other hand, a complete historical presentation, along the lines of Harvard Project Physics (HPP) must be considered impractical. HPP was a heroic effort to teach physics entirely by using sequences of historical contexts connected by large themes that unfortunately ended as a "glorious failure". The text for this splendid course is still available and there are "islands of excellence" in the US were high school physics is taught using this text by exemplary and intrepid physics teachers.

We approve of the supporting arguments and the model presented by Monk and Osborne, but recommend an *eclectic* approach to the insertion of the HPS in science teaching. For a large number of ideas and concepts, especially in middle years, we believe that the model proposed by them would be appropriate. However, we suggest the *timely* presentation and the discussion of a vignette (Archimedes and Hero's crown) along the lines suggested by Wandersee (1990); the use of a case study (Galileo's inclined plane experiment) *prior* to textbook-centred discussion, and the *replacement* of the textbook discussion of some major sections with an historically-placed theme approach (Newton's laws of motion as described by Stinner (1994c)).

Clearly, this kind of eclectic science teaching can only be trusted to teachers who have more than a cursory acquaintance with the history and philosophy of science, and have good content and pedagogical content knowledge in science. Our aim should be to design programs for teacher education that produce such teachers.

We will now turn to the detailed discussion of using contextual settings, stories and modes of presentation and the appropriateness of these approaches for the science classroom, from early years to the college and university level.

Barbara McMillan, an early years science specialist, discusses science education for young children and the appropriateness of including aspects of the history of science in an early years program. She argues that the story aspect of thoughtful, well-placed historical vignettes is appropriate. Arthur Stinner, a science educator, presents a fascinating case study that is suitable for middle years science. He demonstrates that this interesting story can be called a scientific confrontation that middle years students would find interesting and be able to understand. Don Metz, a physics educator specializing in physics teacher education, discusses the changing model of electricity, using a thematic approach. He believes that the study of the evolution of models in electricity will help students better understand the nature of science. Jana Jilek, an instructor at a technical college uses a thematic approach to trace the history of fundamental electric concepts and units. She argues that awareness of the history of science and technology can aid students in developing technological literacy beyond their specialization. Finally, Stephen Klassen, specializing in introductory physics teaching at the university level, presents a sketch for a case study that discusses, what may be called "high-tech" activity of the 1860's. He shows that this involves considerable mathematical skill and is suitable for teaching high-grade physics-in-context to university students.

5. Early Years Science

Given the uncomplicated level at which young children are acquainted with elementary concepts in science, it is not immediately clear how the history of science could make possible a deeper understanding. It is cognitive outcomes as opposed to affective outcomes that are considered here since young children do not have to be convinced that science is exciting and interesting and a practice in which people are actively engaged. From this perspective, the decision to be made regarding the history of science is not how it can be integrated or appended, but where in the curriculum the historical context is the most appropriate for teaching toward the attainment of the general and specific outcomes specified in provincial and national curriculum documents. Finding the answer to the latter is a more difficult task than perusing the learning outcomes embedded in a curriculum and locating the sections in which a biographical vignette, historical experiment, or one of the science stories referred to by Milne (1998) could be incorporated.

Using the Kindergarten-Grade 4 Manitoba science curriculum as the example, one could make use of any number of the following historical episodes: the story of shadow clocks and sun dials; Jan Baptista van Helmont's investigation of a willow tree potted in soil; Gilbert's study of magnetism and the story of the compass; von Guericke's bell-in-a-jar experiment and its confirmation by Boyle; Konrad Lorenz's studies of bird behaviour; Newton's experiments with glass prisms and the refraction of sunlight; and other events too numerous to mention here. Regardless of the episode chosen, one will either notice that its relevance to the cluster is minimal as it supports the acquisition of a very limited number of learning outcomes, or that the conceptual awareness necessary for making sense of the episode is too advanced to be meaningful to children. The Manitoba "Grade 2, Cluster 2: Properties of Solids, Liquids, and Gases", and what is commonly known as Archimedes' "eureka" experiment is a clear case in point.

There are nineteen specific learning outcomes (SLOs) listed in the Manitoba curriculum framework document for Cluster 2, which essentially introduces young children to physical chemistry and states of matter. Three of these nineteen SLOs[1] are focused upon materials or objects that sink or float or can be made to sink or float. It is expected that at the end of the cluster children will realize that solids will vary in the ability to float, that the shape of a material or object will affect its ability to float, that the lightness and heaviness (density) of a liquid will affect how well solid objects float on or in it, and that materials that float regardless of their shape are not affected by fastening them together to make a larger shape, putting holes in them, or cutting them up. There is no attempt to have the children consider why an object floats or sinks in a liquid. Yet, it is this explanation that Archimedes sought to provide when he determined that an object floats when it displaces a volume of liquid that is equivalent in weight to the weight of the object itself. This particular set of circumstances begs the question, does the water displaced by King Hero's crown and the water displaced by a lump of gold of equal weight help children to understand the content of this cluster? What exactly is it that the story of Archimedes would contribute if it were part of the Grade 2 science curriculum? It is not possible to answer this question without knowing the final form in which the story will be presented.

Those who regularly read to young children will appreciate that compared with the biological, earth, and space sciences an inadequate number of engaging materials exist in the physical sciences. Fine pieces of children's literature on sinking and floating, like Pamela Allen's (1982) Who Sank the Boat? do exist, and are used by teachers, but they are rare. In contrast, biographical stories of famous scientists like Galileo, Newton, Pasteur, Faraday, Curie, Darwin, and Einstein are common. Subject and word-in-title searches of the local public library database identified five biographies on Archimedes in juvenile literature.[2] Neither search included the many texts that devote several pages of one or two chapters to important events in Archimedes' life.[3] Without question, biographical resources exist for teachers to access, but, as will become evident, they may or may not be telling the stories that historians and philosophers of science would prefer that children hear.

In Gordon's book, Archimedes receives the crown from Hero, slowly walks home thinking about the problem Hero has posed, "sits down and tries to find the answer" (1971, pp. 22–26). While deep in thought, he decides to bathe. As he steps into the bath prepared by a servant, the water overflows. At this point in the story, Gordon writes, "Here was the answer! He leapt out of the bath and, still naked, ran down the cobbled street, past the market-place to the palace. People stared at his unclothed figure as he ran past them shouting, "Eureka, Eureka", which means. "I have found it, I have found it". Gordon continues by describing Archimedes demonstration, and explanation to King Hero, of the unequal displacement of water by the crown and an equal weight of gold.

Bendick (1962, pp. 54–60), Lafferty (1991, pp. 23–26), and Lexau (1969) deviate from Gordon's telling of the story by having Archimedes spend days and nights sitting and staring at the crown. In Lexau's version, Archimedes is described pacing the floors, bumping into buildings, drawing and writing in the sand floors of his residence, talking to himself (thinking out loud), and forgetting names and people as well as the passage of time. Bendrick has Archimedes forget to eat, bathe, or change his clothes. He becomes so unkempt that two of his slaves eventually pick him up and carry him off to the baths. On the way, Archimedes shouts and demands to be put down because he has more important things to do.

Ispen (1988, pp. 10–17), rather than simply recounting the eureka story in his chapter titled “Naked Truth”, talks about its accuracy. After writing, “Great thinkers seem often to be remembered more for their actions than thoughts”, he advises the reader that historians don’t really know what Archimedes discovered, because “Archimedes neglected to write down what he did”. He then discusses several methods that could have been used by Archimedes to determine the purity of Hero’s crown.

Children hearing these stories will giggle at Archimedes’ absent-mindedness, and may conceivably walk away thinking that scientists are preoccupied by their work, spend an inordinate amount of time in contemplative thought, try to solve the problems of others, and work alone. Several children may even be convinced that if you sit and think about a problem long, and hard, enough the solution will eventually come to you just as it came to Archimedes. Research on long-term recall, however, indicates that students remember personally involving narrative information, imagery, and actions by characters rather than names, definitions, and objectively important content (see Cunningham & Gall 1990; Sadoski & Quast 1990; among others). This suggests that Ispen is more insightful than we would like to believe; that it is the naked run that children will remember, not the name Archimedes or what his prepared mind helped him and others to see in a new way.

Perhaps the best conclusion to draw from the preceding discussion is the one that the authors of the *Benchmarks* document came to articulate. That is, “[t]he history of science and technology is too advanced a subject for students in the earliest grades” (AAAS 1993, p. 15). The science we teach to young children is, after all, more commensurate with natural history than contemporary physics, biology, or chemistry. The content is observable and the focus invariably is *what do you know* and *how do you know* rather than *why are things the way that they are* and *why do things happen the way that they do*. This doesn’t imply, however, that teachers should avoid telling stories of scientists to young children. The science stories and the contexts in which events unfold should simply be of scientists who observed the natural world and described and classified its contents. Explanations of phenomena using mathematics and logical operations can wait.

6. Middle Years Science

6.1. CONTEXTUAL TEACHING IN MIDDLE YEARS SCIENCE

Many of the main ideas and concepts in biology, chemistry, and physics of the 18th and the first half of the 19th century can be discussed in middle years education and many of the key experiments replicated. The story of Lavoisier and the chemical revolution and Dalton atomic theory is appropriate for middle years science. In biology, teachers should develop simplified approaches to show how Pasteur’s experiments refuted spontaneous generation and how Semmelweiss’ observation led to the germ theory of disease. Most of the classic experiments of Faraday on electricity and magnetism, as well as those of Joule in establishing the principle of the conservation of energy, are easily replicated and the relevant concepts are amenable to elementary analysis. We probably should do better here than what conventional textbooks allow us to achieve.

6.2. COUNT RUMFORD AND THE CALORIC THEORY OF HEAT

We have chosen a vignette that discusses a famous confrontation in science that most textbook report in one or two sentences. This mode of presentation can be considered as a "mini-confrontation", suitable for the late middle years science class.

7. The Historical Context

Count Rumford (Benjamin Thompson) was one of the most colourful and imaginative scientists of modern times. He was an amazing character, a combination of an eighteenth century James Bond and Indiana Jones. Most textbooks make a fleeting historical reference to him in connection with his experiments that "refuted the caloric theory of heat". Even a cursory review of the history, however, will reveal that the real story is more complicated and much more interesting. Rumford was an excellent physicist and one of the most imaginative experimenters of the eighteenth century, investigating a host of seemingly diverse physical phenomena.

Benjamin Thompson was born in poverty in 1753 in Woburn, in colonial Massachusetts. He was later known as Count Rumford, General of the Army in Bavaria, famous scientist, versatile inventor, public benefactor, and a clever spy. He was very interested in scientific ideas, mechanical devices, and experiments involving heat, light, and gunnery. He made original contributions to each of these areas (see Brown, 1962, 1968–1970, 1976 for fuller accounts of the life and achievements of Count Rumford). Among his many legacies are the famous "Englische Garten" in Munich and the Royal Institute of London. Today, the former is the favourite park of the inhabitants of Munich and the latter still serves as a well attended forum for public education of science and technology in London.

At the age of fifty-eight, Count Rumford left London and spent his last years in Paris. He married Lavoisier's widow, but the relationship turned out to be stormy one, much to the delight of Parisian society. In Paris, he continued his scientific investigations that ranged from the study of radiation of heat to the invention of a dynamometer to test the efficiency of a horse-drawn carriage.

Rumford died suddenly in Paris in 1814, at the age of sixty-one. His scientific investigations included seminal work in radiation of heat from different kinds of surfaces, diffusion of liquids and gases, measurement of the mechanical equivalent of heat (anticipating Joules' work by some thirty years), development of the photometer to measure light intensity, studies of the transference of heat through a vacuum (the first to clearly differentiate between radiation, convection, and conduction in heat transfer), experiments to test the caloric theory of heat, and the determination of the density of water at various temperatures.

7.1. MAIN IDEAS AND EXPERIMENTS

In order to explain such phenomena as thermal expansion, experimental results of calorimetry, latent heat of water, and the conduction of heat in metals, the *caloric theory* was developed. The caloric theory has left us with a legacy to be found in such conventional expressions as "the flow of heat", "heat capacity", and the less often used "latent heat", "heat of vaporization", and "specific heat". The theory was very successful and was championed by the greatest scientists of the day, including Lavoisier, Laplace, Priestly, and others. Indeed, even Rumford's brilliant experiments were not sufficient to overthrow the theory until decades after his death.

The theory seemed to be a remarkable triumph of rational intelligence (Wilson 1960, p. 61). It could account for the difference between solids, liquids, and gases, for the conduction of heat in solids, and for thermal expansion. The theory was only partially successful in explaining why the specific heat of solids must increase with temperature and why conduction of heat should increase with the density of a solid. However, the caloric theory encountered great difficulties when trying to explain the "latent heat" of substances, why compression of a substance should squeeze out caloric, and why, when pressure is applied the solids, gases, and liquids, their temperature rose.

Rumford was in charge of the work in the Bavarian military arsenal, supervising the boring and the finishing of canons in the 1780's. He believed that the heat involved in this action was much more than could be accounted for by adding up the total amount of heat in the casting, the cutting tool, and the chips. He designed an elegant experiment to test this hypothesis that *the heat generated by friction appeared to be inexhaustible*, even when the bodies rubbed together where perfectly insulated. Rumford then asked two fundamental questions: "Whence then came this heat?" and "What is heat actually?" Referring back a hundred years before him, he believed that Boyle and Hooke must have been right when they suggested that "heat is nothing but a vibratory motion taking place among the particles of the body" (Wilson 1960, p. 164).

7.2. IMPLICATIONS FOR THE SCIENCE CLASSROOM

Many of the experiments that Rumford performed can be replicated by students in late middle years and the first senior years. However, before doing so, teachers could present the caloric theory along the lines previously suggested and discuss it as an explanatory theory for many everyday phenomena. Following that, teachers could set up experiments inspired by Rumford.

After completing the experiment and discussing the results as well as Rumford's explanation for his heat experiments, students could be given an abridged version of the letter the famous John Dalton wrote to Rumford. Dalton vigorously disagreed with Rumford's explanation. Dalton, who believed in the caloric theory, argued that once a body was in temperature equilibrium with its surroundings, it was in a state of complete rest. That is, all the atoms and molecules would be in a state of complete rest. Rumford, however, countered that there was a connection between heat and motion even at equilibrium temperature. To show that this was so, he performed the following experiment that students could try to replicate.

Rumford took two liquids, a salt solution and pure (distilled) water, and put them in a glass container in such a way that the salt was at the bottom of the glass and the water on the top. He put the water in first and then introduced the salt solution below the water by pouring it through a funnel to the bottom of the glass. Then he dropped a single drop of oil of cloves into the glass. The drop sank in the water but floated in the salt solution, coming to rest halfway down the liquid column. The whole experiment was carried out in his cellar, where the temperature was constant. He found that eventually the drop of oil of cloves rose slowly to the surface. His explanation was that the internal motions of particles of the liquid continued even at temperature equilibrium, which contradicted the caloric theory of heat.

Who was Benjamin Thompson? Was he an adventurer, a statesman, a military genius, a great inventor, a social benefactor, perhaps a great scientist? Clearly, Rumford does did not fit the popular stereotype of the reclusive, introverted scientist. By examining their personal lives and while tracking their paths to the discovery of fundamental and far-reaching scientific principles in the context of scientific knowledge and beliefs of their time, students will come to understand that science is something other than the revealed truth as it often seems to be portrayed in textbooks. Of course, this same approach can be used with more contemporary scientists such as James Watson, Francis Crick, Linus Pauling and Steven Hawking.

8. Senior Years Science

In senior years students begin to move from a descriptive mode of science to a more explanatory mode through the use of models, laws, and theories. We have previously stated that science education continues to focus on a textbook-centered presentation of the finished form of science which views science as an established body of knowledge where the models, laws, and theories of science require minimal justification. In spite of recent curricular efforts (Pan-Canadian science frameworks) to promote a more eclectic view of science and an understanding of the nature of science, few contexts exist where such a view may be practised in the classroom. I am arguing that, in many cases, the historical development of conceptual models (HDCM) will provide such a context to meet many of the goals and outcomes of the Pan-Canadian view of the nature of science.

A model is a representation of an idea, object, event, process, or system (Gilbert & Boulter 1995) that can be expressed in many different ways (as diagrams, physical models, language). We infer and build imaginative models that connect our experiences and observations with scientific theory. Models, therefore, hold a position between our observed reality and scientific theory. Gilbert and Osborne (1980) also suggest that models enable concentrating study on special features of a phenomenon and that models stimulate investigations by supporting visualisation of the phenomenon.

Gobert and Buckley (2000) recently outlined the basic assumptions and underlying principles of research programs in model-based teaching and learning. They accept the position that people construct and reason with mental models, and that the evaluation of a model may lead the learner to reject or revise the model. Buckley describes model-based learning as a dynamic, recursive process that involves the formation, testing, and reinforcement, revision, or rejection of mental models. In her study, Buckley uses various models of the heart as a means of developing an understanding of the circulatory system and as an avenue for the learner to generate and consider further inquiries. In lieu of a factual accounting of the relationship between the circulatory and digestive systems, students use a multimedia approach based on an anatomical context which provides open access, when needed, to relevant information.

Stinner (1994a) reminds us that learning in science is well motivated by contextual teaching, and that another way to achieve this is through the context of history. The context of history provides the student with a sense that scientific theories are developed in a historical setting, and that confrontations and competing theories in science play an important role in the development of new ideas. Understanding how scientific concepts were acquired in the first place enables the learner to view the products and processes of science in a more authentic view of the nature of science.

Recent curricular efforts, like Project 2061 and the Pan-Canadian science frameworks, suggest that the nature of science should play a prominent role in today's science curriculum. However, little or no context is provided for teachers to implement goals such as the "development of scientific theories and technologies over time" (p. 26) in the science classroom. Lederman (1998) argues for a more explicit treatment of the nature of science. I suggest that the HDCM can provide a context for addressing these nature of science outcomes explicitly in a pedagogically sound and motivating manner.

The inclusion of the historical development of conceptual models naturally promotes a better understanding of the nature of science. In general, models are viewed as more tentative than theories or laws (Kipnis 1998; Machamer 1992). Additionally, the contributions by many individuals over time, portrays science as a more humanistic endeavour, marked by intellectual struggles, and personal and cultural influences. In this sense, we move from the naive view that textbook models are an exact replica of nature to the view that models are products of human creativity and imagination. Justi and Gilbert (2000) also suggest that the development of historical models outlines a more authentic understanding of the philosophy of science. They propose a Lakatosian view of science using questions such as "how does the model overcome explanatory shortcomings of its predecessor or competitor", to focus attention on degenerating or progressive research programmes.

In another effort to advance a philosophically valid curriculum, Hodson (1988) argues that as children begin to acquire more experience they need to develop their personal theories into more complex structures and pass through several developmental stages. These stages include a tentative introduction of several models, a search for evidence, selection of the best model through discussion and criticism, and further elaboration of the model into a more sophisticated theory. In science instruction, students should be able to introduce their own experiences, make their own ideas explicit through writing and discussion, and explore, challenge, and devise tests for alternative viewpoints.

Final form science, today's textbook approach, does not permit the opportunity for the student to develop tentative models. HDCM allows students to consider their preconceptions in the light of some of the early conceptions of great scientists. These early ideas form an introduction of a tentative model which can be confronted by unsolved puzzles and discrepant events as the model is modified or replaced by more a plausible model. Further, it promotes a better understanding of the nature of science by encouraging students to challenge early models of science and, ultimately, their own conceptions. The following example outlines an HDCM strategy that can be used to introduce electricity in a secondary science classroom.

8.1. DEVELOPING A MODEL OF ELECTRICITY

Students, like scientists, can initiate discovery by relating their own encounters with electricity in a story before they begin formal deliberations. Many students tell stories about walking across a carpet and touching a metal doorknob; using a potato to unscrew a broken light bulb (in a live socket!); or they tell a story of a hair-raising brush with an electric fence down on the farm. Unique tales abound and students attribute their experiences, in a rather vague manner, by claiming that what caused the effect they describe is "electricity". Some students will inevitably invoke the idea of an electron without having a clear idea of what an electron is. Once a student lays out his/her prior knowledge, we can begin to examine the nature of electricity in discussion groups by posing the question, "What could electricity possibly be?" Initially, anything goes, and we do not reject any ideas. Soon we find that some ideas seem more plausible than others and warrant further investigation. Interestingly, all answers can be sorted into one of two categories: electricity is either discrete, like a particle, or continuous like a fluid.

These initial assumptions of students often lead us to the ideas of the early scientists and philosophers. Plutarch, for example, believed that when amber was rubbed, it gave off heat, which warmed the surrounding air. Then, the air swirled behind nearby objects, like tiny bits of straw, and pushed them back toward the electric (Roller & Roller 1954). Good models provide simple explanations, enable predictions, and can be easily tested. Students form groups of three, and they are asked to evaluate Plutarch's model and devise some tests to confront the model. Fundamentally, they recognize that the two important aspects of Plutarch's model are heat and air, and they tend to propose investigations that manipulate one or the other. Some groups may suggest that we measure the temperature of the air or move the experiment to a colder environment. Others will focus on the air alone and propose that an experiment be performed in a liquid or in a vacuum. Further discussion directs us to examine the consistency of the model with the Aristotelian view that a vacuum could not exist. Therefore, heated air, rushing in to fill a void, seemed like a reasonable explanation in Plutarch's time.

Other models are also examined. In 1600, Gilbert presented a model of electricity in his treatise *De Magnete*, which suggested that an "effluvium" was emitted by the "electric" and adhered to the nearby object pulling it back toward the electric. When asked to challenge Gilbert's model, students readily acknowledge that we could put something in between the electric and the object. After students challenge these early models, they must begin to face the consequences of their own conceptions as they construct a proto-model of electricity using simple experiments to demonstrate the existence of two types of charge. For example, we can place a piece of Scotch tape on a table and press another on top. If we remove them swiftly and separate them, they become oppositely charged. In all cases, we find that the top tape repels any other top tape, the bottom tape repels the bottom tape, and the top and bottom tapes attract. The principles of this proto-model soon become clear; charge is the name of the property that gives rise to electrical phenomena and there are two types of charge; like charges repel, and unlike charges attract.

We must now challenge our own model, test it, and modify it to elaborate further explanations and predictions. Using 18th century models of one fluid, two fluid, and two particles, students write their own explanations for simple electrostatic phenomena. Using a one fluid model, students usually propose that when one tape is pressed onto the other, pressure displaces some of the electric fluid from the top tape into the bottom tape. The top tape now has less fluid and the bottom tape more fluid, that is, they become oppositely charged, and charge is conserved. Students recognize the fluid models as the foundation for plausible explanations of electricity. In order to challenge the model, however, consistency with scientific theories in other domains must be considered. Faraday's experiments, Thomson's discovery that cathode rays were particles, Rutherford's gold foil experiment, and Millikan's oil drop experiment provide strong evidence for believing that the particle model is a good model of electricity.

The student is now asked to confront the particle model with another question: "Why isn't there a third type of charged particle, and if there was, what kind of behaviour would it have?" If a third kind of charge existed, it would have to attract or repel both of the other two charges. We can now introduce a discrepant event by bringing a neutral insulator nearby both types of charge. The fact that the neutral object attracts both types of charge is a puzzle. Once more, we need to elaborate our model to include an explanation for the fixed nature of one charge and the movement of the other charge. Finally, we check for consistency with the atomic model of matter and, if you want, you can now even name the charges. A wide variety of electrostatic phenomena can be investigated and, later, the particle model of electricity can be extended to include current electricity and the behaviour of electric circuits. In all cases, students are asked to outline their own ideas and confront and challenge the ideas of some of the greatest thinkers in the history of science.

9. College Science

On the college level incorporating history of science and technology into individual technical courses can give students who have chosen careers in technology a broader view, a greater appreciation of the issues in their chosen field, and assist them in making informed decisions on the advantages and drawbacks of technology and science related issues.

Technology programs in western Canada are usually two year programs. They tend to concentrate on one narrow aspect of technology, for example, telecommunications, power systems, or computers. With the rapidly increasing complexity of our technology, the demands on specialized knowledge are increasing. At the same time, professional organizations demand inclusion of management courses in technology programs. Since increasing the length of programs is often not considered viable, the solution is to cut down on the more general science courses. The cutting down produces technically trained people who are not necessarily technologically literate. They are knowledgeable in only one narrow area of their discipline, and unfamiliar with other types of even closely related technologies.

Well-known Canadian engineer Ursula Franklin (1990, p.12) defines technology as a system that includes the material components, organization, procedures, symbols, new words, equations, and a mindset. According to her, the people engaging in technology as their occupation must acquire a factual knowledge of all these aspects of technology.

Whenever we are involved with technology, designing equipment, using it for control of processes, etc., we tend to believe that only the latest technology counts. We talk of the "leading edge of technology" and imply that whatever was in past is left behind. Technical subjects we teach reveal what is, with no connection to what was before. We tend to forget that developments in technology are often arbitrary, and that they lead to arbitrary standards. We carry these standards along as we go, for better or for worse. Unfortunately, this lack of connection to the past can lead to a lack of understanding, and even to misconceptions. We will use several examples from electrical technology to illustrate that the history of technological developments can deepen understanding of all four types of knowledge.

In the field of electric power transmission, protective equipment on transmission lines is now microprocessor based, but designed in such a way that it emulates characteristics of older analog devices. Learning to use and set these devices (a technical skill) is enhanced by knowing how their properties were determined. Analyzing their performance (engineering knowledge) in a power system is also enhanced. Another example is our use of 60 Hz frequency; students are often puzzled why exactly this frequency is used, thinking that there perhaps were studies done in the past that established this frequency as “the best”. The history of development of electric power transmission, however, reveals that power transmission originally started as direct current transmission, then was supplanted by systems using various frequencies, and finally engineers settled on our present standard for no particular technical reasons. In our experience, narrating the turbulent years of fierce clashes between Edison and Westinghouse toward the end of nineteenth century in courses on power systems for electrical technology students, not only adds excitement but deepens the understanding why the equipment and standards are the way they are. Knowing about the developments and difficulties encountered during the past 150 years of power systems impact on technical skills, engineering knowledge, and depending on the depth of the course, on problem areas and the scientific knowledge of the technology students.

Awareness of the determining factors in developing of ideas of science is an important factor in understanding theories in science and engineering. Similarly, pursuing the history of development of devices and machinery is an important factor in understanding how the devices are modelled and analyzed. History can also put into perspective the relationship between technology and science. Today we think of technology as the application of science. Popular media, and often science teaching, present scientific theories as the necessary starting point for development of new devices, that is done in large institutionalized research laboratories. Historical studies, however, show that the large institutionalized research laboratories did not exist until about 150 years ago. There are many examples illustrating that not only can technology develop without a scientific theory, but that it can actually be a necessary foundation in the development of science theories. Perhaps the best example pioneering technology is the work of T.A. Edison, who employed in his laboratories large number of technically highly gifted people to work on improvements of many technological ideas without the direct use of scientific theories. In fact, entire industries developed by trial and error – shipbuilding, textile industries, building construction are just a few that were well developed without application of science theories. We do not mean to diminish the importance of science in technology, but wish to emphasize how intertwined they are. An example of the interdependent relationship is the development thermodynamic theory. The necessary motivations for the development of the theory of thermodynamics were the invention of steam engine and the need to increase its efficiency. Moreover, the relationship between science and technology is continuously changing. Although in the past it was technology that enabled science developments, in more recent history it is science that drives the developments in technology. The electronic and communications devices that changed our society would not be possible without quantum theory and electromagnetic theory.

I have very briefly attempted to outline how awareness of the history of science and technology can aid development of technological literacy. Both, science and technology develop within the constraints of society at the time the development is occurring. Understanding the changing nature of the relationship between technology and science, and seeing it in its historical perspective enhances our appreciation of both, positive and negative aspects of technology.

10. University Science

In university science teaching the amount of instructional flexibility is significantly greater than at high schools and technical colleges. Typically, the university course instructor need only abide by the published calendar course description, a task that can be achieved through diverse approaches. Provided that university science faculty are convinced of the desirability of the historical contextual approach outlined here, the type of educational reform we would like to see is more likely to happen in the universities. Already, various university and college physics departments have embarked on ambitious reform efforts that incorporate contextual teaching which includes the history of science as a context (Holbrow et al. 1999; Coleman & Griffith 1997). The historically based large context problem is one method of studying topics in a group setting (Stinner 1994b). At the University of Winnipeg, the Physics Department incorporates theoretical investigations as a component of the advanced laboratory. The large context problem approach provides a motivation, framework, and context for laboratory investigations of theory in addition to experimental investigations. One common topic in the university physics curriculum is electromagnetic theory. The story of Lord Kelvin and his development of the theory for signals in a long submarine cable and the subsequent laying of the first Atlantic cable presents this theory in the context of its origin.

10.1. LORD KELVIN AND THE ATLANTIC CABLE

The historical episode of Lord Kelvin (Sir William Thomson) and the laying of the first Atlantic cable between 1857 and 1866 is an epic story. It involves high drama-suspense and life-risking adventure. At the same time, the success of the mission was made possible only through the solution of a wide range of scientific and technological problems. In the story of the Atlantic cable the relationship between science and technology is vividly demonstrated. On the one hand, the success was made possible by Kelvin's science. On the other hand, Kelvin was dependent on the invention of appropriate electrical testing technology to try out his theories.

One of the key issues was the electrical characteristic of a long coaxial cable-a cable 2500 miles (4000 km) long. Natural philosophers of Kelvin's day disagreed on the way in which the cable parameters would affect their capability of rapid signal transmission; for example, Faraday thought that the cable capacitance would be the determining factor; but Kelvin disagreed. In 1855, he published a paper on the electrical characteristics of long cables. Kelvin's answer, which became known as his "doctrine of squares", was that the amount of signal delay depended on the square of the cable length. In addition, he maintained, in his dealings with the Atlantic cable company, that quality control measures be taken to insure the purity of the copper conductor, since cable resistance was a dominant factor (Dibner 1959).

The initial attempts at laying a cable in 1857 had failed, due to the breaking of the cable. In order to improve the capability to detect signals sent over the cable and to check cable integrity during the cable-laying, Kelvin invented a mirror galvanometer, which was called the marine galvanometer. This galvanometer was capable of detecting currents as small as 10^{-11} Ampere (Jewkes 2002). The letters of the alphabet were initially transmitted as certain amounts of deflection on the galvanometer scale. The invention of the marine galvanometer was seen, not surprisingly, as very significant at the time.

Kelvin participated, as an unpaid scientific consultant, in all the expeditions to lay the cables. During that time the pressure to succeed was immense, owing to the huge amounts of capital investment that had been made. Weather conditions added to the stress, with one fearful eight-day storm at sea threatening to sink the ships holding the cable. The atmosphere aboard ship was recorded by one of the electrical workers, who wrote, after a break in the cable had to be repaired while paying out, that "Never was more anxiety compressed into such a space" (Thompson 1910, p. 363). Kelvin, however, never doubted the ultimate success. When notification came on August 5, 1858, that trans-Atlantic cable communication had been established, there were public celebrations throughout the United States as had never before been witnessed. Kelvin (at the time still Prof. William Thomson) was soon knighted, and his personal popularity and scientific reputation never waned, thereafter. Despite the successful outcome, an unanswered question about the entire venture, and one worth discussing with students, is whether it was a gigantic gamble or a scientific certainty. Whether one views the project's success as inevitable is, to a certain extent, dependent on the degree of certainty one assigns to the conclusions of science.

10.2. APPLICATION TO UNIVERSITY CURRICULUM

A number of important physics problems are embedded in the Atlantic cable story. The main problem is the signal delay in a resistor-capacitor circuit, either done simply or according to Kelvin's original paper. In university textbooks, the topic of capacitance is normally presented as a set of facts and equations, at a simple level. The notion of capacitance was not clear at the time of Kelvin, and the development of the theory made the technological development possible. Today, in introductory college textbooks, the capacitance topic rarely goes beyond the defining relationship for calculating capacitance and the relationship yielding the time constant for a simple capacitor-resistor circuit, which may be perceived as dry and meaningless by the student. In considering a long coaxial cable, the student is challenged to take the theory to a more complex level. Other interesting problems are the theoretical calculation of the resistance and capacitance of the cable, based on its original specifications; the relationship of purity to resistivity of copper; the operation of a galvanometer; the strain on a cable being released into the water, applying Kelvin's original theory; the density of sea-water; and cable buoyancy. In using the story to teach a number of physics concepts, students should be encouraged, early on, to identify the problems involved and to choose those that would be both interesting and worthwhile to research and solve.

The Atlantic cable story is one of those rare stories that is not only able to capture the imagination of the reader, but may be used by teachers to motivate the university physics student to attempt to solve challenging problems and, at the same time, to contextualize those problems properly. When Lord Kelvin died in 1907, he was buried in Westminster Abbey, next to Sir Isaac Newton. In that light, it is interesting to note that we have placed Kelvinian problems in the curriculum next to the traditional Newtonian problems.

11. Conclusions

We have tried to present arguments for contextual and historical approaches in the teaching of science, from early years through post secondary education. We presented a description of the variety of approaches which includes the history of science in science instruction. We described the development of vignettes, science stories, historical case studies, scientific narratives, and thematic approaches to help teachers become more effective in the science classroom. Finally, we concluded with five sections in which historical approaches appropriate for early years, middle years, senior years, college, and university level were presented in some detail.

We believe that our work has been a modest response to the challenge that the noted science historian John Heilbron left us at the 5th (1999) IHPST conference in Como, Italy:

1. Produce case studies that are modular, testable, and encourage science beyond the textbook (so that they fit the curriculum or part of it) by an international team of historians, scientists, and teachers. The main reason for introducing the history of science is "that it offers examples of the difficulties that established scientists have had in constructing the concepts, and fitting the facts, that make up theories that students are struggling to master".
2. Write good biographies of scientists, especially those of the Galileos, Newtons, and Einsteins, suitable for the various levels of students' needs and ages.
3. Find funds to write books "showing how the ideas studied with the help of the materials in Part 1 have translated into machines and devices that have enhanced and threatened civilised life".

Education and Science students at the University of Manitoba have designed over one hundred large context problems and about as many case studies. The case studies are collected at the end of the semester and students sometimes use them in their teaching. They can be placed in about 20 groups, from *Archimedes' discovery of the law of flotation* and *Torricelli's experiment to determine the weight of the atmosphere* to *Mendel's experiments in plant-hybridization*, *John Dalton and his atomic theory*, and *Faraday's electromagnetic experiments*. We have also developed dialogues (*Copernicus and the Aristotelians*), confrontations, (*Dalton's atomic theory* and *Priestley's affinity theory in chemistry*). Finally, we have written science dramas such as *The Age-of-the-Earth debate*. This dramatization of a prolonged scientific confrontation among physics, geology, and biology was developed by on of us (Stinner) and performed at the IHPST conference in Como and later for the general public at the Deutsches Museum, Munich in November, 2000. The performance was also shown on Bavarian Television in December 2000 and again in January 2001.

Unfortunately, a systematic way of incorporating these case studies (various units of presentation) into formal school teaching has not yet been developed. As a consequence, evidence of their effectiveness is only anecdotal.

We believe that what is further needed is an international effort guided by historians, scientists, educators, and teachers, that will respond to Heilbron's challenge of writing materials and finding pedagogically sound ways of incorporating HPS in science education. It is time that the ideas of James Conant's case studies be updated and revised to serve the needs of 21st century students and societies. The expertise and the motivation are available. We do, however, need guidance and funding.

Postscript

We have just received another sizable grant from SSHRC for the 7th IHPST conference, to be held at Winnipeg, Manitoba in the summer of 2003. Our group, consisting of the authors of this paper (plus three additional members) are responsible for this conference. We are especially pleased because we see the awarding of these two grants as a recognition of the emerging discipline of the history of science in science education. The grant will allow us to finance a good number of Canadian graduate students who wish to attend the conference, provide partial financial support for invited speakers, as well as scholars from Third World countries, and will allow us to hire students to help us organize and administer the conference.

Notes

[1] SLO 2-2-17 Predict and test to determine whether a variety of materials float or sink in water. SLO 2-2-18 Demonstrate ways to make sinking materials float and floating materials sink. SLO 2-2-19 Use the design process to construct an object that is buoyant and able to support a given mass/weight. (Manitoba Education and Training, 1999, p. 3.31).

[2] Bendick (1962), Gordon (1971), Ispen (1988), Lafferty (1991) and Lexau (1969).

[3] These are books about science discoveries and scientists such as Sutcliffe and Sutcliffe's (1962) *Stories from Science 2*; Lafferty's (1992) *Force & Motion* in the Eyewitness Science Series; Verstraete's (1989) *The Serendipity Effect*; among others.

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