

Worldview Theory and Conceptual Change in Science Education

Running Head: Worldview

A paper presented at the 1994 annual meeting of the National Association for Research in Science Teaching, Anaheim, CA, March 26-29. Revised August, 1995, for submission to Science Education

William W. Cobern, Ph.D.
Associate Professor of Science Education
Arizona State University West

Once again science education finds itself in the midst of reform. Reform documents are too numerous to mention by name but they all share the same view that Americans know far too little science. Durant (1990) noted that even the well educated often know little science. Of course every reform document by its very nature offers a solution. Many in the science education research community "see conceptual change as the emerging focus of science teaching" (Wandersee, 1993, p. 319) and thus focus their research interests here as well. To borrow warfare metaphors, conceptual change activities are tactical devices used to reach small-scale objectives (i.e., individual science concepts) within a strategic framework for reaching the large-scale objective of scientific literacy. For all its merits, my objection to the conceptual change model is that it uncritically accepts the strategic framework in which it operates. In my view, that framework involves a much too narrowly conceived notion of knowledge and the role knowledge plays in an individual's life. The purpose of this article is to discuss the effect of a flawed strategy on the tactics of conceptual change and to draw attention to a broader view of knowledge from a worldview perspective. I begin by recounting a story from cultural anthropology. Readers may wonder at first what this story has to do with conceptual change and science education. Though perhaps not immediately apparent, there is a parallel with science education which I intend to make explicit in due course. In addition to illustrating a point, the decision to use the Rosaldo story is illustrative of my assertion that achieving science for all will require a curricular view of science that places and integrates science within a community of disciplines.

The Rage of a Headhunter

Renato Rosaldo is a cultural anthropologist who spent years in the Philippines studying the Ilongot people of northern Luzon; people who by tradition are headhunters. In good western scientific fashion, Professor Rosaldo wanted to know why the older Ilongot men hunted heads. When he asked an Ilongot, "why he cuts off human heads, his answer [was] a one-liner on which no anthropologist can really elaborate: he [said] that rage, born of grief, impels him to kill his fellow human beings" (Rosaldo, 1984, p. 178). In other words when a loved one died the Ilongot people were filled with grief which led to rage. The older men finding this rage intolerable sought relief by killing and beheading another human being. This explanation as Rosaldo noted is not scientifically acceptable. "The job of cultural analysis... is to make this man's statement plausible and comprehensible... I brushed aside their one-line accounts as too simple, thin, opaque, implausible, stereotypic, or otherwise unsatisfying" (1984, p. 178-179). The Ilongot explanation for headhunting is unacceptable in a scientific analytical framework that seeks the "lysis or breaking down of a whole into constituent parts... the scientific study of man thus aims ultimately at his abolition as man - as free agent - and his reconstruction as mechanism" (Satinover, 1994, p. 14). The pressure in scientific thought is almost always to break wholes into parts where it is believed true understanding can be found.

Renato Rosaldo, however, did not easily find the analytical answer he sought. For years Rosaldo made no progress toward what he considered an acceptable explanation for Ilongot headhunting. He made no progress until he was struck by personal tragedy. While hiking a mountain trail, Rosaldo's wife Shelly slipped and fell to her death. In grief at his loss, Rosaldo was filled with rage at the unjust death of his loved one; and through that time of personal tragedy he began to understand the Ilongot in a way his scientific methodology had been incapable of providing. He discovered through personal tragedy that a simple concept such as

grief requires no further elaboration because its emotional impact on a life give it both scope and force within the life of an individual and community. A concept or belief has force if it is central in an individual's thinking rather than marginal. A concept or belief has scope if it has relevance for the individual over a wide range of contexts. The points I wish to emphasize here are first that Rosaldo achieved a break through in his research when he came to a place of empathy with the Ilongot. Second, his break through came in the form of two concepts, scope and force. I will return to empathy, scope, and force after a brief discussion of conceptual change. (I am allowing an ambiguity concerning the nature of knowledge and belief to enter at this point. A clarification is not necessarily needed here and it is something I have addressed elsewhere. See Cobern, 1994).

Conceptual Change Research

The basic idea of science instruction for conceptual change, that is the conceptual change model, is simple. It is based on the constructivist notion that all learning is a process of personal construction and that students, given an opportunity, will construct a scientifically orthodox conception of physical phenomena if they see that the scientific conception is superior to their pre instruction conception (Posner, Strike, Hewson, and Gertzog, 1982). Researchers have variously defined a superior conception as one that is "useful in making sense of the world" (Roth, 1989, p. 22) or one that is "more powerful and useful in explaining and predicting phenomena" (Hewson, 1981, p. 384). More specifically, it is said that conceptual change requires that a concept be found more intelligible, plausible, and fruitful. Over the past twenty years numerous teaching ideas derived from the conceptual change model have been invented and tested. Scott, Asoko, and Driver (1992) offers a lucid review of this work. Throughout conceptual change work, the assumption of course is that scientific conceptions are superior on these terms to other conceptions, an assumption I will have more to say about later.

Quite naturally the conceptual change model has developed over time. Hewson (Hewson and Hewson, 1983; Hewson and Thorley, 1989) who was one of the original authors offered early refinements. Taking a rationalistic tack, Lawson, Abraham, and Renner (1989) developed a conceptual change teaching approach called the Learning Cycle which has become widely used in both research and practice. Lawson et al. (1989) capitalized on what others considered the excessively rationalistic tenor of the conceptual change model (e.g., Pines and West, 1986). In response to the criticism that the conceptual change model is too rationalistic, two of the original conceptual change model authors in a reassessment acknowledged the role of emotion and intuition in conceptual change (Strike and Posner, 1992). Moreover, Glasson and Lalik (1993) developed a social constructivist adaptation of the conceptual change model which "is consistent with Vygotsky's theory that emphasizes various modes of social interaction in the development of a broad spectrum of thought processes, rather than focusing on the use of argumentation in the development of hypothetical-deductive logic (as advocated by Lawson et al., 1989)" (Glasson and Lalik, 1993, p. 203). The rationalist critique was pursued by Peter Taylor and Ken Tobin. Peter Taylor argued that,

a constructivist reformation of the rationality of traditional science and mathematics requires a critical perspective on the social reality of the classroom and its curriculum straightjacket, In relation to Habermas's theory of communicative action, there is a need

to assist teachers to develop a critical discourse that aims to make visible and subject to critical examination the cultural myths of rationalism and objectivism, in accordance with the emancipatory cognitive interest. (Taylor, Tobin, and Cobern, 1994, p. 6-7)

Ken Tobin (in Taylor, Tobin, & Cobern, 1994, p. 7) argued that the complexity of the classroom requires the research to adopt a sociocultural matrix, "in terms of teacher and student beliefs about teaching and learning, modes of knowing science, the influence of peers and the teacher on learning, within class and school influences, and gender, social class and ethnicity as factors associated with learning science."

The critique I wish to add is prompted by an implicit conceptual change assumption that scientific conceptions are superior to other conceptions for making sense of the world. This assumed superiority of scientific concepts refers to the strategy in which the conceptual change tactics are embedded. The predominant strategy of science education severely limits the context of scientific ideas in science education to science alone and thus fails to recognize that student conceptions "provide a different sectioning of experience precisely because the pursuit of scientific knowledge is not the only or even the most important goal they subserve" (Hills & McAndrews, 1987, p. 216). In other words, in the science classroom all concepts regardless of their origin and source are evaluated by the standards of science. However, since few students share this limited view of knowledge the assumption would seem problematic. It is perhaps part of the cultural myth of which Taylor (Taylor, Tobin, & Cobern, 1994) speaks.

Breaking with Everyday Thinking

In its extreme form, conceptual change is a tacit attempt to mimic a stereotypical scientific approach to experimentation: isolate, control, and manipulate. The science curriculum isolates the student from other domains of knowledge (especially what is called everyday knowledge) and attempts to control the classroom environment such that student attention is dominated by a teaching manipulation. No where is the idea of isolation made more clear than among researchers who call for students to break with everyday experience and thinking (e.g., Floden, Buchmann, and Schwille, 1987; Garrison and Bentley, 1990). Here it is argued that science conceptual change requires a breaking with what is essentially students' natural understanding of their world. Indeed, the common strategy of science education in which the conceptual change model is embedded creates a hermetic classroom environment conducive to breaking with other conceptual ideas. This strategy of isolation, control, and manipulation serves, in Eger's (1989, p. 85) words, the interest of science to have a functioning pipeline that delivers future scientists, but not interest in science which is the proper interest of most students. Eger's distinction echoes Ziman's earlier conclusion that there is, "a serious mismatch between the interests of those who are already inside science, and the motives of those whom they would like to draw in" (1984, 184-185). As a science educator, I cannot help but think that there is something awry with the implicit argument that scientific literacy, which all people are said to need, is to be achieved by breaking with the everyday world in which people live and presumably where they will use their scientific literacy. To clarify the basis for this assertion I return to the story of Rosaldo and the Ilongot headhunters.

Like Rosaldo, science educators want to be scientific. The conceptual change model was born of the questions, Why is it that students do not do better in science than they do? Why is it that students are not more interested in science? If one asks a typical high schooler a direct question about the superiority of scientific conceptions in the fashion that Rosaldo asked the Ilongot a direct question about headhunting, the answer is likely to be a rather nonchalant shrug of the shoulders. Like Rosaldo's pre tragedy study of the Ilongot, science education research is often dismissive of simple student responses. And just as Rosaldo later found that simple ideas and beliefs can have both scope and force, I suggest that conceptual change tactics for the goal of scientific literacy will ultimately fail for most students because scientific conceptions as commonly interpreted at secondary and tertiary schools hold no force and little scope for most students. Moreover, to suggest that students break with everyday thinking is to suggest that they break with that which is meaningful. The high schooler's shrug is indicative of the meaning science has lost for students, and this loss of meaning Eger rightly observed is the most serious long-term "problem for science in relation to students and society as a whole" (Eger, 1992, p. 345).

To illustrate the point, consider the counter example of someone who effectively develops an orthodox scientific conception. A few years ago the cultural anthropologist Sol Tax commented on his own experiences learning the concepts of evolution while enrolled in a college course on evolutionary biology. As a personal challenge he tried to imagine a non-naturalistic theory that accounted for the data presented by his professor. "But this universe of my imagination established for me the absurdity of a supernatural alternative to naturalistic evolution. Needless to say, that was easy because I had never entertained a contrary belief" (Tax, 1983, p. 36, emphasis added). Upon reflection Tax realized that he had not come to his position on evolution through any rational process. Nor did he need to "break" with prior conceptions. Evolution was consistent with what he already believed the world to be like. Of course one may counter that it is those who experience trouble accepting a scientific concept that need to break with everyday concepts or prior concepts. Consider, however, what this means. A student is asked to break with long held concepts steeped in meaning for alien concepts newly encountered.

Gunstone (1990) offers an informative example of just this problem. Gunstone learned from the literature that there are four alternative conceptions typically found among students to explain the action of a light bulb connected to a direct current circuit. Some students, for example, think that there are two kinds of electricity, positive and negative, which come from opposite ends of a dry cell battery and travel in opposite directions. When the two kinds meet at the light bulb there is a "clash" which we see as the lighted bulb. Gunstone directly encountered this "clashing currents model" on an occasion when he taught a series of lessons for an eighth grade science class.

After I had spent a number of science periods with the grade 8 class, providing what I thought was a wonderful sequence of experiences and discussion to challenge existing models, a student who had begun the sequence with a clashing current model informed me that he still held to this belief. Why did he believe this, I asked? His father had told him this, and his father was an electrician. It was suddenly very clear that I would not provoke him to reconsider and reconstruct. (Gunstone, 1990, p. 12)

The point I wish to make is that conceptual change makes little sense when the change is to science concepts that have been presented to the students in such a manner as to hold little meaning for most students. By "meaning" I refer to having scope and force within a student's fundamental understanding of what the world is like, that is, the student's worldview. In this second example, and as Gunstone admits, there is no way that conceptual change tactics as presently construed will be able to convince this student that the orthodox scientific conception of electricity is the superior conception. It is pointless to say that this student needs to "break" with his everyday thinking because, as stated above, that would mean breaking with a long held concept steeped in meaning for an alien concept newly encountered. What is at issue here is worldview; and rather than fostering a scientific worldview through science education, science education tacitly assumes much of what is described as a scientific worldview to already be in place. This issue is not without controversy. Michael Matthews objects to what he calls "sense-ism" which is the radical social constructivist epistemology that a proposition is not valid unless it makes sense to the individual. My use of "meaning" should not be viewed as a variation of sense-ism but a variation of Ausubel and Novak's "meaningful learning" (Novak, 1982). What I have done is to expand the domain in which meaningfulness of science concepts operates to include the entirety of a learner's cognitive ecology or worldview.

Strategic Science Education and Worldview

Worldview provides a non rational foundation for thought, emotion, and behavior. Worldview provides a person with presuppositions about what the world is really like and what constitutes valid and important knowledge about the world. It is according to Kearney, "culturally organized macrothought: those dynamically inter-related basic assumptions [i.e., presuppositions] of a people that determine much of their behavior and decision making, as well as organizing much of their body of symbolic creations... and ethnophilosophy" (1984, p. 1). In 1984, Brent Kilbourn pioneered the use of worldview in empirical science education research by using Pepper's (1942) root metaphor approach. I have more recently adapted logico-structuralism from cultural anthropology for use in science education research (Cobern, 1991a; Kearney, 1984). The power of the logico-structural model of world view lies in its composite structure of inter-related, universal categories: Self, NonSelf, Classification, Relationship, Causality, Time and Space. Each category is composed of logically related presuppositions. In principle groups of people and even individuals can be identified by worldview variations which result from the content variation of categories. This composite nature of the logico-structural model focuses the researcher's attention on the complexity of worldview, and yet the categories themselves provide access to that complexity. And while the composite nature of the model makes it less likely that the researcher will oversimplify the notion of worldview, one can still speak of worldview unity based on salient presuppositions within the seven universal categories. One may thus speak of a scientific worldview but I have written elsewhere (Cobern, 1991a) that I disapprove of this construction as misleading. Worldview is an exhaustive concept that far exceeds the realm of science for all but the most extreme scientific believer. A scientifically compatible worldview is a more modest and useful construction; and what, for example, the AAAS calls a scientific worldview would be more accurately called a metaphysic for science.

More to the point of this article, a worldview cannot be reduced to a set of scientific conceptions and alternative conceptions about physical phenomena. To be rational, for example,

simply means to think and act with reason, to have a reasoned explanation or justification for thought and action. Such explanations and justifications ultimately rest upon one's worldview presuppositions. Thus, worldview is about metaphysical levels antecedent to specific views that a person holds about natural phenomena, whether one calls those views commonsense theories, alternative frameworks, misconceptions, or valid science. A worldview is the set of fundamental non rational presuppositions on which these conceptions of reality are grounded. For example, Sol Tax' out of hand dismissal of anything but a naturalistic theory of origins is grounded in such a presupposition about how the world really is. Moreover, it is no use trying to see behind these worldview presuppositions except in the sense of trying to understand the sociocultural environment that leads to a worldview. As C. S. Lewis once wrote: "it is simply no use trying to see through first principles ... If you see through everything, then everything is transparent. But a wholly transparent world is an invisible world. To see through all things is the same as not to see" (1947, p. 91). This is a difficult concept for the scientifically inclined to grasp because science by its nature is always seeking the next level of explanation. This scientific seeking without limits, however, is ad infinitum. All thinking presupposes a foundation which itself is unprovable. This is the case even in mathematics where Kurt Gödel showed that all consistent axiomatic formulations of number theory must also include unprovable presuppositions. Lewis' point is that there is nothing left to see if one refuses to recognize presuppositions.

How people see the world is of very much interest. Scientists and science educators are interested in how people see the world. Duschl (1991) correctly noted that conceptual change teaching and learning is about how students change their vision of the world. As noted, science education policy documents such as the AAAS Project 2061 call for education to foster a scientific worldview, or in other words, to bring about change so that students see the world scientifically. One of the inadequacies of these documents is the superficial way in which the concepts of worldview and culture are used, though the documents' usage is consistent with their promotion of conceptual change models. Before taking up this inadequacy, however, more must be said about worldview development as a science education objective.

Scientific Literacy and Worldview

Some may dispute my assertion that a scientific worldview, or even as I prefer a scientifically compatible worldview, is a major goal for science education. Indeed, a quick examination of curriculum documents for science education such as the NSTA's Scope, Sequence, and Coordination shows that scientific literacy is frequently given as the main goal for science education. Science for All Americans speaks of both, but a scientific worldview is described as part of scientific literacy. Since the concept of literacy is a borrowed one, it is instructive to examine its source meaning.

"Literacy" is from language literacy and simply means that one can read and write in a language. Language literacy is widely considered the single most important goal for education and thus the arguments for science education are buttressed by association when the concept of literacy is appropriated. Scholars of language, however, understand that there is more to language literacy than reading and writing. Language and thought are closely related. As stated in the Sapir-Whorf hypothesis, "habitual modes of thought of a group are functionally related to the structure of the language of the group" (Morrill, 1975, p. XX). In other words, how one

thinks is related to the language in which one thinks; thus, how one thinks must also be related to language literacy. If a person studies a second language, particularly if the second language is of a totally different linguistic origin (e.g., English and Japanese), becoming literate in that second language also means coming to understand a different view of the world (though it does not necessarily mean adopting a different worldview). For example, in Japanese there is no equivalent for the English word “nature.” The closest Japanese word to “nature” is “shizen” and is the word most frequently used when translating the English word “nature” into Japanese. This forced translation, however, is not without problems because the words have very different culturally based connotations (Ogawa, 1986, 1989; Kawasaki, 1990). As an English speaker learns the Japanese understanding of “shizen” the English speaker also comes to see a different understanding of what in English is known as “nature.” One glimpses the Japanese worldview. Indeed, a native English language speaker would not be considered literate in Japanese without a considerable feel for Japanese culture. Similarly, Ogawa (1986) and Kawasaki (1990) have argued that imposing the Western meaning of “nature” on the Japanese concept of shizen through science education risks alienating many students to the detriment of science education goals. Though neither of these scholars addresses the point, it is also possible that as some students come to accept the Western concept of nature it will be at the expense of traditional Japanese culture.

A similar situation obtains in speaking of scientific literacy in so far as scientific literacy is typically defined (e.g., Champagne, Lovitts, and Calinger, 1989). As one becomes scientifically literate, that is, as one comes both to understand and value the concepts and methods of science, one comes to see the world differently - - though the degree of difference varies with a person’s initial background. The history of science is replete with examples from Copernicus to Newton to Darwin to Einstein and so on where developments in science lead to a significant change in how the world is viewed. This change of perception is indeed what educators want. We do not teach science as a trivial pursuit. No, all the definitions of scientific literacy include the embrace and application of science in everyday life - but, one will apply science only when it fits one’s sense of self and environment, personal goals, and understanding of how the world really is - in short, if one has a scientifically compatible worldview.

My point in summary is that though science educators more often speak of scientific literacy as the primary goal for science education rather than a worldview, the concept of literacy advocated entails the concept of worldview. The one cannot be had without the other. Moreover, just as language literacy discussions in simple terms of reading and writing can easily obscure the more complex relationship between language and thought, especially in bilingual education situations, a simplistic discussion of scientific literacy in terms of concept acquisition and application obscures the perceptual change that accompanies literacy in science. The choice of the concept “literacy” actually contributes to the difficulty of understanding the significant connection between what is called scientific literacy and a scientific worldview. In language literacy the concept is most often used where students already speak (say) English and are learning to be literate in English by learning to read and write the language they already speak. Scientific literacy is not at all like this form of literacy because there is no science language the students already speak. Similarly, Weisskopf (1976) noted that, "In contrast to concepts used in the humanities, there is little or no intuitive preparation or preformation of [physics] concepts in the culture of today" (p. 25) which in his view contributed to the difficulties many students have

with science. Rather, educators should see beginning science students as beginning bilingual education students who are learning both a new language - - and thus the culturally based thought forms of that language - - and how to read and write in the new language. Once one sees scientific literacy as the second and more complex form of literacy, the connection between literacy and worldview becomes fairly evident.

Conceptual Change and Worldview Development

I return now to the use of worldview in the science education literature which is typically a casual use that implies a simplistic linear view of the cultural components of worldview as depicted in the following equation:

$$n_1A_{\text{religion}} + n_2B_{\text{gender}} + \dots + n_{10}J_{\text{ethnicity}} + n_{11}K_{\text{scientific}} = \text{Worldview}$$

The uppercase letters (A, B, C, etc.) represent cultural factors that contribute to worldview and which are operative over a number of contexts (n1, n2, etc.). The contexts could be school, home, the store, polling station, and the like. Here worldview is the sum of whatever number of cultural components (e.g., religion, aesthetics, ideology) a person embraces. Some components will have more scope (larger values of n) and force than others, and the goal for scientific literacy seems to be that the value for n11 in the above equation would be large relative to any other value for n in the equation. In this regard, C. P. Snow makes for an illustrative example. C. P. Snow (1964) wrote of the science/humanities rift as having obtained the status of two cultures, and few disagreed. Snow's influence is such that it is axiomatic that anyone discussing problems between the sciences and humanities will invoke Snow's "two cultures" metaphor. Unfortunately, Lord Snow was more a symptom of the division than an evangelist of reconciliation. Snow fully accepted the positivist position that science is the only truly verifiable and self-correcting mode of inquiry. Lord Snow's concern was for the future. For him, it was not the humanists, but the scientists who "had the future in their bones" (1964, p. 10), and to scientists we must look. For Lord Snow, reconciliation meant the absorption of the humanities by the sciences - scientists know that science is rational, humanists only believe that the humanities are. Moreover, the scholarly literature after Snow which purported to address the "Snow Gap," followed suit (e.g., Stinner, 1995). Scholars focused on interpreting art, for example, in scientific terms -seldomly the other way around. A teacher may decide to use art to bring a group of students to science, but what about bringing to the science classroom an artist's perspective on science?

Consider Figure 1 which uses long parallel arrows to depict the orientation of a worldview in which concepts, depicted by arrowheads, are embedded. In Figure 1A there are three scientific concepts noticeable because they are going against the existing orientation of this individual's worldview. The linear model of worldview suggests that if a critical mass of conceptual change is reached for a student, the sheer force of scientific conceptual weight will shift the orientation of his or her worldview to the scientific. In that case the parallel arrows in Figure 1A would reorient along the lines of the three arrowheads representing science concepts. The other arrowheads would similarly reorient or drop out bringing about what one might call a Kuhnian revolution. Given the critical mass of conceptual change, support for this worldview

shift can be inferred from the Sapir-Whorf hypothesis. The catch, however, is achieving critical mass.

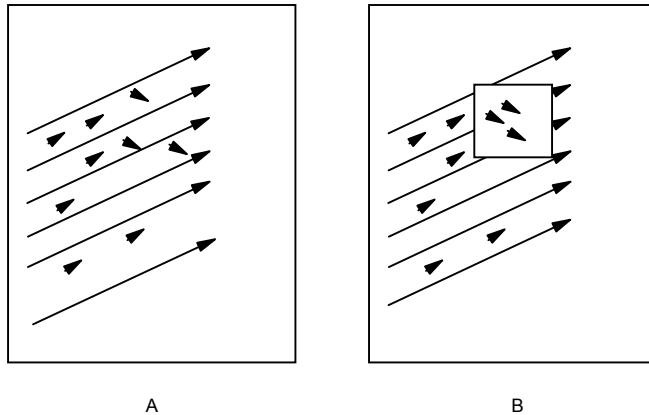


Figure 1. Orienting Effect of Worldview

Classroom experience tells a different story. In another context, Burbules and Linn (1991, p. 228) commented that,

students rarely see a relationship between the science they learn in school and the science problems they encounter in everyday life. This narrowness is attributable not only to the generally recognized difficulty of transferring knowledge from one domain to another, but also to an active belief on the part of students that 'school knowledge' represents a distinct and special category of learning, separate from the common-sense solutions they develop in real-life contexts.

Many students, in other words, practice cognitive apartheid (Figure 1B). Students simply wall off the concepts that do not fit their natural way of thinking. In this case, the students create a compartment for scientific knowledge from which it can be retrieved on special occasions, such as a school exam, but in everyday life it has no affect (Cobern, 1993a; also see Scribner and Cole, 1973). The compartment walls hold as long as there is pressure, such as a pending exam, to hold it in place. Once the pressure is relieved (e.g., the exam is over) the walls go and the concepts revert to forms more consistent with the students worldview or simply deteriorate for lack of significance. Educators correctly assume (albeit implicitly) that there is a certain conceptual critical mass that once achieved will begin to alter the student worldviews towards the scientific. The problem for scientists and science educators is that this critical mass of conceptual change is too infrequently and too unevenly achieved. Jon Miller (1988) refers to the mere five percent of American society he considers to be scientifically literate. Amongst the college educated significant numbers avoid science (Tobias, 1990). Even those students who begin college programs as science majors frequently switch to non science programs (*The Scientist*, 1993). Indeed, there is a growing concern among scientists over anti science attitudes in contemporary society (e.g., Crease, 1989; Dyson, 1993; Gross & Levitt, 1993; Holton, 1993; Ruse, 1994). In the spring of 1995, the New York Academy of Sciences brought together “about

200 worried scientists, doctors, philosophers, educators, and thinkers... [because] there is a growing danger, many said, that the fabric of reason is being ripped asunder, and that if scientists and other thinkers continue to acquiesce in the process, the hobbling of science and its handmaidens - medicine and technology among them - seems assured" (Browne, 1995, p. E2). It should be clearly understood, however, that one need not assume that student worldviews are a hindrance to science conceptual development, nor has it been demonstrated that the perceived anti scientism is not a function of how school science is currently contextualized (see Aikenhead, in press; Brickhouse, 1994; Fourez, 1988).

Of course no student fits neatly into either Figure 1A or 1B. Students bring a broad range of experience and thought to the classroom and their views of the world form a spectrum of many ideas. Again teachers know by experience that some science concepts such as ecology and conservation readily fit many students' worldviews as they are. The point here is that it would be a mistake to assume that ever improved conceptual change tactics will lead to the accumulation of science concepts needed for scientific literacy and a scientifically compatible worldview. It is just as reasonable to assume that many students will simply compartmentalize whatever scientific conceptual change that takes place and hold it only under compulsion. The problem is that science education too often is not about developing scientific understanding but about understanding scientific concepts with the tacit assumption that scientific understanding will follow as a matter of course. That there is concern about a lack of scientific understanding is evident from the literature cited above on anti scientism and irrationality. The standard education response has been the tactical response of more science in the curriculum perhaps in some new arrangement (e.g., NSTA's Scope, Sequence, and Coordination) and the improvement of concept teaching. I suggest that this misses the point that science education as currently conceptualized fails to teach for scientific understanding within the actual worlds in which people live their lives. This article offers a framework for thinking about these issues and for guiding research that would potentially test this article's principle assertions. The balance of the article discusses this framework with examples from research and then concludes with a discussion of implications for practice and specific practical suggestions.

Worldview, Epistemology, and Metaphysics

Rather than a linear, additive model of worldview, logico-structuralism posits worldview as a composite of seven categories holding fundamental presuppositions about existence and being. The model is not rigid and presuppositions are subject to change with experience. Because of their fundamental nature, however, presuppositions tend to be stable. Consider the following scenario which illustrates a presupposition concerning causality.

(I)f you were talking to a pathologist about a certain disease and asked him 'What is the cause of the event E which you say sometimes happens in this disease?' he will reply 'The cause of E is C'; and if he were in a communicative mood he might go on to say 'That was established by So-and-so, in a piece of research that is now regarded as classical.' You might go on to ask: 'I suppose before So-and-so found out what the cause of E was, he was quite sure it had a cause?' the answer would be 'Quite sure, of course.' If you say, 'Why?' he will probably answer 'Because everything that happens has a cause.' If you are importunate enough to ask 'But how do you know that everything that happens has a

cause?' he will probably blow up in your face, because you have put your finger on one of his absolute presuppositions... But if he keeps his temper and gives you a civil and candid answer, it will be to the following effect. 'That is a thing we take for granted in my job. We don't question it.' (Collingwood, 1940, p. 31-32)

At one end of the pathologist's mental framework is his knowledge of diseases and scientific research. At the other is his presupposition about causality and undoubtedly the pathologist's everyday work only strengthens his conviction that all events have material causes. On the other hand, Charles Darwin provides an interesting example of one who during his life underwent a change in the fundamental way in which he viewed nature (an important sub classification with the worldview category of the NonSelf).

I have said that in one respect my mind has changed during the last twenty or thirty years. Up to the age of thirty, or beyond it, poetry of many kinds... gave me great pleasure, and even as a schoolboy I took intense delight in Shakespeare... I have also said that formerly pictures gave me considerable, and music very great, delight. But now for many years I cannot endure to read a line of poetry: I have tried to read Shakespeare, and found it so intolerably dull that it nauseated me. I have also almost lost my taste for pictures or music... I retain some taste for fine scenery, but it does not cause me the exquisite delight which it formerly did... My mind seems to have become a kind of machine for grinding general laws out of large collections of facts ... (quoted in Owens, 1983, p.38)

Upon hearing Darwin's twilight lament one is reminded of E. A. Burtt's comment on Western worldview changes that accompanied the rise of modern science:

The world that people thought themselves living in - a world rich with colour and sound, redolent with fragrance, filled with gladness, love and beauty, speaking everywhere of purposive harmony and creative ideals - was crowded now into minute corners of the brains of scattered organic beings. The really important world was a world hard, cold, colourless, silent, and dead; a world of quantity, a world of mathematically computable motions in mechanical regularity. (1967, p. 238-239)

Both examples illustrate cognitive processes operating on two levels. With the pathologist, for example, there is the level of his particular knowledge of diseases and scientific research rendered plausible by a presupposed concept of causality operating tacitly and at a much more general level. One sees Darwin rejecting specific examples of art because at a more general cognitive level his mechanistic worldview is incompatible with aesthetics. Similarly, the strategy and tactics of science education need to be formulated as an analog to the macro levels (worldview or level of fundamental presuppositions) and micro levels (conceptual level) of everyday thinking. These levels are analogous to the philosophical disciplines of epistemology and metaphysics.

Science educators have long assumed that the case for the importance and validity of scientific knowledge was *prima facie*. This assumption rested on the philosophy of Comptian positivism which essentially claimed that only scientific knowledge was true knowledge. Smolicz & Nunan (1975) referred to this as the mythology of school science. The community of

science educators is now painfully aware of how very few lay people ever accepted the positivistic faith. In recent years, constructivist thought has elbowed aside the mythology of school science. A consistent constructivist teacher cannot approach the recalcitrant learner with ever more teaching tactics, the conceptual change model notwithstanding. In constructivist thought all knowledge entails ambiguity. There are no unambiguous facts. There are no determined theories. So, if scientific concepts do not have the inherent certainty assumed by the mythology of school science, the consistent constructivist must eventually ask what are the principles on which validity or truth is decided? Why do we believe what we do? Constructivism suggests that the concepts of knowledge and belief are not strictly separable (see Cobern, 1994, 1995a, 1995b); and it is with this idea that one can begin to understand how worldview directly influences conceptual development and change. The concept of worldview brings under a single umbrella the philosophical issues of epistemology and metaphysics which respectively deal with arguments that provide explanations and understanding, and the presuppositions upon which epistemological arguments are founded and delimited.

Hannah Arendt (1978) noted that an argument can be rationally flawless. The interpretation of data can be epistemologically perfect, and yet some students will reject the conclusions. The reason, she argued, is the fundamental difference between thinking and comprehension on the one hand, and knowing and apprehension on the other (see Figure 2).

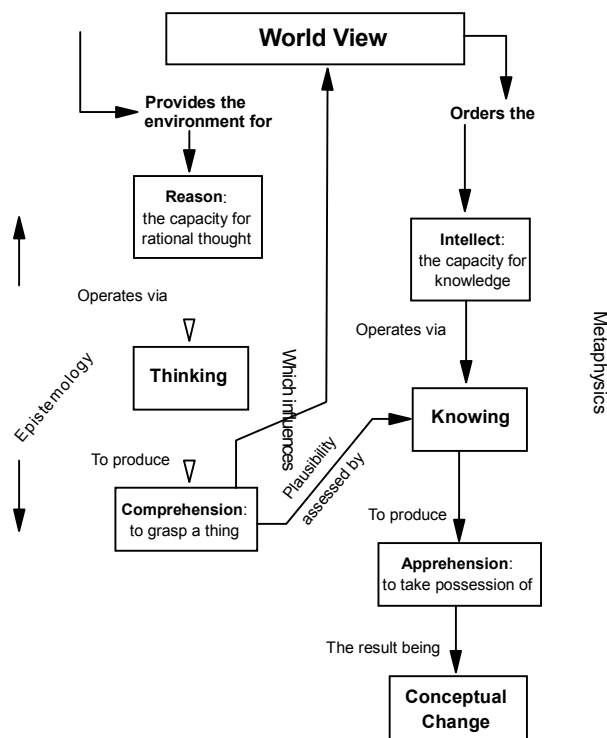


Figure 2. Worldview and Conceptual Change

Thinking is necessary for knowledge, but not sufficient. Thinking is the epistemological process by which one comes to conceptual comprehension. This is what conceptual change tactics are

about. The science teacher, for example, carefully addresses student alternative conceptions and through discussion along with various activities the teacher builds the epistemological case for the orthodox scientific conception. But, even if students comprehend, does this mean that each student has acquired or constructed scientific knowledge? “We are not equally open to all ideas” noted Meyer (1991, p. 12), regardless of comprehension.

The human mind is not like some public plaza where all may come and go as they please. On the contrary, it is a unity, it has an exigence for unity, and it imposes unity on its contents.... every grasp of data involves a certain selection, every selection effects an initial structuring, and every structuring anticipates future judgments. (Meyer, 1991, p. 12)

The answer to the above question is “no” because the students may not have in place the presuppositions that support the concept as knowledge. Knowing is the metaphysical process by which one comes to apprehend, that is to accept as true or valid, the concept one has comprehended (Hasker, 1983; Walsh, 1967). The metaphysical process also assigns the significance of what is apprehended as knowledge. Of critical importance is the fact that comprehension does not necessitate apprehension. One may well reject a concept that he or she fully comprehends while someone else apprehends it as knowledge. Different metaphysical systems operating within different worldviews lead to different views of knowledge (Ogawa, 1995).

This metaphysics of knowing hinges on the answers to perennial questions: What is the ultimate nature of reality? What are the significant ways of knowing this reality? What sources of knowledge are important and in what circumstances? How do I personally fit in this reality? To critically examine the nature of being and existence is to do metaphysics. Hawkins (1972, p. 287) was making a metaphysical statement when he wrote:

only a part of scientific theory is determined by empirical evidence supporting specific, testable generalizations; a part consists of some framework of categories and beliefs brought to the gathering of evidence and linked by boundary assumptions which suggest the kinds of generalizations to be sought and tested and the sorts of inferences these generalizations will sustain.

This metaphysical framework Hawkins writes of is what the philosopher of biology Michael Ruse had in mind when he said about evolutionary theory:

I think that philosophically that one should be sensitive to what I think history shows, namely, that evolution, just as much as religion -- or at least, leave ‘just as much,’ let me leave that phrase -- evolution, akin to religion, involves making certain a priori or metaphysical assumptions, which at some level cannot be proven empirically. (Ruse, 1993, p. 4)

In this case Ruse is asking what non rational presuppositions must be asserted a priori for evolutionary epistemology to be rational? The selection of data and the reasoning about that data

that results (say) in a phylogenetic tree is epistemology. The a priori presuppositions that warrant that epistemology is metaphysics. Chandler (1994) offers a similar argument.

Metaphysics and worldview are similar concepts in that both refer to ultimate categories. Worldview is from cultural anthropology and is a comprehensive concept about the tacit dimensions of cognition subsuming both epistemology and metaphysics. To do metaphysics is to explicitly address a narrower set of fundamental questions about particular cases. What is the metaphysical support for evolutionary theory? What is the metaphysical support for science? What the AAAS offers in Science for All Americans as a scientific worldview is instead a metaphysic for science. If one goes further than this level of the particular to develop a generalized comprehensive system of thought based on evolutionary ideas, for example, as did Simpson in *This View of Life*, then one is attempting to elevate metaphysical thought to the comprehensive status of a worldview. In philosophy, metaphysical debate has long been out of fashion primarily due to the influence of logical positivism. Logical positivists argued that metaphysics was as meaningless as a string of nonsense syllables and took it upon themselves to eliminate metaphysics from serious intellectual discourse (Ayer, 1952). Somewhat ironically, however, it was logical positivism that in 1967 *The Encyclopedia of Philosophy*, vol. 5 declared dead, not metaphysics. In recent years the positivist influence on both science and science education has waned opening the door for new intellectual discussion. Cosmologists and ecologists have shown appreciable interest in metaphysical ideas. Steven Weinberg was speaking metaphysically when he asserted that, "The more the universe seems comprehensible, the more it also seems pointless" (1988, p. 154). Berkeley astronomer George Smoot who participated in the discovery of "exotic" matter informed a gathering of news reporters, "What we have found is evidence of the birth of the universe.... It's like looking at God" (quoted by Ross, 1994, p. 25). In ecology perhaps the best known example and arguably the most controversial example of metaphysical thinking within the practice of science is the Gaia hypothesis (Goldsmith, 1988). In all of these examples, however, it is often unclear from the speaker or writer where the interface lies between their epistemology and metaphysics which at times allows a metaphysic to be disguised as epistemology. Carl Sagan's popular television production *Cosmos* begins with a blatant metaphysical statement, "The cosmos is all there is, all there ever was, all there ever will be" which for all practical purposes is passed off as a scientific statement. The same fuzziness of boundary obtains in science education whether one is reading a science textbook, listening to a science lecture, or doing a science activity. It is here that the logico-structural model of worldview shows its value by helping one to unpack or deconstruct the tacit metaphysical under pinnings of science curricula (i.e., the right side from the left side of Figure 2). For example, one may ask of a curriculum what is being assumed about: (1) the number and importance of Classifications (e.g., the spiritual, the natural, and the social) within the NonSelf? (2) the Relationship of the individual Self to the NonSelf, particularly to nature which is the domain of the natural sciences? (3) the different forms of Causality and the Relationship of these forms to the various Classifications within the NonSelf?

Selection and valuation of knowledge sources provides an illuminating example of metaphysical under pinning. In a science textbook the source of knowledge is ostensibly scientific, empirical research (Smolicz & Nunan, 1975). The knowledge source is centered on nature. Yahuda Elkana (1981, p. 16), however, noted that "sources of knowledge can be sense-experience, ratiocination, revelation, authority, tradition, analogy, competence, originality,

novelty, beauty, and many others.” No person, including any scientist or science educator, and no segment of culture, including the community of scientists and educators, uses a single knowledge source. One function of worldview is to direct the use of various sources of knowledge in different situations.

(T)he different sources of knowledge are themselves ordered hierarchically according to importance and priority. This ordering is, according to yet other images of knowledge [i.e., worldview presuppositions], one level removed from the contextual framework within which the ordering is done. There is nothing in science, or in religion for that matter, to convince us that the evidence of the senses carries greater or lesser weight as a source of knowledge that does revelation. It is our conceptual framework [i.e., worldview] with its images which tell us whether to give primacy to the senses, or to revelation, or to say that in matters scientific we trust the senses, while in matters religious we turn to revelation. (Elkana, 1981, p. 21)

Elkana (1981, p. 21) goes on to say that “if, however, a direct conflict endangers life or some other basic value, then the chips will be down.” I take him to mean that though people ordinarily use different knowledge sources for different situations, in the event of a serious clash, the knowledge source with the greatest personal legitimacy and value (scope and force) will prevail. Thus, for example, Gunstone's eighth grader esteemed his father as a source of knowledge above his teacher when the two sources came into conflict. Typically a science teacher would see the concept about electric current as a simple epistemological issue. Unpacked, one can say that the teacher's worldview leads him to resolve the electric current problem in terms of mechanistic causal operations in the worldview sub classification of nature. Neither the spiritual nor social domains are relevant (though one could argue that behind the teacher's epistemology lies the authority of the social domain of scientists). In contrast, the student's judgment of the epistemological arguments rest on his social classification presuppositions. For this child, there are presuppositions involving his father that organize and pervade his thinking. The concepts his father provides have scope and force, thus a school conflict at the specific level of scientific concepts, the level of epistemology, cannot be resolved at the same level. It must be resolved at an upper level, the level at which different knowledge sources are legitimized and ordered. Going back to Sol Tax, I can now say that he rejected non naturalistic epistemology out of hand because his worldview provided no warrant for such an epistemology. A typical high school biology classroom is likely to have the opposite type of person, that is, students whose worldviews do not warrant a naturalistic epistemology of origins (Cobern, 1994, 1995b). If one accepts Smolicz & Nunan's (1975) critique of school science, then one can say that school science is metaphysically narrow and restrictive. Students, however, are another story. Their diversity is generally acknowledged (Aikenhead, in press; Cobern, 1993b) and it is to student worldviews that I now turn.

A Coherence View of Knowledge and Science Education

As previously noted, nature is a sub classification of the NonSelf and has been treated in several book length reports (e.g., Merchant, 1989; Glaaken, 1967). For several years now I have been using qualitative interviews, that do not explicitly raise the topic of science, to study conceptualizations of nature held by students, science teachers, and science professors. One may ask, for example, How do students understand nature? What concepts have scope and force in their thinking about nature? Where does science fit into their thoughts about nature? How is science interpreted when it has become an integral part of student thinking about nature? In these interviews science is not explicitly addressed because the acid test of whether science has influenced the way a person thinks is not a set of questions explicitly about science such as asking for an explanation of a particular science concept or the construction of an experiment to test a scientific hypothesis. No, the acid test is whether science has become an authentic part of a person's everyday thinking. Thus, the research reported by Cobern, Gibson, and Underwood (1995a & 1995b) asked: To what extent do students enjoin scientific knowledge vis-à-vis other domains of knowledge in a discussion about nature? Given, science is unarguably relevant to the topic of nature and ought easily to be brought to bear; yet, nature is a topic that most people do not immediately associate with science. Moreover, what are the concepts that appear to have scope and force in the students' thinking about this topic? In other words, the interviews are designed to elicit the important ideas a person has about nature whatever those ideas might be. With regard to science, it is one thing to be able to give (or not give) correct answers on a science exam. It is quite another thing to use appropriately scientific knowledge in the absence of any kind of science prompt or cue.

In this research interview transcripts formed the basis for concept maps which show qualitatively the conceptualization of nature held by the person interviewed and first person interpretative narratives on nature. Both concept maps and narratives are reviewed and edited by the people interviewed (i.e., member checked) before the maps and narratives are finalized. What is remarkable about the results from both secondary and tertiary students is that so many students make little voluntary use of science concepts in these naturalistic interviews (Cobern, 1993a; Cobern et. al., 1995a). Quite to the contrary, science professors and science teachers move almost immediately to talk of science when taking part in the identical interview format (Cobern, 1992). For students it is aesthetic, religious, pragmatic, and emotional concepts that have scope and force with regard to nature. For example, I recently interviewed a ninth grade girl who for the purposes of this article I will call Ann. Ann is a good overall student and also one who in the past has been a good science student. Figure 3 is the concept map showing her conceptualization of nature. The dark line encircles that portion of her conceptualization representing knowledge of nature and science. The sub concepts Ann emphasized are underlined. She began her interview with the notion that nature is something Enduring and Inclusive. Her sense of inclusiveness drew together Knowledge of nature, the natural Beauty and Purity of nature, nature as God's Creation, and the Conservation of nature. Ann clearly spoke about nature as something one can know about through science.

Nature is knowable... We can learn to understand many things about nature through personal experience, school and science. Science itself provides us with technology which in turn increases our scientific knowledge. Technology helps

dangerous chemicals they would be handling during the course. The reasons for her displeasure with the class then became clear. She and her teacher had very different views of nature. One might be tempted to dismiss this young lady's aversion to dangerous chemicals as temporary and solely a result of insufficient conceptual understanding. She does not yet understand that there is danger in nature, but with proper understanding and technique this danger need not be viewed as a threat. That may be, but the question is how will this come about? Currently, Ann's aversion is rooted in an aesthetic sense of nature that has more scope and force than her science teacher's assurances and explanations. It is critical that one note that Ann's problem is not with science but with the context her science teacher chose to give science. Figure 3 is not a map dominated by canonical scientific thinking, nor her quoted remarks above. The map and her remarks represent a coherence view of nature where not one but several themes or large concepts have scope and force. I have borrowed the concept of coherence from Thagard (1989, 1994) who suggests that a person accepts a belief or proposition as knowledge on the basis of coherence with other beliefs. Moreover, Aaron Wildavsky (1987) has argued persuasively from his cultural studies of people's political behavior that people are often able to make a broad range of quick assessments or decisions because these are consistent with a few strongly held cognitive elements (i.e., the right side of Figure 2). Unschuld (1995) comes to a similar conclusion in a study of how people make decisions about medical care. Ann likewise is able to quickly assess her teacher's remarks about dangerous chemicals because these remarks are at odds, they do not cohere, with fundamental beliefs she holds about nature. Ann has a sense of wonder about nature that leads her to ask questions about nature and thus adds to her understanding of nature, including scientific and technological understanding. During the interview Ann volunteered some information from science and technology as part of her discussion of what one can know about nature. She showed an interest in scientific concepts but her foundation, the metaphysical frame that gives meaning to that interest, is in conflict with the classroom frame provided by the teacher. Ann has a sense of wonder about nature but it is grounded in her fundamental view of nature as beautiful and pure. If Ann continues in science I suggest it will be because she has found her own way to accommodate what for her is an alienating view of science. On the other hand, she may well become one of Costa's (1995) "other smart people" who take and pass high school science courses only because this is required for college entrance - a science class is simply one more hurdle one must jump in the school game.

It is instructive at this point to examine the conceptualization of nature held by Ann's science teacher, who I will refer to as Mr. Hess. Mr. Hess is a physical science teacher who sat for the same research interview as did Ann. He is not unlike the chemistry teacher, Mr. Jacobs, in Tobin and McRobbie (1995) and his views resemble school science as described in Smolicz and Nunan (1975). Figure 4 represents Mr. Hess' conceptualization of nature. Again, a dark line encircles the portion of this conceptualization of nature given to Knowledge and Science. In contrast to Ann, his conceptualization of nature is essentially monothematic. Mr. Hess is focused and explicit. In marked contrast to Ann, his narrative begins:

Nature is orderly and understandable. The tides and the rotation of the earth, the seasons and so forth are examples of order in nature. That the planets and the stars are governed by physical forces and any deviations are simply because we have not yet discovered the other part of nature's orderliness. According to chaos theory even things that appear to happen randomly have patterns. I think that everything

this as legitimate talk about the natural world. Mr. Hess speaks quite naturally about the world using comfortable language for his lessons, all grounded in his fundamental view of reality. Similarly, Ann on entering the science classroom does not drop her other ideas, especially those with scope and force. Indeed, it is that background that provides meaning for what she learns just as Mr. Hess' worldview provides meaning for what he teaches.

My assertion is that one sees in this situation the impact on a teaching/learning event of tacitly held, powerful beliefs, that is, the monothematic positivism of the teacher in contrast to the coherent aestheticism of the student. The critical point of this teacher/student example is the limitation on the efficacy of conceptual change tactics that can be inferred. Improved conceptual change tactics in this teacher's classroom will not necessarily help this student because the wrong issue is being addressed. The issue is not individual scientific concepts, but the context in which they are presented to the student. Though further research is required (e.g., Allen, 1995; Lassiter, 1993; Lawrenz and Gray, 1995), there is support for the importance of such tacit beliefs that comes from research on teacher beliefs about the nature of science. Research there indicates that "conceptions of the nature of science may be implicitly communicated to students by the language teachers use in presenting subject matter" (Lederman, 1992, p. 348, emphasis added) and that this influences student conceptions of the nature of science.

Implications for Education

In 1956 Ernst Cassirer remarked that, "physical reality seems to recede in proportion as man's symbolic activity advances. Instead of dealing with the things themselves man is in a sense constantly conversing with himself" (p. 43). More recently Michael Matthews similarly noted in the context of a discussion of Newton's Principia that science is no longer about what nature is really like. "The Principia then elaborates a science of colourless, point masses moving in inertial space which is, by definition, free from frictional forces. There is no correspondence between this theoretical object and real, coloured, friction-affected, non-inertial bodies" (Matthews, 1992, p. 9). Matthews goes on to say that Newton's system was about the real world in the instrumental sense that it allowed for "predicted manipulations and successful interventions" (Matthews, 1992, p. 9) in the world, not in the sense of saying what the world really is. Walter Jung (1994, p. 106) goes even further:

We do no longer know if we observe erratic properties of the instruments or independent phenomena of nature.... Thus we are far away from the simple scheme of a double-layered science. It is no longer possible to integrate experiment into common sense, with theory referring to it.... What has been said means that in the most advanced parts of physics the bonds between 'reality', the world everybody is living in, and physics gets more and more loosened.... This is enhanced by one of the most influential changes in the philosophy of science, the elimination of the concept of truth, or of approximation to truth.

The analog in science education of this distancing of science from nature is the "breaking with" school of thought in conceptual change (e.g., Floden, Buchmann, and Schwille, 1987; Garrison and Bentley, 1990). As noted earlier, from this perspective science conceptual change requires a breaking with what is essentially students natural understanding of their world because so much of science is counterintuitive.

Unfortunately, there is among some science educators the tacit assumption that this divorce is of no serious consequence to students other than being difficult, whereas in my opinion this assumption is a major factor in the overall lack of science interest and achievement among students. "Breaking with" entails loss of meaning (see also Eger, 1989). Jung (1994, p. 106) expressed the concern that, "(m)any young people feel that it is not worthwhile to take the trouble of learning theories that are no more than machines for controlling events in nature, or in industry, but do not in any way fulfill their desire to understand... The revolt against this reduction is quite unavoidable." Thus, while instrumentalism and reductionism may well be an accurate description of theoretical science, rather than explicitly encouraging students to break with everyday thinking, and implicitly with other domains of knowledge, science educators need to find ways of reestablishing school science as the study of nature, that is, the everyday world of physical experience. In the words of David Hawkins (1992, p. 219), "as the culture and substance of science spreads more widely into the popular - majority - culture," which is the principle task of science education, "it must also itself undergo enrichment and de-formalization, getting cross-connected with the familiar phenomena of everyday life; and the familiar 'common sense' ideas not suppressed or declared wrong, but reconnected and re-constructed." Science through science education needs to be joined with other school disciplines in the common goal of helping students develop a coherence view of knowledge which is more consistent with how knowledge is organized and used within one's worldview. Concomitantly, science education research needs to seek a better, including a more empathetic, understanding of the themes that hold scope and force in student lives and the ways in which these can be related to the scientific study of nature.

There are all too many occasions when the careful epistemological explication of a scientific concept is not sufficient to bring about lasting conceptual change; but science educators need not be at a total loss to understand why some students fail to develop orthodox scientific conceptions even after the best of instruction. Science instruction typically focuses on conceptual and procedural knowledge with respect to narrowly defined phenomena. The argument from worldview is that in some cases, it is not that the students fail to comprehend what is being taught, it is simply that the concepts are either not credible or not significant. The instruction must also include a discussion of the metaphysical foundation that supports scientific epistemology and how this foundation relates to other ways of knowing. As Nel Noddings (1993) recently argued, education must "address the fundamental questions that teenagers inevitably ask about the nature, value, and meaning of life (and death), and to do so across the curriculum, without limiting such existential and metaphysical discussions to separate religion, philosophy, or even history classes" (see Giarelli, 1993, p. 1). What that would accomplish among other things is a break with the tacit scientific orientation of conceptual change tactics that privileges science concepts. It would in contrast promote a coherence view of knowledge that recognizes the very many metaphysical orientations in which science can be imbedded.

There is insight here as well for multicultural science education both within the USA and abroad. American educators tend to assume that science is a natural part of at least Euro-American students' culture. If so, the example of Ann, who is Euro-American, suggests that there can be large differences between Euro-American students and teachers. When one turns to other Americans in an increasingly pluralistic American society and realizes that there are several cultural subgroups traditionally under represented in science, one has to speculate about how

much greater the differences are between these students and their typically Euro-American science teachers. In other words, if Ann in Mr. Hess' science class is having what amounts to a second culture experience, what must the science classroom experience be like for those students even more culturally removed from their science teachers? A response is suggested in the literature. Robin Horton tells of an early experience in Nigeria where he was explaining to a group of Nigerian university students that he preferred the world of inanimate objects because there one could find "order, regularity, predictability, simplicity" (Horton, 1994, p. 215) - things all quite absent in the world of people. His students to his surprise saw things just the other way around. His perspective on people and things was, "so totally foreign to their experience that they could not begin to take it in. They just stared. Rarely", continued Horton, "have I felt more of an alien than in that discussion" (Horton, 1994, p. 216) Well, if this situation made Professor Horton feel like an alien, consider how the Nigerian students must have felt in his science class. Student alienation, of course, is one of Horton's major concerns.

Professor Vine Deloria who has written extensively on Indian education in the USA provides information for a second example. Deloria writes that the Indian worldview is one that unifies all experience and defines community to include not only human life but all plant and animal life together. In contrast, he argues that western science alienates humans from nature by its reliance on abstraction and a object-subject relationship with nature. "The essence of science is to adopt the pretense that the rest of the natural world is without intelligence and knowledge and operates primarily as if it were a machine" (Deloria, 1992, p. 15). He and others argue that this clash of worldviews in the science classroom, which is a clash about what is meaningful, alienates many Native American students. This clashing experience Deloria writes about differs from Ann's experience, but differs in degree not kind (see Lipka, 1991; Pomeroy, 1992 and 1994; Simonelli, 1994).

The cultural studies on learning by Scribner and Cole (1973), Lave (1988), and Hatano (1990) among others suggests the highly contextual nature and domain specificity of learning. Science educators thus worry whether learning about (say) the atom will transfer to public discourse on nuclear power or whether learning about genes will later inform voting decisions related to the Human Genome Project. At the least transfer of scientific knowledge requires that this knowledge have sufficient scope and force within peoples' understanding of the world. The argument I have presented in this article is that achieving scope and force will require that students be given the opportunity to work with scientific knowledge in conjunction with other ways of knowing such as the social sciences, philosophy, aesthetics, and religion. What this discussion about culture, world view and science conceptual change suggests then, is that it is important for science educators to understand the fundamental, culturally based beliefs about the world that students bring to class, and how these beliefs are supported by students' cultures; because, science education is successful only to the extent that science can find a niche in the cognitive and socio-cultural milieu of students. Moreover, this discussion also suggests that teachers and curriculum developers need to examine and then come to understand the fundamental, culturally based beliefs about the world that they bring to class through teaching and the curriculum. They likely will find that some of these fundamental beliefs are neither necessary for science nor for the effective teaching of science.

Practical Applications

Wilson (1981, p. 40) noted quite correctly that, “(i)t is easy to assert that, to be effective, teaching must take full account of the multi-dimensional cultural world of the learner, to apply this principle in a particular situation, and to express it in terms of curriculum materials and classroom methods, is a formidable task.” Others have taken up the challenge (e.g., Aikenhead, in press) and I will offer some examples of application to both instruction and the analysis of teaching and curriculum. Any discussion of instructional application, however, must begin with some of the common objections to bringing issues of culture into the science classroom. Teachers are especially concerned about the time they have for instruction. If one feels pressed for time as it is, how can something as potentially involved as culture be added? The truth is that it cannot unless something else in the curriculum goes. Thus, to the extent that schools have come to embrace the motto, “Less is More,” strategic curricular changes to bring in cultural issues are more possible. In a traditional high school or college science curriculum it will be much more difficult.

A common objection is that the sheer diversity of some classrooms makes the inclusion of culture impossible. For example, Loving (1995) told of a California classroom with 32 culturally distinct groups. The mistake in such cases is to assume that the cultural groups are incommensurable. A group of Hispanic students can be culturally distinct in that the individuals come from Mexico, Cuba, southern California and so forth, but that does not empty the concept of “Hispanic” of all significant meaning. As a group, Hispanic students can be quite distinct from (say) Asian students on the basis that Hispanic and Asian cultures are unique; yet being Asian no more signifies homogeneity than does being Hispanic. This discussion about worldview suggests that one be alert for fundamental cognitive differences among people, but it does not suggest that every cultural or social difference is the result of a different worldview. Pepper (1942) suggested that there were no more than six or seven worldview types, thus one should be careful not to over estimate the difficulties of dealing with culture even in the most diverse classroom. What a teacher can do is to create a classroom atmosphere that invites students to express and discuss important personal viewpoints as they pertain to the science curriculum. The development of such an atmosphere can begin with lessons specifically designed for this purpose. Cobern, Gibson, and Underwood (in press) describes a group activity for high schoolers in introductory science where the students are encouraged to develop graphic organizers showing their views on the relationship between science and among other things school, society, religion, and government. The teacher uses this as a basis for developing a dialogue (a notion borrowed from Bohm, 1992) on science and its possible meaning among different people.

Moreover, if the science topic is a controversial one, “(s)haring beliefs openly upon beginning study of a controversial topic and sustained, small group, student-led discussions that encourage a kind of Socratic exchange that is valued, encouraged and practiced could bring beliefs to the surface to be examined not by an authority figure [i.e., the teacher], but by a colleague-collaborator -- and finally by the believer herself” (Loving, 1995, p. 18). Evolution is one such controversial topic and Cobern (1995b) offers an approach to the teaching of evolution that follows this advice (also see Jackson, Doster, Meadows, and Wood, 1995). A unit on ecology might begin with the students reading Rachel Carson’s *The Silent Spring*. Brickhouse

(1994) offers insightful remarks on this book. Lucas and Roth (1995) provide an example from physics where the teaching of physics concepts is combined with class readings and dialogue on the much larger question of what it means to know. A science teacher could use Poole's (1995) *Beliefs and Values in Science Education* along with a regular text in any high school science course for the purpose of promoting open dialogue about meaning. STS curricula are more supportive of cultural dialogue (e.g., Cheek, 1992) except for those held captive by technicist presuppositions. At the college science curriculum level Grumbling, Carter, Morgan, Lemons, and Saboski (1991) offer an excellent example of a course series that promotes conjoint thinking about science and the humanities. One of the six program objectives is to "(e)xplore how human values and systems of belief, as expressed in literature, can interpret and criticize science (and technology)" (Grumbling et al., 1991, p. 48). What each of these instructional examples requires is that a teacher think about worldview questions (i.e., questions about Causality, Self and NonSelf, the Classifications within the NonSelf, and Relationships with those classes) and how students might answer these questions differently from the way they are explicitly or implicitly answered in the science curriculum. These efforts at conjoint thinking for the purpose of developing a new or modified understanding of the world based on new concepts and ideas but concepts and ideas interpreted in the light of culturally grounded meaning. One possible result is the development of complementarity thinking which is exemplified by the discourse between science and Christian faith (see Bube, 1971; MacKay, 1974; Reich, 1990).

Implicit in this discussion is that scientific ideas are powerful and reasonably objective. As noted, scientific ideas as learned and appreciated will change the learner's perspective on reality. The concern is not that science education will bring about change in student thinking. If it does not, it is not functioning properly. Rather, the concern is about unwarranted change in students, on the one hand, and dismissal of science by students, on the other hand, due to unnecessary, sometimes inappropriate, and typically unrecognized contextualizations of science curriculum and instruction. Regardless of what one thinks of science proper, science education is unarguably a socially constructed entity subject to all the presuppositions held by policy experts, curriculum writers, and teachers. The application of worldview theory to curriculum analysis means unpacking some of these presuppositions or what is often called the "hidden curriculum." The same worldview questions obtain. For example, using these questions one could in general ask about a science textbook, What is the picture of reality offered by this book? Ausubel (1966) asked this question about one of the early BSCS textbooks and found it excessively reductionistic. Feminist writers asking this question find that science curricula tacitly promote an excessively objectivist view of nature that conflicts with feminine views (Whatley, 1989). Reductionist and objective thinking are part of science but neither is required at the level identified by these critics. The levels reflect the presuppositional thinking of the writers much more than science. Fourez (1988, p. 269) tells of a colleague who protested that his science textbook held, "purely scientific statements, and nowhere these things you [Fourez] call 'ideologies.' My course is scientific, period" which will remind some of Schoolmaster Thomas Gradgrind's view of education in the Charles Dickens story, *Hard Times*:

Now, what I want is, Facts. Teach these boys and girls nothing but Facts. Facts alone are wanted in life. Plant nothing else, and root out everything else. You can only form the minds of reasoning animals upon Facts: nothing else will ever be of any service to them.

This is the principle upon which I bring up my own children, and this is the principle on which I bring up these children. Stick to Facts, sir!"

Thus, the application to analysis is the application of criticism for contrary to Schoolmaster Gradgrind, "science classes, like every other teaching situation, carry ideas, values, projections, and worldviews" (Fourez, 1988, p. 48).

Postscript

I am not advocating the abandonment of the analytical, scientific study of science teaching and learning any more than Rosaldo would suggest that cultural anthropologists drop analytical approaches to the study of culture. It is just that it would be a mistake to think that all the difficulties in science education can be solved by ever more analytical study of science teaching and learning. As Tobin (in Taylor, Tobin & Cobern, 1994) says, the classroom is a very complex sociocultural environment. Even the best ideas on conceptual change will fail with many students if science as it is presented in the classroom has little or no meaning for students. I also would like to think that a personal tragedy such as that suffered by Renato Rosaldo will not be needed to motivate science education researchers to greater empathetic understanding of how different people legitimately make sense of the world in different ways.*

* The research upon which this paper is based was funded by the National Science Foundation, Grant RED # 9055834. An earlier version of this paper was presented at the 1994 annual meeting of the National Association for Research in Science Teaching, Anaheim, California.

References

- Aikenhead, G. S. (in press). Cultural assimilation in science classrooms. Studies in Science Education.
- Allen, N. J. (1995). 'Voices from the bridge' Kickapoo indian students and science education: A worldview comparison. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.
- Arendt, H. (1978). The life of the mind. New York, NY: Harcourt Brace Jovanovich.
- Ausubel, D. P. (1966). An evaluation of the BSCS approach to high school biology. The American Biology Teacher, 28, 176-186.
- Ayer, A. J. (1952). Language, truth, and logic. New York: Dover Publications.
- Bohm, D. (1992). On dialogue. Noetic Sciences Review, 23, 16- 18.
- Brickhouse, N. W. (1994). Bringing in the outsiders: reshaping the sciences of the future. Journal of Curriculum Studies, 26(4), 401-416.
- Browne, M. W. (1995). Scientists do a slow bunsen burn. The Arizona Republic, p. E2-E3.
- Bube, R. H. (1971). The human quest: A new look at science and Christian faith. Waco, TX: Word Books.
- Burbules, N. C., & Linn, M. C. (1991). Science education and philosophy of science: congruence or contradiction? International Journal of Science Education, 13(3), 227-241.
- Burt, E. A. (1967). The metaphysical foundations of modern physical science. London, UK: Routledge and K. Paul.
- Cassirer, E. (1956). An essay on man. Garden City, NY: Doubleday Anchor.
- Champagne, A. B., Lovitts, B. E., & Calinger, B. J. (editors). (1989). This year in school science 1989: Scientific literacy. Washington, DC: AAAS.
- Chandler, M. (1994). Philosophy of gravity: Intuitions of four-dimensional curved spacetime. Science & Education, 3(2), 155.
- Cheek, D. W. (1992). Thinking constructively about science, technology, and society education. New York: State University of New York Press.
- Cobern, W. W. (in press). Constructivism and non-Western science education research. International Journal of Science Education,
- Cobern, W. W. (1991a). World view theory and science education research, NARST Monograph No. 3. Manhattan, KS: National Association for Research in Science Teaching.
- Cobern, W. W. (1991b). The natural world as understood by selected college students: a world view methodological exploration. A paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake Geneva, WI, 1991 : ERIC #344 745.
- Cobern, W. W. (1992). Breadth vs depth: a comparison of student and professor conceptualizations of nature. A paper presented at the annual meeting of the National Association for Research in Science Teaching, Cambridge, MA, 1992
- Cobern, W. W. (1993a). College students' conceptualizations of nature: An interpretive world view analysis. Journal of Research in Science Teaching, 30(8), 935-951.
- Cobern, W. W. (1993b). Contextual constructivism: The impact of culture on the learning and teaching of science. In K. G. Tobin (editor), The practice of constructivism in science education, (pp. 51-69). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Cobern, W. W. (1994). Point: Belief, understanding, and the teaching of evolution. Journal of Research in Science Teaching, 31(5), 583-590.

- Cobern, W. W. (1995a). Belief and knowledge: Unnecessary conflict in the science classroom. In F. Finley (editor), Proceedings of the History and Philosophy of Science and Science Teaching, Minneapolis, MN: HPSST.
- Cobern, W. W. (1995b). Science education as an exercise in foreign affairs. Science & Education, 4(3), 287-302.
- Cobern, W. W., Gibson, A. T., & Underwood, S. A. (in press). Scientific literacy is a life-time skill. The Science Teacher.
- Cobern, W. W., Gibson, A. T., & Underwood, S. A. (1995a). Everyday thoughts about nature: An interpretive study of 16 ninth graders' conceptualizations of nature - Working paper no. 127 of the Scientific Literacy and Cultural Studies Project (SLCSP). Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.
- Cobern, W. W., Gibson, A. T., & Underwood, S. A. (1995b). World view: reality as viewed by students: A synopsis of methodology, Working Paper No. 101 of the Scientific Literacy and Cultural Studies Project (SLCSP); Originated 1991, Phase One completion, 19th April, 1995. Paper presented at the annual meeting of the National Association for Research in Science Teaching.
- Collingwood, R. G. (1940). An essay on metaphysics. London: Oxford University Press.
- Costa, V. B. (1995). When science is "another world": Relationships between worlds of family, friends, school, and science. Science Education, 79(3), 313-333.
- Costa, V. B. (1993). School science as a rite of passage. Journal of Research in Science Teaching, 30(7), 649-668.
- Crease, R. P. (1989). Top scientists must fight astrology - or all of us will face the consequences. The Scientist, 3(5), 9, 11.
- Deloria, J. V. (1992). Ethnoscience and Indian realities. Winds of change: A magazine for American Indians, 7(3), 12-18.
- Durant, J. (1990). The art of science. The Listener, 123(3150), 14-15.
- Duschl, R. A. (1991). Theoretical bases for science education research: Can principles of science inform instructional decision making? A paper presented at the Annual Meeting of the National Association for Research in Science Teaching, The Abbey, Fontane, WI.
- Dyson, F. J. (1993). Science in trouble. American Scholar, 62(4), 513-525.
- Eger, M. (1989). The 'interests' of science and the problems of education. Synthese, 81(1), 81-106.
- Eger, M. (1992). Hermeneutics and science education: An introduction. Science & Education, 1(4), 337-348.
- Elkana, Y. (1981). A programmatic attempt at an anthropology of knowledge. In E. Mendelsohn, & Y. Elkana (editors), Sciences and cultures: Anthropological and historical studies of the sciences Vol. V, (pp. 1-76). Boston, MA: D. Reidel Publishing Company.
- Floden, R. E., Buchmann, M., & Schwillie, J. R. (1987). Breaking with everyday experience. Teachers College Record, 88(4), 485- 506.
- Fourez, G. (1988). Ideologies and science teaching. Bulletin of Science, Technology, and Society, 8, 269-277.
- Garrison, J. W., & Bentley, M. L. (1990). Science education, conceptual change and breaking with everyday experience. Studies in Philosophy and Education, 10(1), 19-35.
- Giarelli, J. M. (1993). Forward. in N. Noddings, Educating for intelligent belief or unbelief, (pp. ix-x). New York: Teachers College Press.

- Glacken, C. H. (1967). Traces on the rhodian shore: Nature and culture in western thought from ancient times to the end of the eighteenth century. Berkeley, CA: University of California Press.
- Glasson, G. E., & Lalik, R. V. (1993). Reinterpreting the learning cycle from a social constructivist perspective: A qualitative study of teachers' beliefs and practices. Journal of Research in Science Teaching, *30*(2), 187-207.
- Goldsmith, E. (1988). The way: An ecological world-view. The Ecologist, *18*(4/5), 160-185.
- Gross, P., & Levitt, N. (1993). Higher superstition: The academic left and its quarrels with science. : John Hopkins University Press.
- Grumbling, V. O., Carter, J., Morgan, P., Lemons, J., & Saboski, E. (1991). Teaching nature literature in a science learning community: Merging "the two cultures". CEA Critic, *54*(1), 47-51.
- Gunstone, R. F. (1990). "Children's science": A decade of developments in constructivist views of science teaching and learning. The Australian Science Teachers Journal, *36*(4), 9-19.
- Hasker, W. (1983). Metaphysics: Constructing a world view. Downers Grove, IL: InterVarsity Press.
- Hatano, G. (1990). The nature of everyday science: A brief introduction. British Journal of Developmental Psychology, *8*, 245-250.
- Hawkins, D. (1972). Philosophical redirection of educational research: Human nature and the scope of education. National Society for the Study of Education Yearbook, *71*(1), 287-326.
- Hawkins, D. (1992). Letter to the editor. Science & Education, *1*(2), 219.
- Hewson, M. G., & Hewson Peter W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. Journal of Research in Science Teaching, *20*(8), 731-743.
- Hewson, P. W. (1981). A case study of conceptual change in special relativity: The influence of prior knowledge in learning. European Journal of Science Education, *4*(1), 61-78.
- Hewson, P. W., & Thorley, N. R. (1989). The conditions of conceptual change in the classroom. International Journal of Science Education, *11*(5), 541-553.
- Hills, G. L. C., & McAndrews, B. (1987). David Hawkins, critical barriers and the education of elementary school science teachers. In J. D. Novak (editor), Proceedings of the second international seminar on misconceptions in science and mathematics, (pp. 210- 223). Ithaca, NY: Cornell University Press.
- Holton, G. (1993). Science and anti-science. Cambridge, MA: Harvard University Press.
- Horton, R. (1994). Patterns of thought in Africa and the West. Cambridge, NY: Cambridge University Press.
- Jackson, D. F., Doster, E. C., Meadows, L., & Wood, T. (1995). Hearts and minds in the science classroom: The education of a confirmed evolutionist. Journal of Research in Science Teaching, *32*(6), 585-611.
- Jung, W. (1994). Preparing students for change: The contribution of the history of physics to physics teaching. Science & Education, *3*(2), 99.
- Kawasaki, K. (1990). A hidden conflict between Western and traditional concepts of nature in science education in Japan. Bulletin of the School of Education Okayama University, (83), 203-214.
- Kearney, M. (1984). World view. Novato, CA: Chandler & Sharp Publishers, Inc.

- Kilbourn, B. (1984). World Views and Science Teaching. In H. Munby, G. Orpwood, & T. Russel (editors), Seeing Curriculum in a New Light, Lanham, MD: University Press of America.
- Lampert, M., & Clark, C. M. (1990). Expert knowledge and expert thinking: A response to Floden and Klinzing. Educational Researcher, 19(5), 21-23, 42.
- Lassiter, I. H. I. (1993). Ways of knowing among college nonscience majors: a world view investigation. Unpublished doctoral dissertation, Georgia State University, Atlanta, GA.
- Lave, J. (1988). Cognitive consequences of traditional apprenticeship training in West Africa. Anthropology & Education Quarterly, VIII(3), 177-180.
- Lawrenz, F., & Gray, B. (1995). Investigation of worldview theory in a South African context. Journal of Research in Science Teaching, 32(6), 555-568.
- Lawson, A. E., Abraham, M. R., & Renner, J. W. (1989). A theory of instruction: Using the learning cycle to teach science concepts and thinking skills. Monographs of the National Association for Research in Science Teaching, 1, 1-57.
- Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. Journal of Research in Science Teaching, 29(4), 331-359.
- Lewis, C. S. (1947). The abolition of man. New York, NY: MacMillan Publishing Co., Inc.
- Lipka, J. (1991). Toward a culturally based pedagogy: a case study of one Yup'ik Eskimo teacher. Anthropology & Education Quarterly, 22(3), 203-223.
- Loving, C. C. (1995). From the summit of "truth" to the "slippery slopes: " Science education's descent through positivist-postmodernist territory. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA, 1995.
- Lucas, K., & Roth, W. (1995). The nature of scientific knowledge and student learning: Two longitudinal case studies. Paper presented at the annual meeting of the 26th Annual Conference of the Australian Science Education Research Association, Bendigo, Australia.
- MacKay, D. M. (1974). "Complimentarity" in scientific and theological thinking. Zygon, 9, 225-244.
- Matthews, M. R. (1992). Old wine in new bottles: a problem with constructivist epistemology. A paper presented at the annual meeting of the National Association for Research in Science Teaching, Cambridge, MA, 1992, March
- Merchant, C. (1989). The death of nature: Women, ecology, and the scientific revolution. San Francisco, CA.
- Meyer, B. F. (1991). Ideology therapy. First Things, (17), 11-13.
- Miller, J. D. (1988). The five percent solution. American Scientist,
- Morrill, W. (1975). Cognitive systems and cultural adaptability. The Journal of General Education, XXVII(2), 137- 148.
- Noddings, N. (1993). Educating for intelligent belief or unbelief. New York: Teachers College Press.
- Novak, J. D. (1982). Psychological and epistemological alternatives to piagetian developmental psychology with support from empirical studies in science education. In S. Modgil, & C. Modgil (editors), Jean Piaget: Consensus and controversy, (pp. 331-349). New York, NY: Praeger.
- Ogawa, M. (1986). A preliminary study on a key concept "nature" involved in science education. The Bulletin of the Faculty of Education, Ibaraki University (Educational Sciences) (In Japanese with English abstract), (35), 1-8.

- Ogawa, M. (1995). Science education in a multiscience perspective. Science Education, 79(5), 583-593.
- Owens, V. S. (1983). Seeing Christianity in Red & Green as Well as in Black & White: Propositional Truth is not the Whole Truth. Christianity Today, 38-40.
- Pepper, S. C. (1942). World hypotheses. Berkeley, CA: University of California Press.
- Pomeroy, D. (1992). Science across cultures: building bridges between traditional Western and Alaskan native sciences. A paper presented at the Second International Conference on the History and Philosophy of Science in Science Teaching, Kinston, Ontario, Canada, 1992, May
- Pomeroy, D. (1994). Science education and cultural diversity: Mapping the field. Studies in Science Education, 24, 49-73.
- Poole, M. W. (1995). Beliefs and values in science education. Philadelphia: Open University Press.
- Posner, G., Strike, K., Hewson, P., & Gertzog, W. (1982). Accomodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66, 211-227.
- Reich, K. H. (1990). The Relation Between Science and Theology: The Case for Complementarity Revisited. Zygon, 25(4), 369-390.
- Rosaldo, R. I. (1984). Grief and a headhunter's rage: On the cultural force of emotions. In S. Plattner (editor), Text, play, and story: The construction and reconstruction of self and society, (pp. 178-195). Washington, DC: The American Ethnological Society.
- Ross, H. (1994). Cosmology's holy grail: How recent scientific breakthroughs are helping us see creation in a new way. Christianity Today, 38(14), 24-27.
- Ruse, M. (1993). Speech (audio taped and transcribed - 7 pages). Annual meeting of the American Association for the Advancement of Science,
- The Scientist. (1993). Study sees alarming science undergraduate drop-out rate. The Scientist, 1.
- Scott, P. H., Asoko, H. M., & Driver, R. H. (1992). Teaching for conceptual change: A review of strategies. In R. Duit, F. Goldberg, & H. Neidderer (editors), Research in physics learning: Theoretical issues and empirical studies, (pp. 310-329). Keil, Germany: Schmidt & Klannig.
- Scribner, S., & Cole, M. (1973). Cognitive consequences of formal and informal education. Science, 182, 553- 559.
- Simonelli, R. (1994). Sustainable science: A look at science through historic eyes and through the eyes of indigenous peoples. Bulletin of Science Technology Society, 24(1), 1-12.
- Smolicz, J. J., & Nunan, E. E. (1975). The philosophical and sociological foundations of science education: the demythologizing of school science. Studies in Science Education, 2, 101-143.
- Snow, C. P. (1964). Two cultures and the scientific revolution. Cambridge, UK: Cambridge University Press.
- Stinner, A. (1995). Contextual settings, science stories, and large context problems: Toward a more humanistic science education. Science Education, 79(5), 555-581.
- Stodolsky, S. S. (1989). Is teaching really by the book? In Jackson, & Haroutunian-Gordon (editors), 88th NSSE Yearbook, (pp. 159-184).
- Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl, & R. J. Hamilton (editors), Philosophy of science, cognitive pyschology, and educational theory and practice, (pp. 147-176). Albany, NY: SUNY Press.
- Tax, S. (1983). Reconciling evolution and creation. Society, 20(2), 36-39.

- Taylor, P. C. S., Tobin, K. G., & Cobern, W. W. (1994). The classroom as a sociocultural site: Toward more insightful understandings of ways of knowing and acting. Symposium presented at the annual meeting of the National Association for Research in Science Teaching, Anaheim, CA, March.
- Thagard, P. (1989). Explanatory coherence. Behavioral and Brain Sciences, 12(3), 435-502.
- Thagard, P. (1994). Mind, society, and the growth of knowledge. Philosophy of science,
- Tobias, S. (1990). They're not dumb, they're different: Stalking the second tier. Tucson, AZ: Research Corporation.
- Tobin, K. G., & McRobbie, C. Beliefs about the nature of science.
- Unschuld, P. U. (1995). Plausibility or truth? An essay on medicine and world view. Science in Context, 8(1), 9-30.
- Walsh, W. W. (1967). Metaphysics, nature of. In P. Edwards (editor), The encyclopedia of philosophy Vol. 5, (pp. 303a). New York: Macmillan Publishing Co.
- Wandersee, J. H. (1993). The declared research interests of NARST members: An analysis of the 1992 NARST 'Directory of Members'. Journal of Research in Science Teaching, 30(4), 319-320.
- Weinberg, S. (1988). The first three minutes: A modern view of the origin of the universe. New York: Basic Books.
- Weisskopf, V. F. (1976). Is physics human? Physics Today, 23-29.
- Whatley, M. H. (1989). A feeling for science: Female students and biology texts. Women's Studies International Forum, 12(3), 355- 362.
- Wildavsky, A. (1987). Choosing preferences by constructing institutions: A cultural theory of preference formation. American Political Science Review, 81(1), 1-21.