What History of Science, How Much, and Why?

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Introduction

Despite the pervasive influence of science within our culture, the nonscientist commonly misunderstands the methods of science and holds a mixture of positive and negative images of science. Science educators have recognized the importance of accurately understanding science and the desirability of positive and realistic attitudes toward science. The history of science can contribute to these goals, but only if we attend seriously to the three questions, "What history of science, how much, and why?" This paper reviews the significance of the history of science in achieving the goals of science education.

Before examining the three questions, "What history?," "How much?," and "Why?," two brief summaries of relevant background material are presented. The first summary describes events and positions regarding the role of the history of science in science education since 1950. The second summary considers the present state of research on attitudes toward science. "How much history of science?" is the first question discussed in the main body of the paper. The major science curriculum development activities in the 1955–1975 period were intended, in part, to influence the attitudes of students toward science. Because Harvard Physics made significant use of history of science materials, data from that project are examined to develop conclusions to the question, "How much history of science is required to influence student attitudes toward a science subject?"

The two remaining questions posed in the paper's title are examined in subsequent sections. Because the history of science is often regarded as a source of information which will improve students' images of science, there is a close connection between the goal of fostering positive attitudes and the question, "Why teach the history of science?" Discussion of educational and cultural influences on attitudes toward science makes it clear that there is good reason to teach the history of science, with careful attention to sources of misunderstanding and negative images of science. The significance of the question, "What history of science shall we teach?," arises from historical work in the past 30 years, showing that significant discrepancies exist between the historical record of science and the historical content often included in science textbooks. The consequences of distorted historical content are particularly significant for that majority of students who do not become scientists. Finally, drawing from the discussion of these three broad questions, the paper concludes with separate sets of recommendations for teaching, for materials development, and for research related to uses of the history of science in achieving goals of science education.

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Role of the History of Science in Science Education Since 1950

A significant line of developments which brought the history of science into science education in several new ways began at Harvard in the late 1940's. Under the leadership of Conant, history of science cases[1] were introduced into undergraduate general education at Harvard around 1950. Conant (1951) argued that laymen need to understand the methods of science and can gain such understanding without studying at the current frontiers of research if they study how science developed in earlier times. In the late 1950's, Klopfer extended the case history idea by developing cases for use by high school students.[2] Klopfer and Watson (1957) indicated they hoped to increase appreciation of and interest in both the methods and people of science by adding historical materials. More recently, Klopfer (1969) pointed out the potential contribution of history to the development of "scientific literacy" and described several appropriate teaching strategies.

During the 1960's, *The Project Physics Course* was developed at Harvard under the leadership of Rutherford, Holton, and Watson (1970). Significant amounts of historical material were incorporated into a complete curriculum package (text, readers, equipment, etc.) which set out, in part, to show the human side of the scientific enterprise, with the intent of attracting students who would not otherwise elect physics (particularly as it is presented in the *PSSC Physics* course). That the history of science was seen as making a direct contribution to the humanistic orientation of Harvard Project Physics is indicated by the directors in the second of five intended course effects.

> To help students see physics as the wonderfully many-sided human activity that it really is. This meant presenting the subject in historical and cultural perspective, and showing that the ideas of physics have a tradition as well as ways of evolutionary adaptation and change. (Rutherford, Holton, & Watson, 1970, p. xi)

The post-war work by Conant at Harvard also set in motion the line of research by Kuhn, leading to publication in 1962 of *The Structure of Scientific Revolutions.* Kuhn was an instructor in the Harvard course using case studies; subsequently, he has worked in the history of science, not in science education. Kuhn's thesis that science progresses by revolutions, rather than by steady, gradual accumulation has educational implications which he addresses by noting that while science textbooks obscure the revolutions he sees in the historical record, those same texts are quite effective as tools for the training of scientists (Kuhn, 1970, pp. 136–138). Yet Kuhn has been descriptive and tended to confine himself to comments on the education of scientists; with respect to the general education uses of the history of science, he has been silent. Brush, who contributed to the writing of historical material in *The Project Physics Course,* stands out as the historian of science who has developed detailed commentaries on the uses of history in teaching science.

Thus we can trace a significant sequence of work based at Harvard which has had

[1] Eight of the case histories were edited by Conant (1966) into the two-volume *Harvard Case Histories in Experimental Science.* These cases are one of the most convenient starting points for a serious venture into the history of science.

[2] Nine of Klopfer's "History of Science Cases" were published in 1966 by Science Research Associates, Inc. but are now out of print.

important consequences for the history of science as a field and for educational uses of the history of science in science education. Interestingly, like Conant, Brush (1969, 1974, 1976) has focused on having students understand the methods of science, while Klopfer and *The Project Physics Course* have made that topic less explicit and spoken more of student appreciation of and interest in science.

Research on Attitudes to Science

The developments in the history of science described above occurred during the 1955–1975 period when substantial curriculum development and implementation activities were underway in the U.S., particularly in elementary and secondary science. Welch's (1979) review of the science curriculum work in this period suggests that those activities were successful in achieving the goals of "updating science content" and "providing curricular alternatives in science" (p. 295). However, given the available enrollment data, Welch concludes that we did *not* achieve the goal of developing "materials that would increase student interest in science and thereby increase our science manpower pool" (p. 296). Welch mentions only briefly the fact that many investigators have attempted, in the last 20 years, to determine the impact of new curricula on student attitudes toward science. He merely hints at the substantial problem associated with developing appropriate instruments for assessing attitudes toward science (p. 298).

As Welch indicates, the development of new science curricula was undertaken, in part, with a view to improving students' attitudes to science, and the history of science is often regarded as related to the same goal. Naturally, attempts were made to detect attitude improvements attributable to the new curricula. Unfortunately, no clear results have emerged, either in terms of enrollment patterns or in specific attitude changes. The methodology of research on attitude change also remains problematic. Before examining the data collected in Harvard Project Physics, it is helpful to note the present state of research relating curricula to attitudes toward science.

Summaries of research on attitudes to science in three recent annual reviews of research in science education are indicative of some of the problems in this area. Mallinson (1977) reports "frustration" with studies published in 1975: "The frustration comes from the inconclusive, and in many cases, contradictory, findings of the studies" (p. 167). Renner, Abraham, and Stafford (1978), summarizing studies from 1976, can only report that "males have better attitudes toward science than do females" and "higher achieving students have better attitudes toward science than do lower achieving students" (p. 66). Peterson and Carlson (1979), looking at 1977 studies and work in the 1972–1976 period, concluded that "attitude research is chaotic, ..." (p. 500); they see as part of the problem a *failure to identify the attitudes we wish to develop*.

Extensive reviews by Gardner (1975a, 1975b) of studies of attitudes to science reveal similar conclusions in much greater detail. Instruments, research designs, and variables have appeared in amazing variety, yet we still do not know whether the various instruments measure a common construct (1975a, p. 31). The overall results seem anything but encouraging:

> Looked at as a whole, the evidence presented in this review must come as a disappointment to those science educators who believe that curriculum innovation must inevitably result in great

improvements in pupil attitudes. Most studies of attitude change show most students declining in attitude; most comparisons of "innovative" and "traditional" curricula show little difference between the two, and even when there is a difference, it is not always in favour of the innovative course. (1975b, p. 35)

Recognizing the problem presented by conflicting and confusing results, Munby (1980) recently tackled directly the methodological problem in attitude studies by examining the reliability and validity of the instruments employed. Starting with 2,000 references (to journal articles, dissertations, and ERIC documents) from the 1967–1977 period, he identified 200 instruments and then scrutinized 50 which were intended to measure general attitudes to science. Only 7 of the 50 survived reasonable standards of demonstrated reliability and validity. His conclusions are blunt and compelling.

. . . on the basis of the analysis given here, there are grounds for viewing research on the affective outcomes of science education with misgiving, simply because there seems little to be said of the instruments as to enlist our confidence in their use. This is surely an embarrassing predicament for the science education research community, not because we might appear to be approaching this area of research and evaluation rather casually, but because there is nothing substantial or insurmountable which might otherwise impede efforts to improve instrumentation. (Munby, 1980, p. 273)

How Much History of Science?

Given the many problems in the general area of research on attitudes to science, the data collected by Harvard Project Physics display welcome clarity. They deserve close scrutiny in the context of this examination of how history of science relates to influencing attitudes to science, because the developers of *The Project Physics Course* deliberately set out to influence student attitudes toward a science subject and, as part of their strategy, incorporated directly into the course substantial material from the history of science. In addition, the project's use of a variety of evaluation measures permits one to judge the actual effects of the course's distinctive features. It is the purpose of this examination of empirical data to reach conclusions concerning the impact of including significant quantities of historical material in a science course.

Welch and Walberg (1972) summarized the significant course effects under four headings. On "course satisfaction," one of 3 *affective* measures, Project Physics was rated significantly higher than "other physics" courses. The *learning environment* measure showed Project Physics classes higher in "diversity" while other physics classes were higher in "favoritism" and "difficulty." The *course reaction* and *physics perception* measures provide particularly relevant results. As a course, Project Physics received significantly higher ratings on "historical approach interesting," "math background unnecessary," and "book enjoyable to read." In contrast, other physics courses had significantly higher ratings on "most difficult course in school" and "physics must be difficult" (pp. 377–381). Finally, "Project Physics students rated the concept Physics as more Historical, Philosophical, Social, and Humanitarian and less Mathematical and Applied than did students in other courses" (p. 382). It is important to note, in addition, that *no* significant differences were obtained on the *cognitive* measures in the course comparisons. The four cognitive measures were an achievement test, the course grade, the Test on Understanding Science, and the Science Process Inventory (p. 378).

What do these results mean, in terms of the effects of using the history of science? At one level of interpretation, students are saying that they noticed the deliberate changes in course content and that *the changes did make differences,* in the directions intended by the developers. It is clear that the addition of historical material and the reduction in the use of mathematics enabled students to see the course and physics itself as more historical and philosophical and less mathematical. Ahlgren and Walberg (1973) report a further analysis of the data, showing that *PSSC Physics* was rated significantly *lower* than traditional courses and Project Physics on the perception of physics as Historical, Philosophical, Social, Humanitarian, and Artistic. As they note, the PSSC project had as its major goal the improvement of the physics content of physics courses (pp. 188–189). Ahlgren and Walberg reach an important conclusion.

> Clearly, then, the content of a physics course can have marked effects on the students' view of physics. Harvard Project Physics was able to draw on the completed work of the Physical Science Study Committee and, going off in a different direction, apparently succeeded in restoring the social, humanitarian, and artistic aspects that had been lost in PSSC, and succeeded in augmenting the historical and philosophical aspects (p. 189).

This statement foreshadows a more general conclusion reached by Walker and Schaffarzick (1974) from an analysis of data in 23 studies (12 dealing with science subjects) comparing "traditional" and "innovative" curricula. Although they expected improved courses to show improved student achievement, closer analysis led them to conclude that "innovative students do better when the criterion is well-matched to the innovative curriculum, and traditional students do better when the criterion is matched to the traditional curriculum" (p. 94). From their review of 23 studies, Walker and Schaffarzick reach the plausible conclusion that we can influence student learning in significant ways by the content we include and the emphasis we give to the content of a course (pp. 97–99).

Walker and Schaffarzick praise specifically the Project Physics work reported by Welch and Walberg (1972); the making of curricular comparisons on a *variety* of different measures, representing many possible learning outcomes, lends support to the generalization about the effect of content inclusion. Thus we arrive at an initial, admittedly broad generalization about how much history of science is required to influence attitudes: *If we wish to use the history of science to influence students' attitudes toward science, we must include significant amounts of historical material in our course content.*

Less encouraging is the result of a second level of interpretation of the Project Physics data. Adding history and reducing mathematics produced student perceptions of physics as more historical and philosophical and less mathematical, and the students reacted favorably to these differences. But these findings tell us nothing of the cognitive impact, if any, of these changes. As noted earlier, no differences appeared on the four cognitive measures. In the Welch and Walberg report (1972, p. 377) and in the more detailed methodological discussion by Welch (1973, p. 374), mention is made of the potential "disappointment" in the finding that *The Project Physics Course* did not achieve its goal of increasing student understanding of science itself. From the analysis by Walker and Schaffarzick (1974), we can understand the absence of differences on course grade and on an achievement test; Project Physics, PSSC, and traditional physics courses were all teaching physics. But why did the historical material fail to produce the desired and intended higher scores on the Test on Understanding Science and the Science Process Inventory? Perhaps, again, "content inclusion and emphasis" (p. 103) will help us. If *The Project Physics Course* uses historical material simply as an alternative way of teaching physics content, without emphasizing scientific processes and the understanding of science, it is not surprising that students learn the same content and, noticing that a more historical and less mathematical route has been used, perceive the subject in that light. Thus a second conclusion is reached: *If we wish to use the history of science to influence students' understanding of science, we must include significant amounts of historical material and treat that material in ways which illuminate particular characteristics of science.*

Why Teach the History of Science?

With reasonable confidence, then, one may say that adding substantial material from the history of science can influence student attitudes, and that teaching emphasis must be given to the objectives which require the addition of historical material. What types of influence do we seek? Why, then, do we teach the history of science? As noted earlier, arguments have been advanced on two main fronts in the 1955–1975 period. Some seek to improve student interest in and appreciation of science; others seek to have students understand the methods of science. The first aim is more affective in nature; the second, more cognitive. The first aim implies that students may have negative or neutral images of science, which science educators would like to see made more positive. The second aim suggests that students may misunderstand science, while science educators would like students to have accurate images of how science works.

The purpose of this section of the paper is not to develop or criticize these two broad goals of science education, to which the history of science often seems most relevant. Rather, the purpose is to enable those who would use the history of science to these ends to understand the broader context within which attitudes to science develop. From the wide range of material related to popular images of science and scientists, examples have been selected which deal with the potential influence of the science teacher and science classroom activities, of the science textbook, and of the culture in which we live. Taken together, the materials presented below confirm the importance of goals to which the history of science may contribute, and they suggest some of the specific misunderstandings and negative attitudes which need to be recognized and addressed by science educators.

The classic study of students' images of scientists and of science, by Mead and Métraux (1957), contains relevant information about the influence of teacher and classroom activities and merits review in terms of the use of historical material in the classroom. Mead and Métraux found both positive and negative aspects to the image of the scientist. The image was positive when stated without personal involvement, but changed dramatically when related to choice of career or spouse. The negative side of the image (tedious allconsuming work, no social life) was its own explanation for rejecting personal involvement with science, but the positive side of the image (hard work with low rewards over long periods of time) was also unattractive to many students, despite the respect it implied. Educators who recommend or actually use historical materials will need to keep in mind these particular student reactions to scientists' work. Mead and Métraux also reported on students' reactions to science teaching, beginning with the very significant point that ". . . the present image of scientific work lacks any sense of the delights of intellectual activity; . . ." (p. 388). They cited as significant factors affecting attitudes toward science both the personality of the teacher and opportunities for participation rather than "passive watching" (p. 388). Similar conclusions have been reached in a recent (and very much smaller) study by McMillan and May (1979), who report that the teacher and the nature of class activities were the two most frequent responses (and 50% of all responses) by junior high students asked what has most influenced their attitude to science.

Science teachers considering the addition of historical material will be interested particularly in two of the nine recommendations made to schools by Mead and Métraux (1957).

> Deemphasize individual representatives of science, both outstanding individuals like Einstein—whose uniqueness simply convinces most students that they can never be scientists—and the occasional genius-type child in a class . . . . Instead, emphasize the sciences as fields, and the history of science as a great adventure of mankind as a whole (p. 389).

> Avoid talking about the *scientist, science,* and *the scientific method.* Use instead the names of the sciences—biology, physics, physiology, psychology—and speak of what a biologist or a physicist does and what the many different methods of science are—observation, measurement, hypotheses-generating, hypotheses-testing, experiment (p. 389).

From students' written statements, Mead and Métraux made inferences about students' images of science and scientists and drew conclusions about the influence of the teacher and classroom activities. The *science textbook* itself is another potential influence on attitudes, *whether or not* the textbook includes historical material. Nelkin (1976) has drawn relevant information from an analysis of debates surrounding textbooks which explain the origin of life in terms of organic evolution and thereby draw criticism from those who believe in special creation. Nelkin sees three major themes within these particular arguments over textbook content.

> First, the protests reflect the fact that a nonnegligible fraction of the population is disillusioned with science and is concerned that it threatens traditional religious and moral values. Second, the protests reflect the fact that many people clearly resent the authority represented by scientific dogmatism, particularly when that authority is expressed in an increased professionalism of the school science curriculum. Third, the protests reflect the fact that many people are afraid that the structured, meritocratic processes operating within science threaten more egalitarian, pluralistic values (p. 35).

The controversy over textbooks reminds us of two important aspects of the image-of-science issue. Textbooks are the major curriculum component which is most readily accessible to the public, whose members rarely have significant access to classrooms to comment on the process of teaching. Also, *textbooks appear to have serious shortcomings* as sources of information contributing to positive or adequate images of science. One of the most interesting features of Nelkin's paper is a full page of illustrations of how changes were made in high school biology textbooks during the process of being accepted for use in California (p. 38). The changes made to "reduce dogmatism" are even more interesting than those made to "avoid evolutionary assumptions," for one is immediately struck by the improvements achieved in representing scientific knowledge as the product of intellectual activity rather than as a collection of irrefutable facts. Nelkin reminds those who would modify images of science, through historical material or other means, that the textbooks written to teach science must be viewed as potential sources of incorrect images.

> Textbooks in particular tend to convey a message of certainty to the nonspecialist. In the process of simplifying concepts, findings may become explanations, explanations may become axioms and tentative judgments may become definitive conclusions. Few textbooks are careful to stress the distinction between fact and interpretation or to suggest that intuition and speculation actually guide the development of scientific concepts (p. 39).

Both the classes we teach and the materials from which we teach science can be seen as contributing, usually quite unintentionally, to the various negative aspects of science's image, and thus in need of deliberate improvements. The history of science can serve as one resource and guide for such improvements.

In addition, forces stronger than science teaching and textbooks may be at work in the creation of images of science, particularly some of the negative images we would like to modify. Basalla (1976) has discussed at length the images of science expressed in *popular culture,* presented to the entire population through media such as comics and television. He uses the term "pop science," to avoid confusion with the literature of "popular science" which is directed to a limited and well-educated segment of the population. Basalla describes the image of the "pop scientist" using numerous examples; eccentricity, social isolation, and irresponsibility are three of the basic characteristics which emerge. In passing, Basalla mentions that his own analysis of comic strips reveals a stable image in the period since the Mead and Métraux (1957) study, despite the advances made by science and despite curriculum and teacher-training efforts within science education.

There are, Basalla suggests, four significant issues involved in the "pop scientist" image: (1) a general anti-intellectualism in the culture, (2) the distance between the public and the scientist's research work, (3) the identification of science with its practical applications rather than its breakthroughs in comprehending natural phenomena, and (4) the scientist's own unwitting contributions to a negative image, as in emphasizing practical results when requesting funds for research. Basalla adds the intriguing comment that the popular image of science and scientists may have roots in much earlier images of the "wizard-alchemist-magician" (pp. 270–275).

> . . . , when one reflects upon the persistent distortion science undergoes in popular culture, one must consider the effect of pop science upon the public's response to science . . . . It is rather the persons who produce popular television shows and feature films, along with the cartoonists of the favorite comic strips—in short the creators of popular culture—from whom the wide American public receives its portrayals of science and scientists (p. 276).

Basalla's analysis suggests the distinct possibility that the nonscientist's images of science and scientists are being shaped by cultural forces potentially more powerful and certainly less informed than individual science teachers or curriculum developers. Indeed, unlike the educator, the media writer seeks first to entertain and has no special regard for accuracy of images.

As science educators, we have good reason to include and appropriately emphasize historical material. Yet historical material seems unlikely to achieve its intended effects on student attitudes and understanding if conflicting messages are presented by our classroom activities or science textbooks. How often do we consider the image of science *directly* in our teaching and writing? The media of popular culture seem to have both a head start and access to a much larger audience. To improve attitudes and understanding, using historical material and other approaches, is an important and difficult challenge.

What History of Science Shall We Teach?

The last of the three broad questions considered in this paper is directly related to the use of history of science to enable students to understand the *methods* of science. The discussion is also relevant to those who would prefer that students' interest in and appreciation of science be based on an accurate portrayal of science. The question, "What history?" arises because the common textbook accounts of the history and methods of science are *not* supported by the actual historical records of science. Characterization of methods of science is an ongoing topic of discussion among historians and philosophers of science (see, for example, Lakatos and Musgrave, 1970), and their interpretations bear little resemblance to textbooks' name-and-date references emphasizing the "discovery" of particular scientific facts and laws. Thus the deliberate use of historical materials in science education demands consideration of the question, "What history of science shall we teach?"

The issue of accurate interpretation of the historical records of science was raised forcefully in 1962, with the publication of Kuhn's *The Structure of Scientific Revolutions*. Kuhn distinguishes "normal" or "puzzle-solving" science from periods of "extraordinary" science in which circumstances cause fundamentals to be challenged. One possible outcome of a period of extraordinary science is a "revolution"—a substantial shift in the explanatory framework of a domain of science. Kuhn explains how the need for his reinterpretation of history went unnoticed for so long by pointing out that science textbooks project an image of science progressing by continuous, gradual accumulation of knowledge. When textbooks are rewritten to incorporate new fundamentals, they typically but incorrectly suggest that a sequence of scientists have worked on the same problems.

> For reasons that are both obvious and highly functional, science textbooks (and too many of the older histories of science) refer only to that part of the work of past scientists that can easily be viewed as contributions to the statement and solution of the texts' paradigm problems. Partly by selection and partly by distortion, the scientists of earlier ages are implicitly represented as having worked upon the same set of fixed problems and in accordance with the same set of fixed canons that the most recent revolution in scientific theory has made seem scientific. (Kuhn, 1970, p. 138)

Kuhn's thesis about scientific revolutions has attracted considerable interest and criticism (Lakatos and Musgrave, 1970). Here the relevant point is not whether Kuhn is right or wrong, but rather that the simple account of scientific method typically presented in science textbooks is *not* supported by the history of science. Kuhn's occasional comments are almost exclusively descriptive, not prescriptive, and they are limited to the education of scientists. Kuhn suggests that textbooks' misleading view of history is *not* detrimental to the education of *scientists.* Presumably, scientists-in-training learn research methods not from textbooks but from actually *doing* research at the forefront of a particular science. Yet science education in the elementary and secondary years *must be concerned with the education of nonscientists about science,* as it also trains and encourages those who will become scientists.

Brush (1976) contends that distortion of the history of science is harmful to nonscientists, given the possible consequences of their being misled by their limited education in science. Brush argues that misunderstandings of method, perpetuated by most textbooks, are at the root of the excessive respect *and* the excessive hostility which accrue to science simultaneously in our culture. Brush maintains that we can ill afford to perpetuate misinterpretations which credit science with the power to solve problems (such as control of nuclear power plants and disposal of nuclear wastes) by simply applying more money and manpower (as "success" in the race to the moon suggests but "failure" to cure the many forms of cancer denies).

Not long after Kuhn's book raised the matter of distortion, Brush (1969) pointed out that one basic challenge involves putting science teachers in touch with the (undistorted) history of science. With the title, "Should the History of Science Be Rated X?", Brush (1974) expressed his serious concern about the use of history of science in science education. He has urged science teachers to rely on the historical record directly, not on the history presented by textbook writers. He notes that current historians and the historical record itself will serve to challenge the ideal of objectivity often associated with "the scientific method."

> My point is that, if science teachers want to use the history of science, and if they want to obtain their information and interpretations from contemporary writings by historians of science rather than from the myths and anecdotes handed down from one generation of textbook writers to the next, they cannot avoid being influenced by the kind of skepticism about objectivity which is now so widespread. They will find it hard to resist the arguments of the historians, especially if they bother to check their original sources. (Brush, 1974, p. 1170).

It is unfortunate that we know so little about how historical material in textbooks influences students' understanding of science and attitudes toward science. For the science educator who pursues the aim of having the nonscientist understand the methods of science, the distortion of history by textbook writers makes the challenge even more complex. Our educational instincts suggest that the history of science which we do teach should be accurate. Reliable empirical data on the matter are sorely needed.

Conclusion

The significance of the history of science in achieving the goals of science education has been reviewed by considering three basic questions:

(1) How much history of science is required to influence students' attitudes toward and understanding of science?
(2) Why teach the history of science in science courses?
(3) What history of science should we teach?

The period 1950–1980 has included major curriculum development projects and significant developments with respect to the history of science. Welch (1979) has concluded that the new curricula have not stimulated the desired increase in student interest in science. The significant amounts of undistorted historical material used by Harvard Project Physics did influence students' views of physics, but not their understanding of science. Empirically, little more can be said. The many studies of curricular effects on attitudes to science have produced a confusing picture and a variety of methodological criticisms. Still, one can recognize the potential value of teaching the history of science to develop an accurate understanding of science and to encourage positive attitudes to science. Within our technological culture, attitudes toward science are influenced in many ways, and the relative importance of science courses is not clear. For the benefit of the many students who do not become scientists, the history of science we teach should be accurate, not distorted to suit textbook logic. A variety of recommendations for teaching and research can be drawn from the preceding discussion.

Recommendations to Teachers

Science teachers should be encouraged by the report that "content inclusion and emphasis" influence student learning (Walker and Schaffarzick, 1974). *The Project Physics Course* has demonstrated that significant amounts of historical material included in the content of a course can influence, in desirable ways, students' attitudes toward science (Welch and Walberg, 1972). However, it appears that historical material *does not ensure* improved understanding of science; due emphasis should be given to historical material to bring out specific characteristics of science. The two goals of accurate understanding of science and positive attitudes toward science are traditional and important, yet they should not be attempted indirectly or without consideration of competing influences. Science textbooks tend not to emphasize these goals. The wording used in some textbooks can be very misleading, and the historical references can suggest a distorted view of science's history and methods. The behavior of the science teacher also deserves careful consideration; students seem to prefer being active in their study of science.

The science teacher should also recognize the cultural ambivalence about science and the persistence of powerful negative images in the media. Perhaps one major topic in every science course should be taught from accurate historical materials, and relevant methodological issues treated directly. Perhaps science teachers should watch popular television programs often enough to be able to discuss with students the images of science and scientists which are suggested and implied. Science teachers who attach importance to accurate understanding of science and positive attitudes toward science are urged to monitor regularly their materials and teaching strategies for direct and indirect messages about science.

Recommendations for Materials Development

Those who would develop historical materials for use in science education must recognize the need for significant quantities of accurate material, to be included in the student textbook and given emphasis appropriate to the purposes the material is intended to serve. The Harvard Project Physics experience illustrates what can be accomplished when large-scale funding and publicity serve to attract a commercial publisher. Klopfer's excellent "History of Science Cases" did not become incorporated into a conventional format, and are now out of print. Large-scale development work seems improbable in the immediate future. As a long-term goal, textbook writers could be encouraged to present one aspect of a course from an historical perspective, and publishers encouraged to learn from the success of *The Project Physics Course*. Not to be overlooked are the major television series which have used historical material to bring science to the general public. Three recent examples are "The Ascent of Man," "Connections," and "The Voyage of Charles Darwin." Using a medium very popular with most students, these series assemble resources otherwise quite beyond the individual teacher. A significant contribution could be made by guidebooks providing science teachers with suggestions for using television series to help students understand science. "The Search for Solutions," a series of nine 18-minute films, addresses directly how scientific processes (especially problem-solving) are understood. A book (Judson, 1980), a Teaching Guide, and a Teaching Notes newsletter are available to science teachers who borrow the films.[3] Data on the effectiveness of this approach could guide the future use of historical materials in television presentations.

Recommendations for Research

First and foremost, researchers in science education need to confront and resolve the problems associated with studies of attitudes toward science. We can hardly afford to develop more "instruments" without determining why so few clear conclusions have emerged from years of attempts to identify curricular influences on attitudes to science. Moreover, there is an equally important need for research which studies the *provision actually made by textbooks and by teaching* for students to develop images of science and scientists. Are we sure there is good reason to expect the effects we attempt to detect? Also, is it possible to determine the *actual importance of science teaching*, as one of the many sources of accurate and inaccurate information about science? From such an assessment we might develop realistic predictions of the potential influence of science teaching.

Other significant questions come to mind. Is it possible for science educators to develop and to agree upon a detailed specification of the understandings and attitudes students should develop? How important to science teachers are the goals of understanding science accurately and fostering positive attitudes toward science? How aware are science teachers of the potential distortion of science's history by textbook writers? Is it possible to influence the writing style and historical content of major science textbooks? Finally, there may be a great deal to be learned by asking questions of science students. We do know something of their attitudes and understandings with respect to science, but we know little about what they take from textbooks and teaching styles and how they relate these to information about science suggested by sources outside the classroom.

[3] The films, Teaching Guide, and Teaching Notes newsletter for "The Search for Solutions" may be ordered by writing to Playback Associates, 708 Third Avenue, New York, NY 10017.

The issue of historical distortion also merits critical inquiry. The most popular science textbooks could be analyzed in terms of quantity and quality of historical material. If distortion is not detrimental to future scientists, why is this the case and when does the correction of distorted understandings occur? What is the impact on future scientists of accurate historical material? (Kuhn abandoned a scientific career and became an historian, once he was exposed to the history of science.) A larger concern for science education researchers is the education of nonscientists, and there is a need to study the impact of both distorted and accurate history on students whose only other sources of information about science are those within the culture at large. It is important to determine whether accurate historical material *can* be used to improve students' understanding of the methods of science.

References

Ahlgren, A. and Walberg, H. J. "Changing Attitudes towards Science among Adolescents," *Nature,* 1973, *245,* 187-190.

Basalla, G. "Pop Science: The Depiction of Science in Popular Culture," G. Holton & W. A. Blanpied (Eds.), In *Science and its Public: The Changing Relationship.* Boston: D. Reidel Publishing Co., 1976.

Brush, S. G. "The Role of History in the Teaching of Physics," *The Physics Teacher,* May 1969, pp. 271-280.

Brush, S. G. "Should the History of Science Be Rated X?," *Science,* 1974, *183,* 1164-1172.

Brush, S. G. "Can Science Come Out of the Laboratory Now?," *Bulletin of the Atomic Scientists,* April 1976, pp. 40-43.

Conant, J. B. *Science and Common Sense.* New Haven: Yale University Press, 1951.

Conant, J. B. (Ed.), *Harvard Case Histories in Experimental Science* (2 vols.). Cambridge: Harvard University Press, 1966.

Gardner, P. L. "Attitudes to Science: A Review," *Stud. Sci. Educ.,* 1975, *2,* 1-41. (a)

Gardner, P. L. "Science Curricula and Attitudes to Science: A Review," *Australian Science Teachers Journal,* 1975, *21,* 23-40. (b)

Judson, H. F. *The Search for Solutions.* New York: Holt, Rinehart and Winston, 1980.

Klopfer, L. E. "The Teaching of Science and the History of Science," *J. Res. Sci. Teach.,* 1969, *6,* 87-95.

Klopfer, L. E. and Watson, F. G. "Historical Materials and High School Science Teaching," *The Science Teacher,* October 1957, pp. 264-265; 292-293.

Kuhn, T. S. *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press, 1962.

Kuhn, T. S. *The Structure of Scientific Revolutions* (2nd ed., enlarged). Chicago: University of Chicago Press, 1970.

Lakatos, I. and Musgrave, A. (Eds.), *Criticism and the Growth of Knowledge.* London: Cambridge University Press, 1970.

Mallinson, G. G. "A Summary of Research in Science Education—1975," *Sci. Educ.* Supplement, 1977.

McMillan, J. H. and May, M. J. "A Study of Factors Influencing Attitudes toward Science of Junior High School Students," *J. Res. Sci. Tech.,* 1979, *16,* 217-222.

Mead, M. and Métraux, R. "Image of the Scientist among High-School Students: A Pilot Study," *Science,* 1957, *126,* 384-390.

Munby, H. "An Evaluation of Instruments which Measure Attitudes to Science," In C. McFadden (Ed.), *World Trends in Science Education.* Halifax, Nova Scotia: Atlantic Institute of Education, 1980.

Nelkin, D. "The Science-Textbook Controversies," *Sci. Am.*, 1976, *234*(4), 33–39.

Peterson, R. W. and Carlson, G. R. "A Summary of Research in Science Education—1977," *Sci. Educ.*, 1979, *63*, 425–553.

Renner, J. W., Abraham, M. R. and Stafford, D. G. "A Summary of Research in Science Education—1976," *Sci. Educ.* Supplement, 1978.

Rutherford, F. J., Holton, G. and Watson, F. G. (Directors), *The Project Physics Course: Text.* New York: Holt, Rinehart & Winston, 1970.

Walker, D. F. and Schaffarzick, J. "Comparing Curricula," *Rev. Educ. Res.*, 1974, *44*, 83–111.

Welch, W. W. "Review of the Research and Evaluation Program of Harvard Project Physics," *J. Res. Sci. Teach.*, 1973, *10*, 365–378.

Welch, W. W. and Walberg, H. J. "A National Experiment in Curriculum Evaluation," *Am. Educ. Res. J.*, 1972, *9*, 373–383.

Welch, W. W. "Twenty Years of Science Curriculum Development: A Look Back," D. C. Berliner (Ed.), In *Review of Research in Education 7, 1979.* Washington, D.C.: American Educational Research Association, 1980.

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