Placing the History and Philosophy of Science on the Curriculum: A Model for the Development of Pedagogy

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ABSTRACT: This article focuses on two of the principal issues for science curriculum developers who wish to introduce the history and philosophy of science into the teaching of science—the justification for, and the placement of, historical materials within teachers' schemes of work. First, it is argued that the history and philosophy of science must have a rationale that is integral to, and consistent with, teachers' main aims to have any chance of being considered for inclusion in a program of study. Second, the justification must point to places in schemes of work where the inclusion of history of science will directly contribute to students *learning of science concepts* and satisfy that principal objective. A new model for the inclusion of such material is proposed that directly addresses both children's alternative frameworks and the historical and sociocultural context of the discovery. It is argued that this model offers potential for improved learning of the concepts of science and for learning *about* science. ©1997 John Wiley & Sons, Inc. *Sci Ed* **81:**405–424, 1997.

INTRODUCTION

> I believe in it (the historical method) and spend much valuable time dealing with historical development, knowing full well that my pupils will benefit hardly a single mark in their examinations. (Haywood, 1927)

Seventy years later, secondary science education is still in much the same position as evidenced by Matthews's (1988, 1994) continued special pleading, rather than confident endorsement for the place of history and philosophy of science (HPS) in science teaching.

Moreover, it is a common observation that present, and past school science textbooks make only passing reference to the history of science. Such textbooks are written to provide students with the popular, contemporary, cleaned-up, and prejustified accounts of the behavior of

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the natural world. Where history is included, it all too often becomes fictionalized idealizations and conveys the Whig[1] view of history that science is a steady and cumulative progression toward the pinnacle of modern achievements (Brush, 1974).

In this article, we seek to discuss briefly some of the reasons for the notable failure of arguments for the incorporation of the history of science within science education, and to explore the reasons for the failure of the message to reach teachers. Furthermore, noting Santayana's sentiments "that those who forget history are condemned to repeat it," we suggest a new model for inclusion of the history of science within science education. Our central contention is that previous endeavors have ignored teachers' overriding concerns with the learning of science concepts and the classroom imperatives of the context in which they work. Hence, we attempt to explore what lessons can be learned from the history of attempts to introduce HPS into science education, and from current arguments which aim to give more emphasis to addressing the epistemological dimension of science.

Instead of the prevalent model, which sees HPS as additional and supplementary, provided to add cultural information or human interest, our proposed model for incorporating HPS, requires past scientists' views on natural phenomena to be set alongside those of students' views as other perspectives for consideration, making HPS a central feature of mainstream science education. The consequent shift to a plurality of viewpoints has two benefits. First, the consideration of alternative interpretations of evidence demands comparison and contrast, forcing science teachers to raise the epistemological questions—"How do we know?" and "What is the evidence for . . . ?" Second, the need for alternative explanations for the phenomena under investigation provides a natural means for science teachers to elicit students' prior knowledge, an action central to any notion of a constructivist pedagogy (Driver & Oldham, 1985). Subsequent introduction of modern textbook accounts for the natural phenomena can then build upon this epistemological openness. It is our contention that such a pedagogic strategy, whose focus is always the conceptual explanation and its justification, would not only support the *learning of* science but *learning about* science.

FRUSTRATIONS IN THE ATTEMPTS TO INTRODUCE THE HISTORY OF SCIENCE

Our argument is developed from two important points rarely considered by the many enthusiasts for HPS in science education. First, there is the view of the nature of science, and thereby science education, held by most teachers. Second, there is the issue of the imperatives of the classroom and the practicalities of teaching.

It is Reichenbach (1938) who is often credited with making the important distinction between the context of historical discovery and the context of epistemological justification. In the former, ideas are tentative, if not speculative, and described in language that is interpreta-

[1] This phrase is used to describe a historical approach which interprets the past in terms of present ideas and values, elevating in significance all incidents and work that have contributed to current society, rather than attempting to understand the then social context and the contingent factors in its production. For example, very crudely, the Whig view would portray Fleming's discovery of penicillin as one more successful achievement by a brilliant scientist in the struggle against infection. A more realistic account would demonstrate that it was a fortuitous event, contingent on problems of current interest in medical research, the weather at the end of July in 1928 which happened to be sufficiently cool to allow the mold to grow, the presence of the laboratory beneath that was investigating molds, and that even then, its beneficial application was delayed for 10 years before other researchers explored ways of producing the mold in commercial quantities. Practically without exception, science texts are simply not written with the intent to convey any of the latter type information on the context of discovery.

tive and figurative (Sutton, 1996), often using new metaphors (Eger, 1993). 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." Gallagher (1992), in looking at prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science, provides a recent reminder that, for science teachers, science is perceived as an established body of knowledge and techniques that require minimal justification. Such teachers often work from weak evidence and inductive generalizations (Harris & Taylor, 1983) and renegotiate classroom observations and events to achieve a social consensus (Atkinson & Delamont, 1977). Gallagher comments that, if science teachers consider the history of science for inclusion, it is generally in terms of humanizing science for the purpose of fostering positive attitudes toward science, rather than for the purpose of understanding the nature of science. For teachers of science, only the development of an understanding of science concepts and the nature and methods of science are internal to an education *in* science. The rest lie beyond the boundary of "what we now know," which, as Haywood recognized in 1927, is the limit that curtails science teachers' incorporation of history into schemes of work—that is, the necessity to teach specific content for the requirements of formal examinations.

Second, there is the effect of priorities in the process of teaching itself, highlighted in an elegant study by Hodson (1993) on the impact of the philosophical stance of five New Zealand teachers on their curricular decisions. Hodson found that such decisions were retrospectively rationalized in terms of three broad categories of concern. In order of decreasing importance these were: management and organizational principles; considerations about concept acquisition and concept development; and, finally, considerations about the nature of science and scientific activity. Hodson's data strongly support his conclusion that "even when they (teachers) hold clear and coherent views about science and scientific inquiry, teachers do not plan laboratory-based lessons consistently or carefully in relation to those views." Lederman (1995) too, in a similar study, also concluded that "teachers' conceptions of the nature of science do not necessarily influence classroom practice." The evident lesson of this research is that the successful management of classroom events is the dominant imperative to which all other considerations are subordinated.

Consequently, even materials produced for teachers, for example, those produced in the UK (Honey et al., 1990; SISCON, 1983; Solomon, 1991), are not used for the reason given by Haywood (1927). Attempts to produce restructured courses that put history at the center of the enterprise (Arons, 1965; Klopfer, 1969; Nielsen & Thomsen, 1990; Schwab, 1962) have enjoyed only marginal success, as have those that have sought to introduce a more rigorous and current view of the philosophy of science (Connelly, Finegold, Clipsham, & Wahlstrom, 1977). In the now long history of attempts to introduce HPS into the curriculum, only *Harvard Project Physics* (Rutherford, Holton, & Watson, 1970) can be said to have enjoyed any success. In part, this failure may be due to the fact that many scientists and science teachers would not concede that the study of the history of science has anything to teach about the methods of research necessary to become a practicing scientist.

Therefore, the lesson of *the* history of attempts to introduce HPS into the science curriculum, which is the message that we will highlight, is that the history (and philosophy) of science will continue to remain *more talked about than taught* as long as the materials that teachers are provided with have *a bolt-on and additional-extra character* focusing on the context of discovery, rather than the dominant perspective of mainstream science teaching whose concerns are overwhelmingly with the products of epistemological justification and the methodology of science. Put simply, it is clear that too many of the justifications for the use of the history of science are provided by historians and philosophers with little knowledge of primary or secondary pedagogy rather than by teachers with a reasonable knowledge of history and philosophy. Even the recently established journal, *Science and Education,* set up in part to create a common forum for these two communities, has been highjacked by academia,[2] and is now of little practical interest or use to practicing science teachers. As long as the two communities maintain their mutual distance, this important aspect of science education will remain marooned in a sea of good intentions.

THE PROCESS APPROACH—AN INCOMPLETE EPISTEMOLOGY

Within the last two decades, a reaction within science education in the Anglo-Saxon world to the dominance of the *products* of scientific inquiry and the ever-expanding boundaries of scientific knowledge has been to place an increasing emphasis on courses that give preeminence to the *processes* of science. *Warwick Process Science* (Screen, 1986) and *Science in Process* (ILEA, 1985) are just two English examples of such curriculum offerings. In part, such courses sought to escape the narrow conceptual focus of science for scientists and offer a curriculum with wider appeal to all children. Their justification lay in the development of a set of generalizable skills applicable to a wide range of everyday problems. Whereas such courses have been the subject of substantive critiques (Atkin, 1968; Millar & Driver, 1987), the emphasis on process and, in particular, investigative work in science, has diverted attention away from the interpretative question—"What do these data mean?," and replaced it with the more insistent methodological concerns such as the identification and control of variables.

Essentially, this has occurred because many curricula have forgotten Schwab's (1962) important distinction between the syntactic (the rules for knowing) and the semantic (the meanings of knowing)—that is, the epistemology of science has not only a methodological component but also a interpretative component. Now, although there is considerable heterogeneity in the methods of science, at a fundamental level, the methodological component is concerned with the generation of appropriate hypotheses for testing, the identification and control of the relevant variables (fair testing), the collection of reliable data, the use of basic statistical methods, replicability, and validity of measurement. All of these justify a belief that the evidence is relevant, significant, and trustworthy. However, within school science, a focus on this restricted set of processes, the exigencies of time, and an overcrowded curriculum lead to foreclosure so that a singular interpretation of the evidence is offered—the standard scientific idea. Alternatively, when practicals fail to produce the "correct" results, teachers are forced into "talking their way out of it" (Nott & Wellington, 1995), which ironically conflicts with any ideas that the teacher may have previously attempted to establish that the methods of science enable the results to be trusted. It is no small wonder that such experiences have generated a well-defined sense of classroom cynicism which believes that "If it's physics, it doesn't work" with its associated demand of "What's supposed to happen, sir?" (Wellington, 1981). The failure to seize the moment and spend a few minutes discussing the nature of the evidence and any possible alternative interpretations shuts off any consideration of "how, with what confidence, and on what bases, scientists come to know what they do" (Shapin, 1992).

Furthermore, the "process"[3] approach gives the strong impression that scientific investigation is an empirical process in which rigid application of the standard "rules of knowing" will

[2] A count of the last six journals shows that of the 54 contributing authors to the last six journals, only one is a practicing teacher.

[3] Throughout this article, we are making a distinction between the "processes" of science as commonly portrayed by science courses which overemphasize the methodological component at the expense of the interpretative and the true processes of science which we see as a much more balanced and heterogeneous mixture of these two components.

lead inexorably to the derivation of certain knowledge—the ”laws of science.” More importantly, it forgets the crucial point that what individuals learn from any situation depends not only on what they can abstract from the context but on the mental constructs that they bring to it. Thus, the “final form” (Duschl, 1994) scientific ideas set before children are the products of creative human thinking located in a particular social and cultural dynamic. To comprehend the importance and significance of scientific ideas, it is essential to have some insight into the social context, the dominant forms of thinking, the numerous blind alleys of pursuit, and the difficulties of persuading others of the validity of any new theoretical interpretations. The study of scientific ideas in their original context of discovery will help to develop students’ conceptual understanding:

- because historical thinking often parallels their own;
- because the now accepted scientific idea was often strongly opposed for similar reasons to those proffered by students; and
- because it highlights the contrast between thinking then, and now, bringing into a sharper focus the nature and achievement of our current conceptions.

Thus, it is our contention that neither the study of process, as currently embodied in the school science curriculum, nor the study of the products of science can, in our view, provide either an adequate account of science or an adequate education in science without the incorporation of some history and philosophy of science.

Consequently, as laudable as attempts are to introduce the methodological component of science into the curriculum, without a serious attempt to address the interpretation of evidence and the reasons for preferring one view to another—which is Schwab’s semantic component—science education presents an incomplete epistemology and fails to equip children with the critical skills required for participation in public debate of contemporary scientific issues. Such omission misrepresents science giving the impression that objectivity and certainty are universal values when even a cursory glance at *Nature* or the *British Medical Journal* shows that the production of new scientific knowledge is a contested[4] process. For it is exactly an understanding of science as a social product, where theories are undetermined by the data that will help students to understand, in a more intelligent and informed manner, current scientific controversies such as the nature of the debate about creationism (Schmidt, 1996), BSE and the risk of eating beef, global warming, and other topical issues.

SCIENCE AS A PRODUCT AND THE NEGLECT OF EPISTEMOLOGICAL JUSTIFICATION

A central thesis of the argument presented here for our model for the incorporation of HPS is that epistemology *does matter*—because the answer to the question of “how we know” is an important aspect of our account of science and the evidence for our ontological commitments. Furthermore, it is an education in the central project of scientific epistemology—that is, “to tell how to distinguish between *justified* and *unjustified* beliefs” (Laudan et al., 1986) and an essential critical skill required to participate in any scientific discourse.

[4] An excellent historical example is provided by Geison’s (1995) recent study of Pasteur’s laboratory notebooks. His work illuminates the debate surrounding Pasteur’s findings and his discovery of Pasteur’s deliberate misrepresentation of the nature of the vaccine used in his famous and public trial of his anthrax vaccine at Pouilly-le-Fort in 1881 is a fascinating example of the extent to which scientists will go to establish their ideas.

Courses that emphasize the products of science place an unjustified emphasis on the "survey of facts" and effectively introduce children to the topology of the scientific landscape without exploring any of the underlying geology that accounts for why the landscape is the way it is and how "we have come to be at this particular juncture in our understanding of the way the world works" (Duschl, 1990). In so doing, such courses fail to address significant aspects of the cultural product that we call science—the significance of creativity and imagination for hypotheticodeductive reasoning, the fact that scientific thinking is historically and socially situated, and the need for courage in the face of substantial opposition. The consequence of this omission in school science is that much science is presented as a set of concepts "as though they were inevitable, rocklike formations that have existed for all time" (Arons, 1988). School science therefore misses the opportunity to raise Chalmers's (1982) questions—"What is this thing called science?" and "Why is it so important?"

Science without a serious consideration of epistemological questions leaves the learner in the position portrayed by Horton in his seminal discussion of the nature of African traditional beliefs in which he concludes that:

> The ground for accepting the models proposed by the scientist is often no different from the young African villager's ground for accepting the models propounded by one of his elders. In both cases the propounders are deferred to as the accredited agents of tradition . . . For all the apparent up-to-dateness of the content of his world-view, the modern Western layman is rarely more 'open' or scientific in his outlook than is the traditional African villager. (Horton, 1971, p. 262)

Moreover, the failure to consider how scientists come to know "is running the risk of developing students who do not acknowledge the scientist's views as rational" (Duschl, 1990) because the provision of evidence, crucial to traditional epistemology, is downplayed, if not absent altogether. To transcend that position, an explicit treatment of the procedural basis of Western scientific knowledge is *essential* in science education. These points have been discussed more extensively by Hodson (1988), Duschl (1990), Matthews (1994), and Osborne (1996).

Now, although an historical approach is not a necessity for the achievement of such understanding, as some insight can be gained from recent studies of modern laboratory life (Latour & Woolgar, 1986; Traweek, 1988), the presentation and interpretation of evidence for well-established scientific concepts in an *ahistorical* setting is the literary equivalent of arguing for the importance of work of Shakespeare without discussing the sociocultural context of the work. Scientific knowledge, too, is a contingent, cultural product and, like the works of Shakespeare, the significance of its achievements and an understanding of its nature will only be enhanced by some knowledge of the historical context.

CURRICULUM CHANGE—A WAY FORWARD?

The arguments outlined so far lead us to share Rogers's (1982) proposal that "process," as used in science education, be reinterpreted in terms of procedures for marshaling evidence to arbitrate between competing views—providing a very different focus for laboratory work. The historical treatment of scientific knowledge can then find a role in teachers' schemes of work by providing a rich repertoire of alternative interpretations of evidence forcing students to consider critically the status and claims of current scientific thinking.

For us, the popular offering provided by science teachers is untenable, providing as it does a very narrow and restricted fare of the important cultural product called science. As Jenkins

(1996) points out, at the end of the twentieth century, school science continues to transmit the notion of a uniform and homogeneous methodology of science which is fundamentally empiricist—and which is essentially a nineteenth century conception! Such understandings are now *arcane* and their ossification with the school science curriculum calls into question any claims that science teachers can make to be an authority on their subject. Remediation of this omission can only be achieved by some focus on the context of discovery, that is, through the introduction and use of some historical material that provides an opportunity to examine the evidential nature of scientists' beliefs. The heterogeneity of evidence and a discussion of the reactions of scientists to its interpretation then leads directly into a consideration of the nature of science itself.

The lesson of the history of curriculum change suggests strongly that it is a process of slow, evolutionary transformation which needs both institutional and personal support (Fullan, 1991) because the history of attempts to radically alter the science curriculum is a history of heroic failures. Hence, greater potential for change is still offered by the gradualist route and the development of models of pedagogy that address teachers' foremost concerns—content coverage and conceptual understanding. For instance, for teachers in England and Wales, some overdue acknowledgment of epistemological issues can be found in the present version of *Science in the National Curriculum.* This document has two sections at the beginning of the program of study which refer to the fact that all students should be given opportunities to consider the application of science and the nature of scientific ideas. Under the section on the nature of science the program of study expresses the need for students to be given opportunities to:

a. develop their understand of how scientific ideas are accepted and rejected on the basis of empirical evidence, and how scientific controversies can arise from different ways of interpreting such evidence;

b. consider ways in which scientific ideas may be affected by the social and historical contexts in which they develop, and how these contexts may affect whether or not the ideas are accepted.

These two unambiguous statements seem to have recognized the inadequacy of mere authority as a basis for knowledge claims and require science teachers to incorporate a historical dimension into their science teaching. The emphasis on evidence enables, and demands, the study of the justificatory connection with knowledge-claims and the rational grounds for confidence in the scientific enterprise where the historical record reveals that issues are ultimately, if not initially, settled by the weight of empirical evidence.

Hence, we argue that the proponents of HPS must work within such contexts to offer models that address both the ontology of science and its epistemology. In short, we suggest that advocates for the role of HPS must use small changes in emphasis within curricula as a Trojan Horse to achieve some of the broader aims previously outlined.

A NEW RATIONALE FOR THE INCLUSION OF HPS

So far, we have argued that the failure of HPS to contribute to the mainstream of science teaching is because teachers have no confidence that a historical context adds anything to their students' examinable knowledge and skills. Within the classroom, teachers' dominant concerns are the development of the student's knowledge and understanding of the content of science; that is, the *products* of epistemological justification, and the imperatives of classroom management necessary to achieve this objective. Second, we have attempted to show that science education that stresses the "processes" of science also neglects HPS because of an obsessive focus on methodological questions, which diverts attention from Schwab's equally important semantic component—the interpretation and meaning of data. Consequently, explicitly, but more often implicitly, science is portrayed as a process of inductive empiricism.

However, we believe that within the science education literature, there are three aspects which, as yet, have been inadequately combined, but when taken together, offer the potential for synthesis around a historical-based treatment of certain topics and which would also address teachers' mainstream pedagogic concerns. The crux of our case draws on the constructivist notion that students' knowledge is construed rather than absorbed. Moreover, it is our contention that students' knowledge can be more securely constructed if the very process of the construction of scientific knowledge itself is an explicit part of the science curriculum.

Lessons from Constructivism

In the past 15 years, children's scientific thinking has been the subject of considerable investigation through a school of research broadly labeled "constructivist." The growth of publications in this field has been virtually exponential (Duit, 1993). What this body of literature has demonstrated is that teaching is not a process of filling children's empty minds. Rather, that it is more appropriate to characterize the teaching and learning of science as a process of conceptual restructuring (Driver & Oldham, 1985). Pedagogic practices that have been developed to meet this new interpretation have been rooted in the Ausubelian maxim that ascertaining the learner's prior knowledge is an essential initiatory act. The major achievement of constructivist research has been to document the wide ranges of children's thinking and to develop an understanding of their origin and legitimacy. What was commonplace and unremarkable has become significant and essential knowledge for the teacher who wishes to engage in a meaningful discussion with their students, reflecting the learner's knowledge back in a manner that enables them to question their own understanding and construct the scientific concept. Such a perspective portrays teaching as a dialogic process in which new meaning is negotiated (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Sainsbury, 1992) as teacher and learner exchange and discuss their contrasting conceptions. Although, there is as yet insufficient empirical evidence to justify such approaches, constructivists have undoubtedly articulated a convincing case that the elicitation of children's thinking, knowledge, and understanding is an essential process of formative assessment necessary for the appropriate presentation of new material. Thus we would concur with such arguments that good pedagogic practice requires time and opportunity for children to elaborate and clarify their existing conceptual structures before further instruction, and hence, it is a requirement of our model.

The Value of Philogeny for the Ontogenesis of Children's Thinking

A recurrent feature of note in the body of constructivist literature is the attention drawn to the parallelism between the ontogenesis of children's scientific thinking and the phylogenesis of the scientific products of the culture. Many investigators have pointed to such correspondences (Driver & Easley, 1978; McDermott, 1984; Viennot, 1979; Vosniadou & Brewer, 1987).

However, the notion that the ontogeny recapitulates the philogeny is not supported by the evidence from detailed examinations of the historical evolution of scientific concepts. Wiser and Carey's (1983) exploration of the elaboration of the concepts of heat and temperature, Wandersee's (1985) examination of students' understanding of photosynthesis, and Vosniadou and Brewer's (1987) investigation of the development of the concept of the Earth as a round sphere where "down" is toward the center of the Earth, all show that there are important differences between children's thinking and the phylogenetic origins of these concepts. This point has also been effectively made by Lythcott (1983) and Gauld (1991), both of whom point to the significant differences in context. Given that "metaphysical, epistemological and sociological factors do play an important role in the formation of a representation " (Nersessian, 1989), and that the child of today lives in a very different material and sociocultural milieu from his or her forebears, this is possibly to be expected.

What is significant, though, is that these and other studies show that children's thinking is more akin to preparadigmatic thinking and that they:

> . . . often harbour misconceptions which were similar to views held at one time or another during historical development of that science concept—thus making the history of science a useful heuristic device for anticipating some students' conceptual difficulties. (Wandersee, 1985)

Or, to put it in Matthews's (1989) terms, "appreciating where great minds had difficulty attunes a teacher (and the child) to where lesser minds might also have difficulty." Thus clearly children's intuitive conceptions often have features that have appeared at one time or another in the past. Hence, we join with Nersessian in arguing that it is the *nature* of the changes, rather than the actual changes that need to be made in conceptual restructuring, and the *kinds of reasoning,* rather than the actual argument involved in the process of constructing a scientific representation, which are likely to be the same for scientists and students of science. For instance, Aristotelian and early scientific thinking are characterized by an emphasis on perception, description, the nature of the essence of objects, and teleological notions of causality, as is much children's thinking. In contrast, the strong features of modern scientific thought are its use of imagined entities, initially abstract representations of the way the world might be, their quantitative representation and manipulation, and causal explanations that examine the interactions between such objects, essentially what Koyré has termed the "mathematisation of nature" (Koyré, 1978). Hence, much of modern scientific thinking, arrived at through abstract mathematical reasoning, can often seem unnatural (Wolpert, 1992) and anti-commonsense (Cromer, 1993).

Introducing aspects of the history of science into the science curriculum provides two modes of support to learners. First, it is comforting to perceive that others have thought in a similar manner—that to hold such thoughts is not to be guilty of mere stupidity. For after all, highly respected and intelligent men of the past have thought in very similar ways.[5] Second, such identification having been achieved, it is also self-evident that such modes of thought are simply historical, of the past and not of the present, and that current thinking offers an improvement, an idea which is more valuable in its scope, detail, utility, and predictions than any that the student may currently hold. The self-realization of the historical nature of their thinking would, we believe, impel the student to attend to the inadequacy of their own conceptions and to examine the modern scientific ideas. Thus, it is our contention that the recognition of any similarity between their thinking and its historical antecedents offers a powerful motivation to the learning of science, the foremost concern of the science teacher.

[5] Gauld (1991) makes the important point that this is only true at the highest level of generality. Any examination of the historical record reveals a great deal of elaboration and complexity to support the basic idea.

Raising the Importance of Epistemology

More importantly, perhaps, the introduction of a plurality of interpretations, some provided by the pupils and some by historical account, brings into focus the matter of evidence and the justification for what may seem at first sight an unnatural and alien way of thinking. What are the data that justify the science teacher's views? Why is their view a more fruitful and valuable interpretation of nature's phenomena? Such questions are fundamentally epistemological and would provide an opportunity to redress the imbalance, previously discussed, which is a consequence of the overdominance within school science on the products of epistemological justification rather than the justification itself.

In advancing our model for pedagogy, we too share Brush's (1969) earlier view that "history, when introduced intelligently into a science course, can increase understanding of science and scientists, and their role in society without detracting from the amount of scientific knowledge transmitted to the students." Furthermore, rather than heed Brush's (1974) cautionary notes on the subversive nature of the history of science for its capability to undermine notions of objective and absolute truth, we urge that it is *only* HPS in science education that offers a means of divorcing science education from the naive notions of science it currently perpetuates.

TOWARD A PEDAGOGIC MODEL

The previous discussion has highlighted the pedagogic need to give consideration both to children's alternative frameworks and the curricular need to broaden the scope of what is offered in science education; that is, to consider fully the important epistemological question of "how we know." Therefore, we suggest a model for incorporating the history of science that addresses both of these issues. However, first and foremost, it addresses teacher's overriding priorities in the development of conceptual understanding and classroom management.

The model, shown in Figure 1, assumes that there is a natural phenomenon which is the focus of study, such as the behavior of falling objects, or where plants get their food from, or the study of burning. In phase 1, *Presentation,* the teaching would begin with a practical demonstration or the teacher drawing the children's attention to some phenomenon and making it problematic:

> Can you predict which of these two stones, the large or the small, will hit the ground first when they are dropped?
>
> Will a piece of metal weigh more or less after burning in air?
>
> or
>
> Can you say what will happen to the weight of a plant growing, without soil, in tap water?

The elicitation of a prediction is a key feature of this model. White's (1988) pedagogic model of Predict, Observe, Explain (POE) offers a useful parallel, but without the historical input. For our model, the phenomena that are presented to students in the first place must have been the subject of some historical theorizing by earlier scientists that can be set alongside the students' own ideas. Hence, not every topic might be given an historical treatment in this way, and indeed, it would be tedious to do so.

In phase 2, *Elicitation,* students' ideas and theories about the phenomenon should be gathered, using any relevant method, that is, simple question and answer routines, the use of con-

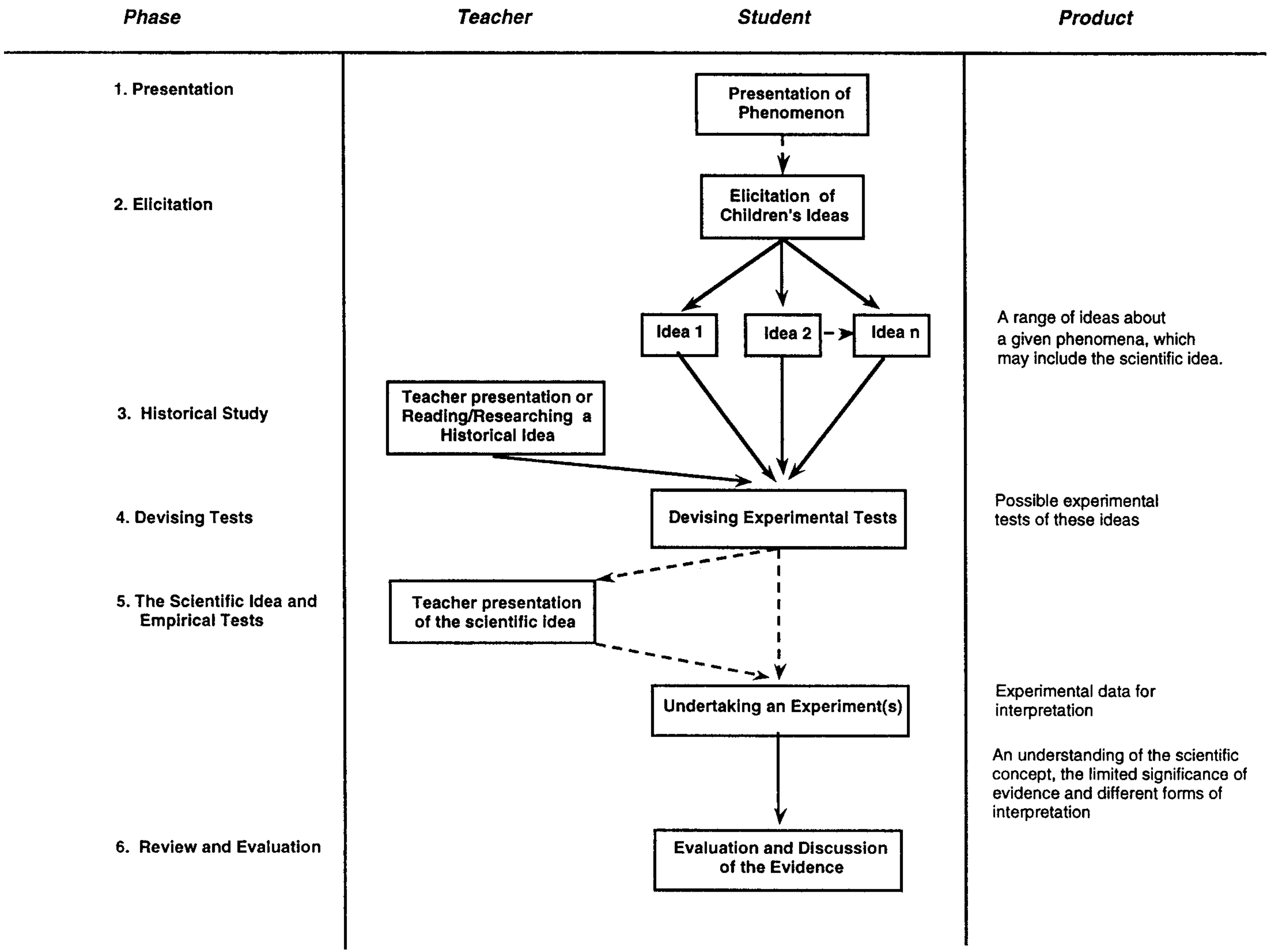

Figure 1. Model of the teaching process.

cept maps, word association, drawings, discussion of instances, etc. Such strategies have an additional advantage of encouraging small group work which provides opportunities for more students to be actively engaged. We hope that plural viewpoints emerge and consider it important that the multiplicity of views and their differences are emphasized by the teacher who should try to show how different groups of students think different things, maintaining a non-judgmental stance toward all ideas. The teacher should also encourage the groups of students to explain, if they can, why they think as they do. The work of Nussbaum and Novak (1981) on "brainstorming in the classroom" provides a suitable model for this approach and demonstrates the wide range of ideas children are capable of holding about a given phenomenon.

In proposing this starting point, pedagogically we draw something from the model of constructivist pedagogy which calls for a period of orientation and elicitation that serves to define why the topic under consideration is important, and to provide an opportunity to make children consciously aware of their own thinking (Driver & Oldham, 1985). Philosophically, we draw on more recent arguments that there are always multiple interpretations of experimental evidence, and that any realistic portrayal of the practice of science must provide opportunities to expose a plurality of interpretations and engage in the process that leads to resolution and consensus.

Moreover, such a pluralistic approach encourages the use of language in a figurative and flexible manner so that they might sense that the role of the scientist is not just to discover the "facts of science" but also to construct them through the use of their creative imagination (Sutton, 1996). This model, therefore, provides a mechanism for transcending the slavish devotion of science education to transmitting knowledge of the "final-form" products of the context of epistemological justification. However, this phase serves an additional and necessary function within our model. If the study of historical thinking is to have any value, students will become aware that there are often parallels between their thought and earlier scientific thought. This will only be achieved if a suitable opportunity has been provided for students to articulate and clarify their own understanding and interpretation of the phenomenon in question. Hence, this phase is an essential component of the proposed model of pedagogy.

Moving to phase 3, *Historical Study,* multiple inputs are required. Teachers will need to introduce:

- an example of *early* thinking on the phenomenon as yet one more view to consider;
- background information on the economic–social–political conditions of the time;
- an example of competing ideas from other scientists and not necessarily the modern textbook version;
- some discussion or exploration of the data or other background that might have added support for the historical view; and
- a brief chronology in terms of dates and events that needs sorting.

Teachers can present orally, or through textual and multimedia materials with students actively working in small groups, or by attending to short student presentations. The exact choice of which ideas are to be presented requires some careful consideration but, for instance, suitable early conceptions, given the appropriate topic, could be Galen's ideas on the purpose and nature of the blood, Van Helmot's early puzzlement on plant nutrition, or Aristole's ideas on falling bodies. This helps build a pluralism of viewpoints to be discussed. It also creates the opportunity to contextualize the viewpoints held in terms of the material, economic, social, political, and other factors. Why might these people have thought what they did? Figures from the past need to be presented sympathetically. The ancients were not fools. They had limited access to data and data-gathering instruments, they employed different conceptual systems, and of course they were differently situated. Peat's (1995) study of the beliefs and ethnoscience of the Blackfoot Indians is one of several studies that support such a view. Such arguments can be brought to the fore and used to show that what one thinks depends upon how one thinks and that thought is constrained by the existing metaphors which are dependent on the existing social and cultural contexts (Sutton, 1996). This might look like a slide into relativism. Rather it is a deliberate move to pluralism and contextualism

Good stories are often about people, about their courage, ingenuity, and hopes. Thus, flesh must be added to the bare bones to provide details of the social and historical context. What was happening at the time that enabled one person to introduce a new way of thinking and what difficulties did they face in introducing their idea? For instance, why was Harvey, an Englishman, in Padua, Italy, in 1678? When was the pump first invented? Would it have been possible to think this way if you have never seen a pump? Then, why did people think it was reasonable to think that way and why did people come to believe their idea? For instance, why were Galileo's ideas about pendulum motion, which were evidently not commensurate with observation, accepted? Or how was it that Darwin's ideas, which radically challenged accepted biblical accounts, become dominant in a strongly Christian country?

To address these, and allied questions, teachers need historical vignettes (Wandersee, 1990). These should aim to present a brief (approximately 10 minutes of students' work), historical narrative based on the ideas of one scientist which would locate the scientist's work *in the social and historical contexts of the time.* Such episodes must be carefully selected for their potential to add a new voice to those of the groups of students in the class. Moreover, such vignettes must, at a very minimum,[6] surpass the one-page potted biographies of "famous scientists" which invariably decontextualize their work from any social, historical, and economic context to be of any value. Meadows's (1987) book, *The History of Scientific Discovery,* provides a rich visual mine of contextual detail, contemporary issues, and biography that are suitable for use with secondary school students.

Many commentators have pointed to the paucity of appropriate curriculum materials for teaching the history of science (Bybee et al., 1991; Duschl, 1994; Solomon, Duveen, Scot, & McCarthy, 1992), which supports the view that there is a pattern of underemphasis on these aspects of science. Undoubtedly, one of the fundamental problems is teachers' lack of knowledge of either the history or the nature of science (Brickhouse, 1991; Koulaidis & Ogborn, 1995). The demands of the classroom context that a teacher be *in authority* is legitimated, at least in part, by the fact that they are *an authority* on the topic in focus (Peters, 1966). Teachers are therefore naturally reluctant to consider topics that expose weaknesses in their own knowledge and understanding, which additionally erodes their status as an authority that justifies their actions in the classroom. Consequently, the history of science will only be adopted by teachers if there is at hand material that is brief and easily assimilable. It is our contention that the carefully crafted vignette, examples of which can be found in Solomon (1991), offer a promising means of providing the essential support necessary to overcome teachers' reluctance to handle unfamiliar material which threatens their sense of self-confidence. Limited evidence to support this assertion is provided by Wandersee (1992) who found that, with some

[6] Such vignettes are considered to be the very minimum necessary to achieve a significant introduction of HPS into the curriculum. Although far from perfect, as many scientific achievements are the subject of several books themselves, they provide sufficient detail to address historical issues and set a social context that helps to demonstrate the achievement of the work and its meaning. It is, of course, hoped that interested teachers would further provide a more extensive treatment.

initial guidance, teachers were able to develop a range of vignettes. Our own experience of working with preservice teachers supports this view.

Support for the use of narratives and stories in teaching can be found in Egan's (1988) portrayal of *Teaching As Story Telling.* He argues that the traditional model of teaching based on aims/objectives/strategies and evaluation is mechanistic and that its aims are limited to a narrow cognitive perspective that seeks to improve rational thinking skills, failing to develop and use the imaginative and creative dimension of children's thought, which is capable of comprehending abstractions of an affective and ethical nature. Education, particularly science education, has been based on:

> an impoverished empiricist view of science that has misused the authority of science to promote in education a narrow kind of logical thinking at the expense of those forms of thinking which we see most clearly in children's imaginative activities. (Egan, 1988, p. 18)

Instead, he offers an approach which takes the journalist's line of "What's the story on this?"—which Egan contends is natural and cultural universal, not just some form of casual entertainment, but a powerful and basic form with which we make sense of the world and experience. Sutton (1996) too argues that the "stories of science"—that is, the ideas and suggestions of some author, should form the core of a lesson. In many senses, history is just that, a story retold and reinterpreted a thousand times. Such a form of presentation is capable of engaging children affectively with powerful conceptual tools that can be extended beyond their normal restriction to imaginative activities. Here, we are at one with Egan (1988), particularly when he stresses:

> The educational achievement is not to make the strange seem familiar, but to make the familiar seem strange. It is seeing the wonderful that lies hidden in what we take for granted that matters educationally. (Egan, 1988, p. 47)

However, predominantly, the stories of science with their impersonal constructions and passive verbs, imply a narrative in which the object studied, not the researcher, is the main actor. Only by providing a narrative focusing on the context of discovery can those items conventionally excluded from research reports—historical chronology, human actors, and an audience—be reintroduced to the practice of science teaching and a human voice added (Myers, 1990).

In phase 4, *Devising Tests,* having established a pluralism of viewpoints, both contemporary and historical, teachers can ask groups of students to consider how they might decide upon which version is correct. Here, Egan's desire to capitalize on young students' imagination can be usefully employed. In designing their experiments to decide the validity of any one view, they need to think creatively and imaginatively. The presentation of experimental designs can follow with the rest of the class acting as a community of scientists refereeing proposals. Empirical tests may, or may not, be possible at this stage. It would be nonsensical to insist that the students must carry out their experimental designs as time would not allow such activity. Teachers need to use their professional judgment as to which topics might lend themselves to such practical investigations as an additional phase of activity.

Students need to be shown that there are often a wide variety of alternative or auxiliary hypotheses that can be generated to explain experimental evidence, some of which they may generate themselves. For instance, Torricelli's demonstration of the pressure of air in 1638 was open to a diversity of different interpretations and his interpretation was never widely accepted for many decades. Similarly, as Arons (1988) has pointed out, the attraction between two current carrying wires could be due to an electrostatic force, but this hypothesis is never tested in standard presentations in schools. Clearly, students need to be directed to modern experiments to provide data that substantiate modern interpretations. But, in giving time to explore a plurality of possible interpretations, both before and after, the teacher brings to the fore both the methodological issues associated with the collection of valid evidence, and the issues of its interpretation and the justification of "how we know" that simultaneously presents what it is that makes science a distinctive form of knowledge.

Hopefully, by this stage, the teacher has now prepared the class so that they are aware of:

- the phenomena under study;
- the fact that different people in the class think slightly different things about what is going on, and why;
- the fact that people have thought about these things in the past;
- the historical context in which people in the past confronted the phenomenon; and
- possible experimental tests that could be used to check the validity of one view or another.

Now is the time to move to phase 5, *The Scientific View,* and introduce the modern textbook version of the phenomenon. This phase needs to be a short, formal presentation by the teacher. The teacher's exposition is by now, one more voice offering one more viewpoint, rather than a singular, unquestioned view. However, unlike the previous voices, it is part of the canon of modern science and should be justifiable, in part, through modern experimentation.

Because it is important that closure of the story is achieved within one or two lessons, any experiments will inevitably be simple, curtailed, and limited. However, well-chosen episodes will allow the rapid collection of readily observable data that will at least suggest some resolution in favor of the accepted scientific model. Moreover, it will enable teachers to consider whether the evidence is sufficient and reliable and to discuss the treatment of anomalous results, which are now a requirement in the English and Welsh National Curriculum (Department for Education, 1995).

The evidence will merely provide support for the scientific interpretation, but is not irrefutable. The history of science shows that such a neat, clean, epistemological settlement has rarely, if ever, occurred and that experimental evidence alone, at least initially, is not the sole determinant of scientific knowledge as:

> The critics cite a preponderance of negative results as grounds to dismiss the controversial phenomenon and any residual positive results are explained away as incompetence, delusion or even fraud. The proponents on the other hand, account for the negative results as having arisen from the failure to reproduce exactly the same conditions as used to obtain positive results. Experiments alone do not seem capable of settling the issue. (Collins & Pinch, 1993)[7]

Simplistic assertions that the scientific view is *correct* must be rigorously rejected in favor of the more instrumental view that the modern explanation gives more accurate predictions, or a clearer account, or has wider application. And yet, some form of realism needs to be sustained. This is best done by differentiating the phenomenon from the explanation. The realism of the phenomenon needs to be separated from the ontologically distinct account of the phenomenon. Harré's (1986) scheme of realms of reality may help teachers to clarify where the boundaries lie. Monk's (1995) article points to which ontological realms of reality students may be capable of working with.

[7] Collins and Pinch's portrayal of the role of evidence in science is illuminating. However, we do not share their conclusion that scientific knowledge is a socially constructed product which is unexceptional and undistinguishable from other forms of knowledge (Osborne, 1996).

The final phase of our model, phase 6, *Review and Evaluation,* is a brief but essential component requiring a consideration of the implications of the evidence, either by class discussion or through the use of small groups and reporting back.

The epistemological focus has additional value in introducing the nature of science in an implicit, rather than explicit, manner. For it is difficult to consider issues of evidence, justification, and belief in science without considering and discussing what it is that scientists do. Is a single experiment sufficient to lead to a instantaneous change in the dominant paradigmatic thought of the culture? Why was Wegener's theory of continental drift strongly rejected in 1912 despite the fact that any schoolchild can see the apparent fit between the west coast of Africa and the east coast of South America and there existed significant geological and botanical evidence to support his theory? Why was Darwin's theory of evolution accepted by some despite strong arguments based on the rate of cooling of the Earth provided by Kelvin that the Earth could not have the necessary age claimed?

Consideration of the evidence will then, in turn, enable closure of the story where a consensus within the class emerges in favor of the scientific version. Moreover, in our model, the final review will require an opportunity for students to reflect on the products of the resolution of the conflict, which have now become the products of the context of discovery, and compare them with their own thinking. Hopefully, such a phase will enable them to note that historical thought cannot be considered ignorant or stupid, for they too have had similar ideas. It may also become apparent that the ideas of science are not often based on what seems self-evidently salient. Rather, that it has taken imaginative and creative leaps of thought to transcend the limitations of commonsense thinking and scientific ideas are the contingent product of a sociohistorical and geopolitical context and culture. However, most importantly, this approach does focus on *what we think now*—that is, the science concept that is in the curriculum, whose knowledge and understanding by children is the main aim of the science teacher. Therefore, it is our belief then that this approach offers a method of incorporating the history of science, without detracting from the achievement of the central concern of the science teacher.

Furthermore, such an approach only requires a marginal increase in time and its justification lies both in the rationale advanced here and the many familiar arguments for the role of the history of science (Matthews, 1994). In addition, it offers a means of adding what research shows to be a vital ingredient of successful teaching—variety (Cooper & McIntyre, 1996; Piburn, 1993). Research also shows that HPS is successful in improving "course satisfaction" and attitudes toward science (Russell, 1981), which is currently a matter of considerable international concern with the declining interest in school science. Ultimately, HPS will only achieve its rightful place in the science curriculum by a consistent attack on the one-dimensional nature of existing science curricula and their failure to achieve even a minimal scientific literacy or generate positive attitudes toward science. In the interim, only approaches which make the history of science an integral feature, such as the model proposed here, rather than offering material that appears to be of an extraneous and nonessential character, will appeal to, and be used by, teachers in the classroom. Otherwise, failure to recognize the overriding concern of the practicing science teacher will always result in the avoidance and marginalization of the history of science.

In the long term, how can more radical change be achieved? From this perspective, a paradigm shift in the normative practice of science teachers will only result from consistent attempts to expose the current crisis in science education, rather than liberal attempts to remediate its deficiencies.

The radical position for the incorporation of the history and philosophy of science in the curriculum, for which certain seeds of sympathy are evident, has its roots in the rising international concern with the notion of "scientific literacy." Although this is a multifarious term, not without its own problems (Jenkins, 1994; Shamos, 1995), the specific argument has been advanced, most strongly in *Science for All Americans*, that without a study of the history and nature of science, the nature of the scientific enterprise would be reduced to mere slogans, leaving individuals ignorant of some of the major achievements of our cultural heritage. Essentially this is the argument that the study of the history of science has intrinsic value in its own right as scientific knowledge is one of the great cultural achievements of humanity—a third culture of equal value to that of literacy and numeracy (Brockman, 1995). Proponents of this view (Millar, 1996; Osborne, 1996; Shamos, 1995) argue not for the curriculum to develop scientific knowledge but for a science education, which, for want of a better term, might be described as "scientific awareness" that would embody the notion of cultural studies of science, technology, and society. Such a curriculum would seek to consider:

- What is a scientific theory?
- What is scientific knowledge?
- What is the role of experiment?
- How do scientists know?
- How have scientists "discovered" new knowledge in the past?
- A limited set of the important concepts of science, for example, electricity, the Earth in space, the periodic table, photosynthesis.
- How does scientific knowledge progress?
- What is the impact of science and technology on society?
- The assessment of risk.

By its very nature, HPS would be integral to such a course as some of the foci and questions, particularly those of an epistemological nature, can only be understood by the study of some historical case studies.

Just as the study of English literature does not seek to make great writers out of children, seeking rather to develop an understanding for what constitutes "great" literature and the reasons why, so would the "cultural studies of science" seek to develop an understanding of what science is and why scientific knowledge would be valued. After all, the notion that any education could introduce children to the sum total of all the world's great literature is absurd. Similarly, we have to recognize that there is sufficient time to cover only a small part of the corpus of knowledge that constitutes science and the science teacher must be freed from the constraints of an overburdened and overburdening curriculum.

WORK IN PROGRESS

We are currently working with teachers on a preservice training course: raising the issues discussed in this article; and helping them to collate ideas, construct vignettes, and lay out worksheets for student activities. The student-teachers are introducing their materials into lessons they teach in secondary schools. We are asking experienced science teachers, who are mentoring the student-teachers, to help the novices in this work. They suggest from their own experience viable topics, alternative activities and resources that they know work well. This work is in an exploratory phase and we are expecting to learn lessons that will enable us to streamline our production and refine our product.

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