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Psychology and epistemology: match or mismatch when applied to science education?

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Cognitive psychology's descriptions of an individual's knowledge resemble those philosophers' offer of scientific theory. Both offer resources for conceptual change teaching. Yet the similarities mask tensions – philosophers stress rationality and psychologists focus on causal structure. Both domains distinguish two kinds of change in knowledge structures – one common and cumulative, the other rare and non-cumulative. The structures facilitate incremental development but resist major revisions. Unless instruction actively induces restructuring, students' knowledge will be confused and incomplete.

Knowledge is largely organized by schemata, representing the significant concepts and relations in a domain. But using knowledge also requires procedures for recalling, applying and revising schemata.

Questions discussed include:

When should we present a theory in the context of justification – where knowledge claims are systematically but ahistorically delineated; and when in the context of development – where knowledge claims are initially developed?
How can prototypical examples facilitate schema acquisition and appropriate retrieval?
How can individuals be made active participants in the restructuring process?
How can the need for restructuring be motivated?
To what extent should we stress the historical and rational *development* of modern science?
Are educators prepared to employ complex teaching strategies identified by researchers?
To what extent do students' naive theories parallel early stages of science?

Introduction

The process of theory development by scientists has often been compared to an individual's acquisition of knowledge of the world. Scientists assimilate new information to their existing theories and accommodate these theories when presented with contradictory information. This comparison raises the question of how the processes responsible for theory development and justification, and the structure of theoretical knowledge, influence each other. The answer to this question has profound implications for the design and development of science instruction based on both psychological and epistemological principles.

Philosophy of science and cognitive psychology appear to be making similar discoveries and using similar terminology in describing the acquisition and modification of knowledge. It would seem foolish not to use the resources of both in improving science teaching. Yet the similarities mask differences, and there are problems when implications for curriculum revision conflict.

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Our discussion will focus on how the new ideas in cognitive psychology and epistemology may confound the acts of learning and teaching science. We offer a word of caution for those willing to apply principles of philosophy and cognitive psychology in an educational context. We also address the difficulties in a teacher decision-making model which partitions curriculum and instruction between knowledge justification and knowledge development frameworks. The focus is the tension when the two fields are applied to education. By examining the anomalies between the domains of philosophy of science and educational psychology, new interfield relationships may be spawned.

Cognitive schemata

A first step is to adopt 'schema' as the cognitive unit for representing an individual's theoretical knowledge. Schemata are considered by many to be the building blocks of cognition (Rumelhart 1980). As units of knowledge the schemata are joined together with rules and associations about how this knowledge is to be used. A schema is a unit of knowledge with thematic content. For example, we possess unitary knowledge concerning our expectations of what occurs in certain settings, e.g. restaurants. The schema for restaurant would consist of the typical sequence of events which occur in going to a restaurant: procedures for ordering, paying for the meal and related knowledge such as types of restaurants and typical foods. Schemata consist of: (1) an organized set of prototypical concepts related to a theme, (2) the strategies and rules that allow the individual to evaluate new facts and events as additions or alternatives to existing knowledge subsumed within the relevant schema, and (3) the procedures for using and justifying this knowledge (Rumelhart 1980, Thorndyke 1984). The concepts, strategies, rules and procedures are instances of procedural knowledge – an active dynamic knowledge which is responsible for all our internal and external activities. The verbal facts and descriptions of events subsumed within schemata are instances of declarative knowledge – a static knowledge. Although declarative knowledge may include cues which are helpful for gaining access to relevant knowledge, it is procedural knowlege that is primarily responsible for our ability to apply schemata to appropriate situations.

Cognitive psychology has progressed in describing the nature of an individual's knowledge, and these descriptions are similar to those offered by philosophers of science for scientific theory. Studies in both domains distinguish two kinds of change in knowledge structures – one frequent steady cumulative type of change, the other a rarer less continuous and non-cumulative type. Vosniadou and Brewer (1987) characterize the first type as weak restructuring and the second as radical restructuring. Weak restructuring results in the accumulation of new facts and the formation of new relations between existing concepts. In contrast, radical restructuring consists of a change in core concepts, structure and phenomena to be explained. The rarity of the latter type may be due to characteristics of knowledge and knowledge acquisition systems. The systems facilitate incremental addition of factual information but are resistant to wholesale abandonment of information. There is a strong intertial component that resists knowledge restructuring.

Educational researchers have discovered that the schemata employed by learners are often not well grounded by sound rules or relevant associations of concepts. The research of students' alternative frameworks (Osborne and Freyberg 1986), has

found that young learners frequently have schemata that are inconsistent. Such results argue that the task of understanding the cognitive development of children can not be divorced from understanding the processes associated with how learners change schema. 'Cognitive development involves conceptual change' (Carey 1986: 1127).

Theories

Researchers have compared the structure and function of 'schemata' to 'theories' (Gibson 1985). Both are concerned with the interpretation of an event, object, or situation; and both are a source of predictions about unobserved events. Until fairly recently the predominant view of theories in philosophy of science was that theories were direct descriptions of the world. Copernicus' theory of the solar system was a paradigmatic example. More recently an alternative conception has gained currency according to which theories provide a schematic description, which requires application to a specific part of the world before any predictions are forthcoming. Newton's laws can be thought of as specifying the relevant parameters for describing any mechanical system. A Newtonian description of the earth–moon system is an application of the general theory. The theory tells us explicitly that forces, masses, positions and velocities are relevant for mechanics; it tells us implicitly that colour, material composition and place of origin are irrelevant for mechanics.The new conception of theory bears a much greater resemblance to the schema of everyday reasoning than did the previous conception.

But differences remain. Theories are explicitly formulated, even if many features of their application and assessment are not, and they are explicitly taught: schemata are not. Theories are often mathematically formulated. These differences are quite important to bear in mind when applying cognitive psychology precepts about schemata to designing a curriculum for science. Another difference that may or may not prove important is that schemata tell us about the behaviour of normal or typical objects, whereas theories tells us about the behaviour of ideal objects – frictionless planes, dimensionless points, perfectly elastic spheres. The application of scientific theories may be less immediate than the application of schemata. According to the newer philosophy of science, something like theories/schemata are needed to apply the explicit theories (Suppes 1967, Giere 1988, Grandy 1990).

In general, theories are developed to explain and predict events. They represent a synthesis of knowledge claims which seek to account for past, present, and future events. Historians and philosophers of science investigate the growth of knowledge among communities of scientists who seek explanations for data, patterns, and facts derived from many modes of inquiry. The process of knowledge restructuring occurs through activities involving both the development and justification of theories (Nickles 1980, Kuhn 1970, Laudan 1977).

Thus conceptual change is the most significant idea that recent philosophy of science contributes to science education. It is especially significant because the principles of conceptual change are generally recognized to be implicit. They are not formally articulated, and may elude formal study. This possibility has led some philosophers, especially Feyerabend, to claim that science is governed by no principles, and ought not to be! Opponents of this point of view have advanced suggestions as to how restructuring of scientific knowledge could also be subsumed

under a logic of discovery. More recently, philosophers of science (Giere 1988) have argued for applying the principles of cognitive psychology to philosophy of science in order to account for conceptual change.

Joining schemata and theories

The treatment of scientific theories as cognitive schema raises questions about the consequences for educational policy and practices. More exactly, what effect would a position which seeks to join epistemological and psychological principles have on curriculum planning, implementation, and evaluation?

Carey (1986), a cognitive psychologist, calls for educational researchers to consider what contributions principles and concepts from the history and philosophy of science can make to researchers attempting to understand the conceptual development of young learners. In an essay addressing how children's schemata change in the course of acquiring new knowledge, she writes:

> If my diagnosis of the problem that developmental psychologists face is correct, then at least we know what we are up against – the fundamental problems of induction, epistemology, and philosophy of science. We ignore the work in these fields at our peril (Carey 1985, p. 514).

Yet another example of the symbiotic relationship between cognitive psychology and philosophy of science can be found in the fundamental premises of a leading theory of conceptual change learning (Posner *et al.* 1982). Instructional ideas are adapted from philosophical positions on theory change and development as described by Kuhn (1970) and Lakatos (1970).

The degree to which the principles of cognitive psychology and epistemology are similar when applied to the task of knowledge growth is seen clearly in science education research literature. Linn (1986), Novak and Gowin (1984), Resnick (1983), Anderson and Smith (1986), Krupa *et al.* (1985), and others, all speak to the effect that knowledge has on subsequent learning. Furthermore, the collective body of this research implies that learners, as Carey (1986) asserts, develop their cognitive abilities through the process of changing conceptual schemes. Many believe that the growth of knowledge in the individual can be understood in terms outlined by historians of science (Nussbaum 1983).

The path between cognitive psychology and philosophy of science is a two-way street. Philosophers of science have argued for epistemologies which employ concepts from cognitive psychology. Giere (1988), argues that attempts by philosophers to develop a better understanding of theory change in science ought to consider applying concepts from cognitive psychology that deal with knowledge restructuring. Referred to by Giere as 'naturalized realism', the position seeks to apply psychological models of schema and schema change to the interpretation of the growth of theoretical knowledge in science. Theory change has both a developmental aspect – 'constructive'; and a justificatory aspect – 'realism'.

Evoking the language of philosophy of science in the study of scientific theories and the language of cognitive psychology in the study of conceptual schema, an argument can be made that the nature of theory change described in philosophy and the nature of schema change described in cognitive psychology have much in common. However, tensions arise from attempts to marry epistemology with psychology.

Tensions

The framework of common terms–'schema', 'theory', 'conceptual' 'change'–suggests a more unified view of conceptual development in philosophy and psychology than actually exists. Some of the dichtomies are closely related. For example, the Kuhnian distinction between normal and revolutionary periods in science, parallels at the level of the scientific community, the distinction between weak and radical restructuring of knowledge that Vosniadou and Brewer (1987) describe at the personal level.

Another important distinction for philosophers is that between the context of justification–the situation in which knowledge claims are systematically presented in relation to the data, and the context of discovery–the situation in which knowledge claims are created and initially developed. One tension that exists in choosing how to present a theory in the classroom is whether it will be presented in the ahistorical context of justification (without regard to predecessor theories), or in the historical context of discovery (considering the alternative predecessor theories). A suggestion would be to use the context of justification whenever the development was within normal science and the context of discovery whenever it was revolutionary science. Another suggestion would be to use the context of justification whenever new theory requires only weak restructuring on the part of the student, and the context of discovery when it requires radical restructuring. Perhaps these two suggestions converge, and any historical revolutionary episode corresponds to a radical restructuring on the part of the student, but this remains to be demonstrated.

A second tension arises from the fact that epistemology is concerned with the rational evaluation of theory choice, regardless of the actual historical developments that may produce them. Epistemology is concerned with *knowledge*, which must be true and justified. The fact that a certain conceptual structure is internally represented does not make it knowledge for the epistemologist. Cognitive psychology, on the other hand, is concerned with understanding the nature, causes, and dynamics of internal representations of conceptual structures; it has no concern with rationality, truth or justification. This difference is often obscured because cognitive psychologists use the term 'knowledge' in the way that an epistemologist uses 'belief' which for him/her is contrased with 'knowledge'. The researcher and teacher may have to choose whether to emphasize rationality or effectiveness in changing concepts.

A third tension concerns the appropriate domain of procedural knowledge to be inculcated. It is agreed that the declarative knowledge related to principles, laws, theories and generalizations must be taught, and that in appropriate laboratory settings the procedural knowledge to apply these must be developed. Within the context of normal scientific developments, or weak restructurings, there is a small amount of procedural knowledge to be acquired about the fine tuning of theories and the adjustment of conceptual relations. But if we are to effect radical restructuring of concepts, the personal correlate of revolutionary science, then it seems that we must also teach the procedural knowledge involved in wholesale re-evaluation of theory and data. The nature of such procedural knowledge has been little studied, and not at all agreed upon. Moreover, it may well vary greatly from one scientific domain (and epoch) to another! Perhaps the teaching and learning of science entails more complex procedural knowledge than we have yet recognized. The instructional strategy and design that are employed to teach a unit on the Theory of Evolution, or the Theory of

Plate Tectonics, might require a very different set of procedural knowledge guidelines than a unit on biological or mineralogical identification and classification.

This proposal for varying procedures contrasts with the view that the growth and development of scientific knowledge are of a single, cumulative kind. Unless science instruction integrates activities that induce restructuring, student's knowledge of science will be confused and incomplete. Cognitive psychology, may be used to induce more effectively in students the schemata and heuristics associated with testing and justifying new information in particular scientific domains. But this type of knowledge is domain specific and does not impart a holistic sense of the nature of science, or of its historical development.

On the other hand an appreciation of the historical development of scientific theories requires the study of succession of conceptual structures. This course of study may produce an appreciation of the overall nature of science and scientific development without producing an adequate understanding of any particular scientific domain.

This tension affects educational decisions concerning what and how to teach, and reflects the philosophical argument about the relative importance of the contexts of justification and of discovery. Whereas the psychological perspective argues for teaching knowledge structures based on assimilation to current theory, the epistemological perspective suggests teaching how the new data undermines previous theories and leads to their revision. There is a fundamental tension in this interdisciplinary dialogue and it has important consequences for educational policy! If we have limited time and resources we must choose what is to be the focus of science education curricula.

The perspective of cognitive psychology

One of the major concerns of cognitive psychology has been the nature of knowledge representation. One particular theory that has been useful for the organization of existing research, and the development of principles of application, has been schema theory. As indicated, a schema is a unit of knowledge with thematic content, which includes knowledge related to the theme, strategies to evaluate new related information, and procedures for using this knowledge.

The adoption of a 'schema' representational format has been useful in summarizing the effects of schematic knowledge on the *encoding* of related information and *retrieval* of this knowledge. In terms of encoding, schemata have been found to be helpful for both the preservation of incoming information and for the integration of new information with old knowledge. Schemata give individuals appropriate frameworks and themes which help preserve and integrate new knowledge. In terms of retrieval, schemata are helpful as guides for searching for schema-related information and knowledge and eventual retrieval of this information (Brewer and Nakamura 1984, Thorndyke 1984).

These results point to two characteristics of schemata which it may be helpful to remember in the design and development of science instruction. The first is the prototypicality of concepts subsumed within the schemata; and the second is the encoding of contextual attributes during schema acquisition, and the instantiation of these attributes during retrieval. A schema consists of a set of generalizations which describe the thematic characteristics that will tend to be true of most instances to

which the schema can be applied. In this way, these generalizations are 'prototypical' of schema related events or instances. This suggests that the integration of 'prototypical' instances of concepts, scenarios, etc., within instructional materials will aid learners to develop appropriate schema to be applied in future situations. Research has found that presenting students with prototypes of mathematical and social science concepts produces higher levels of concept acquisition than presenting students with definitions and descriptions of critical attributes of the target concepts (Tennyson and Cocchiarella, 1986).

The prototypicalility of core concepts subsumed within schemata should help in the encoding and retrieval of appropriate knowledge. The core concepts share many characteristics with most relevant and related information/concepts and may make available appropriate contexts within which to encode related information and gain access to this information at the time of retrieval.

A second important aspect of schemata that may influence the success of instructional materials is the degree to which the materials integrate relevant contextual variables. One needs to identify the context within which the learners will be required to use the knowledge, and build both the attributes of the future tasks, e.g., experimentation with materials, and future processing requirements, e.g., scientific method, into instructional material. A variety of experiments have found that often relevant knowledge (e.g., study strategies, problem-solving strategies) is not spontaneously accessed when appropriate (Brown *et al.* 1983). This inacessible knowledge is described as 'inert knowledge' (Whitehead 1929).

Bransford *et al.* (1986) emphasize the importance of integrating *problem-oriented activities* into instructional materials in order to ensure appropriate transfer by making knowledge accessible. Problem-oriented activities involve: (1) information presented within the context of future use (e.g., laboratories, real life), and which includes the processing requirements for the future use of this information; and (2) information presented as close to the medium within which learners will be required to use this information (e.g., video presentation of problem scenarios). Matching the encoding context with the retrieval context takes advantage of the schema-based format of knowledge.

When applied to the area of theory development and justification, two specific types of knowledge can be described: one type of knowledge would be schematic and would consist of facts and descriptions of events that relate to a theory (i.e., declarative knowledge), as well as coordinated sets of concepts and rules which make up the core of a theory (i.e., procedural knowledge). The other type of knowledge would contain procedures that relate to the use and development of scientific theories or schemata. The second type of schema would be responsible for theory development and for theory justification. It is unclear whether instruction could be developed which would explicitly include this latter type of knowledge.

In science education there has been an impetus to use ideas from both cognitive psychology and epistemology to help learners acquire a new conceptual structure, to induce 'conceptual change', and to increase the level of abstractions which exist within the schema (Anderson and Smith 1986, Carey 1986, Otero 1985). The instructional prescriptions have aimed at overcoming misconceptions and presenting appropriate contextual information to make this possible.

Although this blends the notion of context of discovery from epistemology, with the notions of schema/knowledge structure from cognitive psychology, it fails to address the basic psychological processes involved in the retrieval of this knowledge.

From a psychological perspective, the above focuses primarily on encoding issues. Presenting the context of discovery should be very useful for the development of schemata of appropriate scientific theory, but contribute little to the development of methods to gain access to this knowledge. By presenting the historical context and problems that were responsible for the initial development of a scientific theory, one is focusing primarily on the acquisition of facts, events and a conceptual structure that relates to the target theory or theories. However, unless this context is similar to the context within which this knowledge is to be used, this approach may result in knowledge which is inaccessible.

Without the use of techniques aimed at making schema accessible, we will run into the problem of learners who possess 'inert knowledge' (Bransford *et al.* 1986). The context of discovery notion may be the best vehicle to bring about 'conceptual change'; however, it may not be helpful in ensuring retrieval of appropriate information. The distinction here is a simple one between those procedures that are useful for encoding and those that are useful for retrieval. Traditional learning research has supported the notion that contextual cues that are present during encoding are most successful at inducing retrieval of the encoding information. Thus, there are questions concerning how procedural knowledge ought to be a part of instruction and learning. Are the procedural cues associated with the context of discovery those which will be most useful for applying one's 'scientific knowledge' to future problem situations, or will they be those most useful for developing an understanding of the revisionary nature of scientific inquiry – a 'knowledge about scientific development'?

The focus in integrating epistemological and cognitive psychology notions in the teaching of science should be to evaluate how the epistemological notions (e.g., context of discovery and justification) not only influence the acquisition of an understanding of where scientific theories come from and how they might work, but also the ability to use these theories and one's knowledge of theories in future scientific situations. We need to identify the best techniques to ensure both the acquisition and the application of scientific knowledge.

The perspective of epistemology

Problems arise in describing radical changes in the structure of theories (Kuhn 1970, Rumelhart 1980). Educational psychology and the history of science both speak of the changing character of an individual's knowledge and of a scientific community's knowledge. Given the revisionary character of scientific methodology, focusing on the development of theories will show that a much wider range of procedural knowledge is significant.

Cognitive psychological models of learning maintain that individuals ought to be active participants in the learning process. One important element of this process is for the learners to become aware of the need to restructure their knowledge and thereby engage in tasks which bring about a conceptual change. Of course the need and subsequent tasks are often identified by the teacher. A problem, though, is that the knowledge bases of science become increasingly more sophisticated and complicated as students progress. It becomes increasingly more difficult to establish a rational basis for knowledge restructuring. The complicated dynamics of knowledge restructuring can be justified and made comprehensible when epistemological criteria that emphasize developmental characteristics of scientific theories are

addressed. One example is the important role anomalous data have in the genesis of scientific knowledge. The concept of *anomalous data* is an important and subtle epistemological one. There is considerable tension in accepting as *data* facts which are perceived as *anomalous*. The other is the importance of establishing a rational mechanism for explaining the never-ending replacement and substitution of knowledge claims, methods and cognitive aims in science.

Consider a recent example from geology. Employing a context of development approach to the study of Plate Tectonics requires attention be given to the important role British physicists played in the revival of the idea of continental drift during the 1950s. These scientists found that the magnetometer – an instrument initially designed to test theories about the dynamics of the magnetic core of the Earth – could be used to measure the remnant magnetism of rocks. Their subsequent studies of continental rocks in England, India, and America produced a set of data which indicated that the remnant magnetism directions differed with the age of the rocks. Employing a context of development point of view, we find that a change in method (using the magnetometer to measure rocks) led to a change in cognitive aim (physicists turning their resources and efforts away from a classical problem of magnetism to the problem of whether the differences in rock magnetism were due to wandering poles or drifting continents), which in turn led to a restructuring of our knowledge of the earth. Shifts in commitments to method and aims preceded shifts in commitment to scientific theories.

A context of justification approach, on the other hand, to the teaching of Plate Tectonics would only need to cite magnetic reversals in ocean floor rocks as a reliable source of evidence for proposing the theory of sea floor spreading. How we came to learn about magnetic reversals, and how that knowledge contributed to a revival of the idea of continental drift, are not relevant to the encoding and retrieval of our contemporary knowledge. In the end an incomplete picture of the restructuring of knowledge is provided.

The context of development approach is concerned with how the restructuring of knowledge has taken place and with establishing a basis for understanding the generation of new scientific evidence and the shift in commitment from one theory to another theory. Thus, changes in knowledge, in method, and in aims are equal partners in the restructuring of scientific knowledge. The context of justification, on the other hand, stresses the final form of the restructured knowledge. It places changes in commitment to knowledge claims above all other influences to knowledge restructuring, i.e., historical and sociological criteria, and changes in methodological commitments.

The relevance of including epistemological criteria that focus on the development of scientific knowledge is supported by a leading theory of conceptual change learning advanced by Posner *et al.* (1982). We have already cited how their theory of conceptual change is taken from Kuhn's (1962) and Lakatos' (1970) epistemological arguments that the growth of scientific knowledge develops through cyclic periods of consensus and dissension among practitioners. Supported by studies in the history of science, Posner *et al.* suggest that this conceptual change view of the growth of scientific knowledge can be applied to education. Their position suggests that if children are to change their commitments to scientific ideas, then four conditions must be met:

(1) Existing ideas must be found to be unsatisfactory.

(2) The new idea must be intelligible; it must appear to be both coherent and internally consistent.
(3) The new idea must be plausible.
(4) The new idea must be fruitful; it must be preferable to the old viewpoint on the grounds of perceived elegance, parsimony, and/or usefulness.

Inasmuch as the consensus/dissension activities are involved in the process of theory change, it is an issue that focuses on establishing a context of development in science. Scientific knowledge, while seemingly a story of success when examined by broad strokes, is when examined more carefully, a story of many false starts and misdirections. At issue is whether the growth of knowledge in science is perceived as involving continual revision. What our classroom teachers need are better mechanisms for describing and prescribing changes in knowledge structures. Epistemological criteria which embrace a context of knowledge development can be used by teachers to outline the complexity of the revision.

Consider the concerns of the science teacher. In presenting instruction which seeks to bring about a restructuring of knowledge, the teacher is faced with the difficult task of demonstrating that the growth of knowledge in science, with its periods of consensus and dissension, is, nonetheless, a rational activity. If the process of change within science is viewed by learners as an irrational process, then one of the fundamental criteria of conceptual change teaching–plausibility–is threatened. While the philosophical issue is whether changes in scientists' central commitments involve holistic changes or piecemeal changes (Lauden 1984); the educational issue is which view of the nature of knowledge change provides a better curriculum to bring about conceptual changes in learners. Our position is that the problem of plausibility is best addressed if the central commitments of science are parcelled out to the distinct categories of knowledge, method, and cognitive aim.

Precollege science education curricula should address not only *what* is known by science, but should also include *how* science has come to arrive at such knowledge. To teach what is known in science is to stress declarative scientific knowledge. To teach how the scientific enterprise has arrived at its knowledge claims is to develop declarative and procedural knowledge of scientific developments. Knowledge of scientific development, as opposed to scientific knowledge, then, is knowledge of both why science believes what it does and how science has come to think that way. In the distinction between scientific knowledge as a curricular objective, and knowledge about scientific development as a curricular objective, it is that the latter is more inclusive. This is the distinction between learning science, and learning about science.

Similarly, in establishing criteria for what will be important procedural knowledge to teach students, epistemological perspectives of a context of development would be more inclusive. Through an understanding of the procedures of knowledge restructuring in science, teachers of science gain a perspective on how and what declarative and procedural knowledge ought to comprise the planning, implementation, and evaluation of the science curriculum.

Implementation and research

The adoption of a curriculum and an instructional perspective which joins together constructivist views of educational psychology with new views from the history and

philosophy of science has deep implications for teachers of science, students of science, and science education researchers. Partitioning learning processes, for example, into encoding/retrieval categories, and scientific knowledge into declarative/procedural components, and processes of scientific knowledge growth into discovery/testing contexts – represents a more accurate description of the growth of knowledge. But when we consider that each of these paired sets of terms would be applied differently depending on the science content or context being employed, then and only then, do we truly begin to grasp the complexity of the task we face. In this last section we do not intend to offer solutions to the complex problems and issues. Rather, we hope to offer comments and questions which will assist the efforts of those developing interfield relationships between philosophy of science and educational psychology within the areas of instructional implementation and research.

The synthesis of cognitive psychology with history and philosophy of science requires that we consider how domain specific guidelines would affect educational practice. This recommendation is not that different from Resnick's (1983) call for a better qualitative understanding of the academic work of our classrooms. Thus, procedural guidelines for learning biology concepts are different from guidelines for learning chemistry; and the key foundation concepts for understanding the theory of Plate Tectonics owe more to an understanding of physics than to an understanding of chemistry.

An important issue here is the extent to which educators are prepared to explore, define, and employ teaching and learning stragegies identified by researchers. We have proposed that a science for scientist curriculum design would be very different from a science for all design. Given the constraints of classroom time that already limit the amount of science education that can be provided at most levels, this seems to pose a difficult choice between imparting the knowledge requisite to moving towards a scientific career, on the one hand, and the culturally important appreciation of the power of science as a cognitive enterprise, including its continually evolving character and its dependence on diverse internal and external factors, on the other hand. It poses a difficult challenge for educators of teachers and researchers.

Research on teaching (Clark 1988, Peterson and Walberg 1979) has found that teachers' beliefs about subject matter, teaching, and learning, influence the academic work of the classroom. More to the point, it seems teachers' knowledge of science and knowledge of pedagogy, and beliefs about teaching and learning alter the intended curriculum (Doyle 1984, Tobin and Gallagher 1987). There is a significant difference, then, between what is actually being taught by teachers and what is intended to be taught. Questions which emerge include: How should teacher decision making be guided to ensure that their translated curriculum reflects the intended curriculum? What are the decision making strategies which emerge from our synthesis of epistemology and psychology? How might these be integrated effectively into the repertoire of the classroom teacher?

If teachers' conceptions of the subject matter, and the goals teachers set for the instructional tasks they employ, alter the ways teachers implement instruction (Clark 1988, Shavelson and Stern 1981), then teachers need to have a richer understanding of subject matter developed from the study of epistemology. Speaking to the foundations of a teacher's knowledge base, Shulman (1986) argues that teachers' knowledge of content must necessarily include an understanding of

what we know – the declarative knowledge of science. But, and he stresses this point, teachers' pedagogical knowledge base must also include an understanding of the rules of the discipline – rules which explain why we have come to believe what we believe to be our scientific view of the world. We agree. This second element of teacher knowledge stresses knowledge of procedure and focuses on why we believe what we do. Relevant questions include: What combination of the contribution of cognitive science and epistemological frameworks is best in helping students learn science and, therefore, teachers teach science? Should this combination vary with each change in specific content domain of knowledge or should it remain invariant? Are teachers capable of using multiple and complex sets of instructional heuristics?

Research reveals that students are reluctant to change conceptions even in the face of instruction which seeks such change. A recent review by Gunstone *et al.* (1988) laments that attempts to change students' conceptions are usually unsuccessful and quite time consuming. Perhaps we have underestimated what must be considered in bringing about restructuring of knowledge. It seems plausible to suggest that changes in the declarative knowledge structures need to be accompanied by concomitant changes in procedural knowledge structures. We have also given arguments that the context of discovery is likely to be more effective. However, it is unclear what the most appropriate combination of declarative and procedural knowledge would be given the nature of restructuring, the scientific domain, and the context of instruction.

There is also the question of to what extent do the naive theories of students parallel those of early stages of science. Parallels have been demonstrated between medieval theories of dynamics and those of young students. But in other cases the psychological and historical records may not converge. The naive astronomical theories of students are certainly not as complex and observationally accurate as the Ptolemaic theories that Copernicus confronted. And the current naive astronomical theories certainly do not include assumptions about the immutability of the heavens or the existence of crystalline spheres surrounding the earth. Thus, a case by case study needs to be made of the dominant naive theories in various domains, and of how much individual variation there is.

A final concern for research on student learning and knowledge change is the identification of characteristics of future tasks and situations within which they will employ their restructured knowledge. For knowledge to be accessible, it must consist of appropriate cues related to the contexts of future use (cf. Bransford *et al.* 1986). Given this, there is a need to identify heuristics and strategies that allow students to access and employ their knowledge in appropriate situation. How will these procedures differ for contexts of discovery and justification? Can these procedures be invariant across knowledge domains? The discoveries of 'alternative frameworks' in learners that affect subsequent learning, and the limited capacities of learners for processing knowledge, and the constructive, active character of learning (Driver and Easley 1978, Resnick 1983, Wittrock 1978) – all suggest that extant models of instruction in science ought to change (Champagne 1988, Wittrock 1974, West and Pines 1985).

For historians and philosophers of science, there are two important areas of research. One is to develop more cognitively oriented accounts of the development of the many scientific theories that have not yet been investigated in this mode. If we are right that teaching methodology must vary with the content and context of theory then we need a large amount of such information. Even to test our claims that such

variation is desirable, considerable amount of work must be done in order to design a satisfactory experimental test.

A larger and more difficult issue is that if we are to have teachers employ epistemological rules in teaching science, then philosophers of science must come to considerably more agreement about what those rules are. There is a serious danger that if we attempt to implement the complex and varied methodological approach that we have discussed we will only succeed in conveying the impression that science is an arbitrary hodgepodge of unrelated theories. The last 35 years of the philosophy of science illustrate how difficult it is to overthrow the dogmas that science has a single, unified methodology, and that scientific knowledge is totally cumulative and unrevisable. It is difficult to replace these with a more realistic and complex account without falling into what is perceived as an anti-scientific position, arguing that science is only a matter of social construction. If it is difficult to maintain the proper balance in detached scholarly discussion, it is certainly more difficult to convey to teachers, and much more so for them to maintain in the classroom under public scrutiny.

References

ANDERSON, C. A. and SMITH, E. 1986, Teaching science. In V. Koehler (ed.), *The Educator's Handbook: A Research Perspective* (Longman, New York).

BRANSFORD, J., FRANKS, J., VYE, N. and SHERWOOD, R. 1986, *New Approaches To Instruction: Because Wisdom Can't Be Told.* Paper presented at a Conference on Similarity and Analogy, University of Illinois, June.

BREWER, W. and NAKAMURA, G. 1984, The nature and functions of schemas. In R. Wyer and T. Skull (eds.) *Handbook of Social Cognition*, (Academic Press, New York).

BROWN, A., BRANSFORD, J., FERRARA, R. and CAMPIONE, J. 1983, Learning, remembering and understanding. In J. Flavell and E. Markman (eds.), *Carmichael's Manual of Child Psychology*, Vol. 1 (Wiley, New York).

CAREY, S. 1985, Are children fundamentally different kinds of thinkers and learners than adults? In S. Chipman, J. Segal and R. Glaser (eds.), *Thinking and Learning Skills*, Vol. 2 (Lawrence Erlbaum Associates, Publishers, Hillsdale, NJ).

CAREY, S. 1986, Cognitive psychology and science education. *American Psychologist*, Vol. 41, pp. 1123–1130.

CHAMPAGNE, A. 1988, *A Psychological Model for Science Education.* Paper presented at the meeting of the American Educational Research Association, New Orleans.

CLARK, C. 1988, Asking the right questions about teacher preparation: Contributions of research on teacher thinking. *Educational Researcher*, Vol. 17, pp. 5–12.

DOYLE, W. 1984, Academic work. *Review of Educational Research*, Vol. 53, pp. 159–199.

DRIVER, R. and EASLEY, J. 1978, Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, Vol. 5. pp. 61–84.

GIBSON, B. S. 1985, The convergence of Kuhn and cognitive psychology. *New Ideas in Psychology*, Vol. 3, pp. 211–221.

GIERE, R. 1988, *Explaining Science: A Cognitive Approach* (The University of Chicago Press, Chicago).

GRANDY, R. 1990, *Theories of Theories: A View from Cognitive Science* (University of California, Berkeley, CA).

GUNSTONE, R., WHITE, R. and FENSHAM, P. 1988, Developments in style and purpose of research on the learning of science. *Journal of Research in Science Teaching*, Vol. 25, pp. 513–530.

KRUPA, M., SELMAN, R. and JAQUETTE, D. 1985, The development of science explanation in children and adolescents: A structural approach. In S. Chipman, J. Segal and R. Glaser (eds.), *Thinking and Learning Skills*, Vol. 2 (Lawrence Erlbaum Associates, Publishers, Hillsdale, NJ).

KUHN, T. S. 1970, *The Structure of Scientific Revolutions*, 2nd Edition (The University of Chicago Press, Chicago).

LAKATOS, I. 1970, Falsification and the methodology of scientific research programs. In I. Lakatos and A. Musgrave (eds.), *Criticism and the Growth of Knowledge* (Cambridge University Press, Cambridge).

LAUDEN, L. 1977, *Progress and its Problems* (University of California Press, Berkeley).

LAUDEN, L. 1984, *Science and Values: The Aims of Science and their Role in Scientific Debate* (University of California Press, Berkeley).

LINN, M. 1986, Science. In R. Dillion and R. Sternberg (eds.), *Cognition and Instruction* (Academic Press, Inc., New York).

NICKLES, T. (ed.), *Scientific Discovery, Logic, and Rationality* (Reidel, Dordrecht, Holland).

NOVAK, J. and GOWIN, R. 1984, *Learning How to Learn* (Cambridge University Press, Cambridge).

NUSSBAUM, J. 1983, Classroom conceptual change: the lesson to be learned from the history of science. In H. Helm and J. Novak (eds.), *Proceedings of the International Seminar on Misconceptions in Science and Mathematics* (Department of Education, Cornell University, Ithaca, NY).

OSBORNE, R. and FREYBERG, P. 1985, *Learning in Science: The Implications of Children's Science* (Heinemann Press, London).

OTERO, J. 1985, Assimilation problems in traditional representations of scientific knowledge. *European Journal of Science Education*, Vol. 7, No. 4, pp. 361–369.

PETERSON. P. and WALBERG, H. (eds.) 1979, *Research on Teaching* (McCutchan Press, Berkeley).

POSNER, G., STRIKE, K., HEWSON, P. and GERTZOG, W. 1982, Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, Vol. 66, pp. 211–227.

RESNICK, L. 1983, Mathematics and science learning: A new conception. *Science*, Vol. 220, pp. 477–478.

RUMELHART, D. E. 1980, Schemata: The building blocks of cognition. In R. Spiro, B. Bruce and W. Brewer (eds.), *Theoretical Issues in Reading Comprehension* (Erlbaum, Hillsdale, NJ).

SHAVELSON, R. and STERN, P. 1981, Research on teachers' pedagogical thought, judgements, decisions, and behavior. *Review of Educational Research*, Vol. 51, pp. 455–498.

SHULMAN, L. 1986, Those who understand: Knowledge growth in teaching. *Educational Researcher*, Vol. 15, pp. 4–14.

SUPPES, P. 1967, What is a scientific theory? In S. Morgenbesser (ed.), *Philosophy of Science Today* (Basil Books, New York).

TENNYSON, R. and COCCHIARELLA, M., 1986, An empirically based instructional design theory for teaching concepts. *Review of Educational Research*, Vol. 56, pp. 40–71.

THORNDYKE, P. 1984, Application of schema theory in cognitive research. In J. R. Anderson and S. M. Kosslyn (eds.), *Tutorials in Learning and Memory* (W. H. Freeman, New York).

TOBIN, K. and GALLAGHER, J. 1987, What happens in high school science classrooms? *Journal of Curriculum Studies*, Vol. 19, pp. 549–560.

VOSNIADOU, S. and BREWER, W. F. 1987, Theoreis of knowledge restructuring in development. *Review of Educational Research*, Vol. 57, No. 1, pp. 51–67.

WEST, L. and PINES, A. (eds.) 1985, *Cognitive Structure and Conceptual Change* (Academic Press, New York).

WHITEHEAD, A. 1929, *The Aims of Education* (Macmillan, New York).

WITTROCK, M. 1974, Learning as a generative process. *Educational Psychologist*, Vol. 11, pp. 87–95.

WITTROCK, M. 1978, The cognitive movement in instruction. *Educational Psychologist*, Vol. 13, pp. 15–29.

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