International Journal of Environmental & Science Education
Vol. 3, No. 4, October 2008, 193-206

Constructivist Approaches to Learning in Science and Their Implications for Science Pedagogy: A Literature Review

Mustafa Cakir
Marmara University, Turkey

Received 09 June 2008; Accepted 11 September 2008

This paper draws attention to the literature in the areas of learning, specifically, constructivism, conceptual change and cognitive development. It emphasizes the contribution of such research to our understanding of the learning process. This literature provides guidelines for teachers, at all levels, in their attempt to have their students achieve learning with understanding. Research about the constructive nature of students' learning processes, about students' mental models, and students' misconceptions have important implications for teachers who wish to model scientific reasoning in an effective fashion for their students. This paper aims to communicate this research to teachers, textbook authors, and college professors who involved in the preparation of science teachers. This paper is divided into two major parts. The first part concentrates on a critical review of the three most influential learning theories and constructivist view of learning and discusses the foundation upon which the constructivist theory of learning has been rooted. It seeks an answer to the question of "What are some guiding principles of constructivist thinking that we must keep in mind when we consider our role as science teachers?". The second part of this paper moves toward describing the nature of students' alternative conceptions, the ways of changing cognitive structure, and cognitive aspects of learning and teaching science.

Key Words: learning theories, constructivism, science pedagogy

Introduction

Research about the constructive nature of students' learning processes, about students' mental models, and students' misconceptions have important implications for teachers who wish to model scientific reasoning in an effective fashion for their students. First part of this paper concentrates on a critical review of the three most influential learning theories and constructivist view of learning and discusses the foundation upon which the constructivist theory of learning has been rooted. It seeks an answer to the question of "What are some guiding principles of constructivist thinking that we must keep in mind when we consider our role as science teachers?". The second part of this paper moves toward describing the nature of students' alternative conceptions in science, the ways of changing cognitive structure, and cognitive aspects of learning and teaching science. It introduces implications for science educa-

ISSN 1306-3065

http://www.ijese.com/

tion and science teacher education as well. Studies that address how teachers might facilitate the ability of students to take control over their learning have the potential to inform teachers and researchers alike. Studies of this kind could inform teachers about the implementation of instruction designed to effect conceptual change in their students, and researchers about the role a teacher plays in bringing about these changes.

The Learning Theories of Ausubel, Piaget, and Vygotsky

Three cognitive theorists who have been highly influential in understanding the process of human learning are Jean Piaget, David Ausubel, and Lev Vygotsky. Many view the theories of Piaget, Ausubel, and Vygotsky as distinctly contrasting explanations of cognitive development (learning). Ausubel and Vygotsky were more explicit in their recommendations for teaching than Piaget. However, despite different labels, strong similarities do exist between the cognitive processes described by the three theories.

For Piaget, children and adults use mental patterns (schemes) to guide behavior or cognition, and interpret new experiences or material in relation to existing schemes (Piaget, 1978). However, for new material to be assimilated, it must first fit an existing scheme. Very similarly, for Ausubel, meaningful information is stored in networks of connected facts or concepts referred to as schemata. New information, which fits into an existing schema, is more easily understood, learned, and retained than information that does not fit into an existing schema (Slavin, 1988). For both theorists then, new concepts that are well anchored by, or attached to existing schemata (or schemes) will be more readily learned and assimilated than new information relating to less established schemata. The same holds true for information not attached to any schemata at all (e.g., the case with compartmentalized, or rote learning).

The aspects of Vygotsky's work that have received most attention among educators and psychologists are his arguments for the cultural basis of cognition and for the existence of a "zone of proximal development" (Moll, 1990). The latter refers to the idea that there is a zone for each learner, which is bounded on one side by the developmental threshold necessary for learning and on the other side by the upper limit of the learner's current ability to learn the material under consideration (Vygotsky, 1978).

Ausubel defines rote learning as arbitrary, verbatim, non-substantive incorporation of new ideas into cognitive structure. Information does enter cognitive structure, but with no specific relevance to existing concept/propositional frameworks (Ausubel, 1963). Partly for this reason, rote learning may involve interference with previous similar learning, and exhibit some of the difficulties in patterns of recall, including fail to notice associations.

When a learner encounters situations in which a learner’s existing schemes cannot explain new information, existing schemes must be changed or new ones made. This process, as termed by Piaget, is accommodation. The condition leading to accommodation is known as disequilibration; that is, the state encountered by a learner in which new information does not fit an existing scheme (Slavin, 1988). The process of disequilibration and the characteristics of accommodation will further be discussed. To restore balance to the cognitive system, new schemes are developed, or old ones modified, until equilibration is reached, and the new information accommodated into the learner’s view of the world.

Vygotsky distinguished between (a) spontaneous or everyday concepts formed from a learner's experience and independent thinking and (b) nonspontaneous or scientific concepts taught in school (Moll, 1990). He associated scientific concepts with systematic, hierarchical knowledge as opposed to the non-systematic, unorganized knowledge gained from everyday experience.

Vygotsky believed that there is an important connection and interaction between the two; what a student is learning in school influences the course of development of concepts acquired through everyday experience and vice versa. The crucial difference between the two categories of concepts is the presence or absence of a system.

Spontaneous concepts are based on particular instances and are not part of a coherent system of thought; on the other hand, scientific concepts (i.e. those learned in school) are presented and learned as part of a system of relationships. When a student has reached some understanding of the organization of concepts into a hierarchical system of interrelationships then this knowledge influences understanding of related everyday concepts by transforming and giving new direction to them. In order to elaborate the dimensions of school learning, Vygotsky (1978) described an exceptionally important concept: the zone of proximal development (ZPD). In his words, ZPD is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers.

Seen in this light, one may agree that prior cognitive structures are an important part of Piaget's theory of cognitive development as its existing schemes, which largely determine opportunities for disequilibration, and subsequent accommodation or conceptual change. Even more so for Ausubel, prior knowledge or existing schemata are of central importance if the learner is to meaningfully acquire new information or concepts. Ausubel postulated that meaningful learning occurs when new information is subsumed by existing relevant concepts, and these concepts undergo further change and growth (Novak, 1988). As a part of his reception learning instructional model, Ausubel further suggested that effective instruction requires the teacher to choose important or relevant information to teach, and to provide the means to help students relate this to concepts they already possess (existing schemata) (Slavin, 1988). For the student, both of these depend to a large degree on prior knowledge, or existing cognitive frameworks. Ausubel (Ausubel, Novak & Hanesian, 1978) made this abundantly clear when he stated:

> 'If I had to reduce all educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him/her accordingly' (p. iv).

Vygotsky, too, sought to show that spontaneous concepts grow and change under the influence of instruction in scientific concepts and that scientific concepts develop fully as they incorporate related everyday concepts (How, 1993). Scientific (nonspontaneous) concepts are taught in school by means of verbal definitions and explanations or mathematical symbols and reside on a level of abstraction. In contrast, everyday concepts develop outside a definite system; in order to be understood in relation to what has been learned in school, thinking must move upward toward abstraction and generalization. The student eventually comes to see his/her spontaneous concepts as part of a system of relationships and, at the same time, comes to see how the phenomenon he/she has experienced fits into the scientific system he/she has been taught.

Of course there are also significant differences between Piagetian, Ausubelian, and Vygotskian cognitive theories. Well known is the fact that Piaget's theory is stage dependent: children as learners progress through four distinct stages of cognitive development, able to grasp concepts at increasing levels of abstraction depending on their level of maturity (Slavin, 1988). Quite differently, Ausubel's theory of how children learn concepts is not stage dependent. As mentioned above, prior knowledge in the form of cognitive schemata is the primary determinant of learning. Central to Vygotsky's thinking was the importance of language in mediating thought. The belief in the dominance of language is a fundamental difference between his view of concept development and that of Piaget. Piaget gave little attention to language and never assigned it a primary role in conceptual development. For Piaget language was a means of expressing thoughts that had already developed (Gredler, 1997). For Vygotsky language was central to the development of thought; words were the means through which thought was formed. It is important to go beyond direct experience in teaching scientific concepts and to mediate experience with words; experience alone is not enough since the experience is an isolated observation unless it is put into words and understood in a larger context (Howe, 1993).

It is also clear that Ausubel favors a "top-down" approach to instruction as evidenced by his advocacy for the use of advance organizers. Piaget on the other hand, seems to have suggested a "bottom-up" approach to instruction and learning in which the learner acquires pieces of the larger picture before gaining access to an overall view. Vygotsky's idea of zone of proximal development suggests another approach to instruction, namely scaffolding (Gredler, 1997, p.103). Scaffolding occurs when a tutor (either adult or capable peer) helps the student build an extension from an existing schema into new cognitive territory through a series of small steps of which the student would not be independently capable. It involves developing a mutual understanding of each other's ideas as the extension is constructed. Eventually the tutor can withdraw, leaving the student under full control of the newly constructed extension. Despite these differences, however, three learning theories depend to varying degrees on the existing cognitive frameworks that students bring to any learning environment.

Constructivism

One reason for the broad, intuitive appeal that has fueled the growth of constructivism as an epistemological commitment and instructional model may be that it includes aspects of Piagetian, Ausubelian and Vygotskian learning theories; namely, the importance of ascertaining prior knowledge, or existing cognitive frameworks, as well as the use of dissonant events (relevant information) to drive conceptual change. Naussbaum and Novick (1982) wrote "The conclusions… of leading theories in cognitive psychology seem, therefore, to be mutually supportive" (p. 184). From a different point of view, but on the same theme, Yeany (1991) critically suggested that the theory "seems so elastic that, instead of demanding adherence, it simply accommodates many perspectives" (p.3).

Von glasersfeld, a leading proponent of radical constructivism, philosophically emphasizes the position of the radical constructivist: knower cannot objectively test the accuracy of correspondence between human knowledge and the external world, as the process of human knowing itself makes objectivity impossible (Confrey, 1990).

Constructivist Principles of Knowing

Von glasersfeld's work (i.e., 1995) set forth several principles, which describe knowing, and knowledge in their development, nature, function, and purpose. First, Von glasersfeld stated how knowledge is, and is not, made. Knowledge is actively built up from within by a thinking person; knowledge is not passively received through the senses or by any form of communication. Second, Von glasersfeld described the importance of social interaction in the construction of knowledge. Social interactions between and among learners are central to the building of knowledge by individuals. Third, the character of cognition is functional and adaptive. Cognition and the knowledge it produces are a higher form of adaptation in the biological context. Fourth, Von glasersfeld described what the purpose of cognition is, and what it is not. Cognition's purpose is to serve the individual's organization of his or her experiential world; cognition's purpose is not the discovery of an objective ontological reality.

Von glasersfeld has further suggested from a very Piagetian point of view that it is only through some dissonant event that we envision our own concepts or constructs, and thereby determine their viability (fit with natural phenomena). Thus, to investigate the concepts and constructs of learners, one must seek out their problems and not impose one's own view (Confrey, 1990).

The Constructivist Way of Seeing the World

Constructivism is more a philosophy, not a strategy. Rather, constructivism is an underlying philosophy or way of seeing the world. This way of seeing the world includes notions about:

- The nature of reality (mental representations have "real" ontological status just as the "world out there" does).
- The nature of knowledge (it's individually constructed; it is inside people's minds, not "out there").
- The nature of human interaction (we rely on shared or "negotiated" meanings, better thought of as cooperative than authoritative or manipulative in nature).
- The nature of science (it is a meaning-making activity with the biases and filters accompanying any human activity).

Cognitive Structure

What is the meaning of cognitive structure? Cognitive means "of mind, having the power to know, recognize and conceive, concerning personally acquired knowledge," so cognitive structure concerns individual's ideas, meanings, concepts, cognitions, and so on (Pines, 1985). Structure refers to the form, the arrangement of elements or parts of anything, the manner of organization; the emphasis on the way those elements are bound together.

Concepts

Concepts are packages of meaning; they capture regularities, patterns, or relationships among objects, events, and other concepts (Novak, 1996). Each concept is a human invention, a way of "slicing up" and organizing the world. Concepts are formed, not by interplay of associations, but by an intellectual operation in which such mental functions as memory, attention and inference participate and in which language is the guide. Putting things into words is an essential part of science teaching and learning, a process that depends on interaction between teacher and learner because the learner cannot discover the vocabulary for science independently. Putting it into words centers attention, clarifies thinking, provides a means of symbolizing thought and is an integral part of the process of concept formation.

Whenever a concept has restricted meaning a single definition in the form of an analytic proposition can be given. This is often done in science. This gives the false notion that concepts are single units. Because of the complexity of concepts, we should be willing to accept the fact that their acquisition is a long process, which can never be complete. There is no such a thing as the final acquisition of a concept (Pines, 1985). Rather concept becomes differentiated in the mind of a person. As more and new relationships are acquired, the respective concepts take on new meaning. The only reason that different individuals can communicate and understand one another is because of the overlap between their conceptual-cognitive structures.

Individual learners do construct meaning from their experiences; learning should be meaningful and derive from an authentic context; learners should be allowed to pursue individual learning goals (Confrey, 1990). In summary, those at the theoretical core of constructivism stress the importance of determining the learner's constructed view of the world through detailed, long-term examination, and respecting this as useful to the learner (if not viable in a scientific sense).

Students' Alternative Conceptions

The most influential conceptual change models assume that each child comes to school with misconceptions about natural phenomena that these misconceptions need to be elicited, challenged by explaining or demonstrating contrary examples and corrected by providing a more general concept that the student will accept and assimilate. The aim is to guide students toward accepting current scientific views and incorporating them in their cognitive scheme.

There are two sources of knowledge for the individual. There is the knowledge that a student acquires from interaction with the environment (Dewey, 1938). This might be called intuitive knowledge, "gut" knowledge. Its primary characteristic is that it constitutes the individual's reality. The other source of knowledge is formal instruction, disciplined knowledge, school knowledge. Its primary characteristic is authority. Learning of this knowledge is goal directed.

The body of research into students' alternative conceptions has seen tremendous growth over the past three decades (Pfundt & Duit, 1994). Research findings consistently show that misconceptions are deeply seated and likely to remain after instruction in the students' cognitive structure, or even to resurface some weeks after students have displayed some initial understanding immediately following instruction (Clement, 1982; Halloun & Hestenes, 1985). Students cling to their erroneous beliefs tenaciously. Because students have spent considerable time and energy constructing their naive theories, they have an emotional and intellectual attachment to them.

A model of conceptual change was developed by Posner, Strike, Hewson, and Gertzog (1982) at Cornell University. It describes learning as a process in which a learner changes his/her conceptions by capturing new conceptions or exchanging existing conceptions for new ones. Dreyfus, Jungwirth, and Eliovitch (1990) were involved in trying to induce conceptual change in students from six high schools in Israel. The concepts being examined were respiration; the cell membrane; and the transmission of hereditary traits. Cognitive conflict strategies were attempted using small-group interviews and discussions. The findings of this qualitative study provide additional support for the importance of prior knowledge. Conceptual change can be seen in terms of recognizing, evaluating, reconstructing: the individual needs to recognize the existence and nature of their current conceptions, the individual decides whether or not to evaluate the utility and worth of these conceptions, and the individual decides whether or not to reconstruct these conceptions.

According to Hewson (1981) a key factor in the learning process is the status that new and existing conceptions have for the learner. There are two major components of the conceptual change model. First is a set of conditions, which determine the status of the concept, that need to be met in order for a person to experience conceptual change. Second is a person's conceptual ecology that provides the context, in which the conceptual change occurs, influences the change process, and gives a meaning to the change itself.

The Status of Students' Conceptions

The conditions for the status apply to conceptions that a learner either holds or is considering. A critical point is that it is only when the learner, rather than the teacher, decides, implicitly or explicitly, that the conditions have been met that conceptual change occurs. Hewson and Thorley (1989) stated the conditions as follows:

1) Is the conception *intelligible* (meaningful) to the learner? That is, does the learner know what it means?

2) Is the conception *plausible* (truthful) to the learner? That is, if the learner also believe that it is true?
3) Is the conception *fruitful* (useful) for the learner? That is, if a conception achieve something of value for the learner? Does it solve otherwise insoluble problems? Does it suggest new possibilities, directions, and ideas?

The extent to which the conception meets these three conditions is termed the *status* of a person's conceptions. The more conditions that a concept meets the higher its status is. If the new conception conflicts with an existing conception it cannot be accepted until the status of the existing conception is lowered. This only happens if the learner holding the conception has reason to be dissatisfied with it. The learner's conceptual ecology plays a critical role in determining the status of a conception because, amongst other things, it provides the criteria in terms of which he or she decides whether a given condition is (or is not) met (Hewson & Hewson, 1984).

Making Status Explicit

Technical language of the conceptual change model (CCM), i.e., intelligible, plausible, and fruitful, includes terminology that are not clear for every individual. Hennessey (1991) built a consensus about a set of descriptors for each of these technical terms. The final set of descriptors is contained in Table 1. When explicit meanings of the technical terms are discussed both students and teacher know what they are talking about when they are using the technical term.

Initiating Conceptual Change

A person becomes committed to a conception because it helps interpret experiences, solve problems, and meet emotional needs. A new conception should do more than the prior conception for the person but it must do so without sacrificing any of the benefits of the prior conception (White & Gunstone, 1989).

It is useful to think of changes in the knowledge state of a learner in terms of assimilations, accommodations, and disequilibrations (Posner et al., 1982). These terms are useful, from the standpoint of learning and pedagogy, for describing the necessary conditions for conceptual change.

Assimilation is the recognition that an event fits an existing conception. This recognition process is also a selective ignoring of discrepancies deemed not salient. Assimilation strengthens existing beliefs or convictions. Accommodation is a change in a belief about how the world works, that is, change in a conception, which enables an event to be assimilated that could not have been assimilated under previously held conceptions. Accommodation can be viewed as a competition between conceptions (Posner et al. 1982).

Table 1. Descriptors for the technical terms of the CCM (Hennessey, 1991).

For an idea/concept to be	Descriptors
INTELLIGIBLE to me	-I must know what the concept means -The words must be understandable -The words must make sense -I should be able to describe it in my own words -I can give an example -Examples that belong -Examples that do not belong -I can find ways of representing my ideas to others -By drawing or illustrations -By talking about or explaining it -By using idea maps (concept maps)
PLAUSIBLE to me	-It must first be intelligible -I must believe this is how the world actually is -It is true -It must fit my picture of the world -It must fit in with other ideas or concepts I know about or believe -It is the way I see things work
FRUITFUL to me	-It must first be intelligible -It should be plausible -I can see it as something useful -It can help me solve problems -It can help explain ideas in a new way -I can apply it to other ideas -It gives me new ideas for further investigation or exploration -It is a better explanation of things

Dissatisfaction with the existing conception decreases its status, while exploring the fruitfulness of an alternative conception increases alternative's status. Whenever the alternative's status exceeds the existing conception's status, accommodation will move forward. Scientific as well as an everyday concept is not taken in all at once in completed form but develops over time. There is movement back and forth in the student's mind between the spontaneous and the nonspontaneous concepts until they come together in a system. For accommodation to occur, a student must become motivated to change by entering a state of cognitive disequilibration.

Disequilibration can occur when the student's expectations are not met, that is, an event does not fit with the student's existing beliefs. The fact that certain conceptions are not changed as a result of normal instruction is due to the failure of that instruction to disequilibrate students with respect to the conceptions they hold. If students can assimilate events presented in the course of instruction, then there is no disequilibration and no conceptual change. Disequilibration is not contradiction. Contradiction refers to a logical inconsistency whereas disequilibration is a conceptual inappropriateness. Disequilibration is not a consequence of formal, truth-valued statements, but rather of the surprise produced when an expected event does not occur.

Nurturing Conceptual Change

The cumulative advice of conceptual change researchers to teachers has therefore been to diagnose, or become familiar with, their students' views (knowledge, preconceptions, naïve conceptions, misconceptions, or alternative frameworks), and then to apply a cognitive conflict or dissonance strategy (if needed) to change these frameworks into more scientifically acceptable ones (Hewson & Thorley, 1989).

It is essential to create a classroom environment in which students are free to suggest tentative ideas and then to test them without concern for the rightness or wrongness of these ideas. In the heat of the debate progress is made when each side attempts to understand the other's position well enough to find holes in their argument.

What seems principally required by conceptual change theory (Strike & Posner, 1992) is for teachers to teach science so that students can see that the world is a rational and intelligible place. Learning with understanding is one of the most highlighted concerns in science education literature and community. On the other hand, students often have limited time and opportunities to understand or make sense of topics because many curricula have emphasized memory rather than understanding. Textbooks are filled with facts that students are expected to memorize. In addition, students' evaluations and tests are designed to probe students' abilities to remember and recite the facts. Perhaps what conceptual change theory requires is fewer teachers who emphasize calculating the right answer in their tests and instruction, and more teachers who emphasize the connections between conceptions, experimental evidence, and students' current conceptual ecology (O'Loughlin, 1992). The means to effective instruction are to be found in persistent attention to the argument and in less attention to right answers.

The Importance of Students' Epistemological Beliefs

Research has shown the relationship between students' epistemologies and their approaches to learning science, which, in turn, influence their choices of learning strategies and whether they integrate what they learn. For example, Edmondson and Novak (1993) found that students identified as logical positivists tended to be rote learners oriented to grades, whereas those identified as constructivists used meaningful learning strategies as the primary goal of their understanding of the material. Tsai (1998) found that students having constructivist epistemological beliefs engaged in more active learning as well as used more meaningful strategies when learning science, whereas students having epistemological beliefs more aligned with empiricism tended to use more rote like strategies because they believed science was like a collection of correct facts. Thus, students' epistemological beliefs seem to shape their metalearning assumptions and influence their learning orientations, and the adoption of a constructivist epistemology is related to more meaningful learning.

Conclusions and Implications

It can be concluded that students' prior knowledge, expectations, and perceptions determine what information will be selected out for attention. What they attend to determines what they learn. In order to learn a concept meaningfully, students must carry out cognitive processes that construct relations among the elements of information in the concept.

I suggest that science teachers might be more effective if they understood the barriers to conceptual learning (particularly the strong hold of prior misconceptions and the resistance to conventional instruction) and if they became familiar with the educational research and strategies dealing with those misconceptions. Some may get the impression from the foregoing discussion that conceptual-change instruction is practically the same as to a movement of finding and eradicating students' misconceptions. This is not the case. The constructivists understand of the fact that students' conceptual knowledge evolves in time, and many misconceptions will disappear naturally as students gain expertise. The expectation that a scientific concept can be learned within the space of a few days, weeks or even months is a notion that needs reexamination. Concept development cannot take place in these circumstances (Howe, 1993). Another obvious implication is the importance of language in concept development. A concept is not fully realized or understood until it is represented in words. From Vygotsky's zone of proximal development perspective, learning is viewed as a profoundly social process. Dialogue with the teacher and peers plays crucial role in learning. The more exposure of students to new materials through oral lectures neither allows for teacher guidance nor for collaboration with peers.

Meaningful learning does not occur by throwing more science facts and principles at the students or increasing the number of students' laboratory activities. A trendy emphasis on "hands on" will not, by itself, increase students' understanding of science either. What is additionally needed is a "minds on" emphasis in the learning of science (Pines, 1985). Organizational processes are essential for building conceptual networks (Novak, 1988). Teachers can support students' organizational processes by techniques such as concept mapping. By comparing the concept maps that students produce over the course of instruction, the teacher can trace developments in students' conceptual networks.

Learning for understanding in classroom requires well-designed hands on, as well as minds on, activities that challenge students' existing conceptions leading students to reconstruct their personal theories. As Driver, Asoko, Leach, Mortimer, Scott (1994) pointed out the view of scientific knowledge as socially constructed and validated has crucial implications for science education. Scientific entities and concepts are unlikely to be discovered by individuals through their empirical enquiry. Therefore learning science involves being initiated into the ideas and procedures of scientific community and making these ideas and practices meaningful at an individual level. It is a perspective on science learning as a process of enculturation rather than discovery, arguing that empirical study of the nature will not reveal scientific knowledge because scientific knowledge is discursive in nature

As a science educator, we should emphasize the quality of our students' understandings rather than just surface learning or their test scores. Conceptual understanding is crucial and it should be a focus of our interest in science teaching, we need to promote conceptual learning over rote memorization. Science teachers should call attention to the process of science rather than just the content, because students who understand the process are better prepared to acquire science content on their own (Basili, & Sanford, 1991). Today's teachers should not just consider themselves teachers but also students of learning.

Implications for Science Pedagogy

Constructivism similarly provides a sound theoretical foundation for explicating science pedagogy. This brief discussion focuses on alternative conceptions, conceptual change teaching, and cooperative learning. Summarizing and interpreting the research literature on alternative conceptions in science, Wandersee, Mintzes, and Novak (1994) pointed out that the cornerstone of this body of research rests on the evidence-documented claim that students harbor a wide variety of alternative conceptions about objects and events when they enter formal instruction in science. Moreover, the origins of these alternative conceptions lie in students' diverse personal experiences, which include observation, perception, culture, language, prior teachers' explanations, and prior instructional materials. Students hold tenaciously onto these alternative conceptions in the face of traditional formal instruction. Finally, all of this prior knowledge interacts with whatever is presented in formal instruction, resulting in a wide variety of unintended learning outcomes by students.

The integrated principles of constructivism accounts very well for these claims. Recounting them, first, knowledge is actively built up from within by individuals and by communities. Second, language-based social interactions are central to the building of knowledge by individuals and communities. Third, the character of cognition and a language, which is employed to express cognition, is functional and adaptive. Fourth, the purpose of cognition and language is to bring coherency to an individual's world of experience and a community's knowledge base, respectively. Students have worked diligently over a long period of time to organize their experiential worlds, and substantial reorganization similarly requires diligent thought and time. Innovations in science pedagogy such as conceptual change teaching strategies hold much promise for dealing with students' alternative conceptions. According to Wandersee et al. (1994), these strategies are grounded in constructivism, contemporary philosophy of science (e.g., Kuhn, 1970), and conceptual change theory (Posner, Strike, Hewson, & Gertzog, 1982).

Implications for Teacher Education

There have been many studies on students' misconceptions which aimed to help teachers facilitate learning through a conceptual change approach (Novak, 1987; Perkins & Simmons, 1988; Strike, 1983; Hewson & Hewson, 1983, as cited in Martens & Crosier 1994) and to help assess students' growth in understanding of science and mathematics concepts (Anderson & Smith, 1987; Hennessey, 1991; Hewson, 1981; Thorley, 1992 as cited in Martens & Crosier 1994).

Based on these studies Martens & Crosier (1994) explored the usefulness of a conceptual change approach to learning by examining the relationship between the pedagogical experiences provided in a science methods course and pre-service elementary teachers' changing concepts about teaching and learning science (p.139). Martens & Crosier found that the science methods course structured to promote conceptual change provided preservice elementary teachers pedagogical experiences that would change their concepts about science teaching and learning. The results of these studies indicate that when teachers were more self-reflective in their pedagogy, they were more successful in terms of the eventual conceptual understanding of their students. In agreement with previous research, such an approach to preservice teacher training was implemented and tested by Hewson and his colleagues at the University of Wisconsin (Hewson et al., 1999).

Perhaps, teaching teachers instructional strategies that foster conceptual change is the most difficult of the tasks, largely because most of the cognitive research effort to date has focused on studying learning rather than instruction. Yip (1998) suggested that, teacher education programs should aim at equipping science teachers with the following knowledge and skills:

- What science educators have found out about students' misconceptions in science: this knowledge helps the teacher to develop an awareness and understanding of the nature and sources of students' misconceptions, which is a first step in designing suitable instructional strategies.
- Methods for diagnosing misconceptions held by students before and after instruction: this information allows the teacher to monitor students' learning problems, which will provide continuous feedback on the effectiveness of the teaching strategies used.
- Designing instructional strategies that tackle students' misconceptions: this involves planning and structuring curriculum materials and learning activities using the constructivist approach that aims at promoting conceptual changes and development, such as the use of examples and analogies, cognitive conflicts, concept maps, demonstrations and student activities.
- Reviewing selected areas of subject matter in which teachers have conceptual problems. Teacher training courses should provide learning experiences for teachers to refresh and consolidate their understanding on certain difficult concepts of the school curriculum.

References

Anderson, C.W. & Smith, E.L. (1987). Teaching science. In V. Richardson-Koehler (Ed.), *Educators' Handbook: A Research Perspective* (pp. 84-111). White Plains, NY: Longman.

Ausubel, D. P. (1963). *The psychology of meaningful verbal learning*. New York: Grune & Stratton, Inc.

Ausubel, D.P., Novak, J.D., & Hanesian, H. (1978). *Educational psychology: A cognitive view* (2nd ed.). New York: Holt, Rinehart and Winston.

Basili, P.A., & Sanford, J.P. (1991). Conceptual change strategies and cooperative group work in chemistry. *Journal of Research in Science Teaching,* 28(4), 293-304.

Clement, J.J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics*, 50, 66-71

Confrey, J. (1990). A review of the research on student conceptions in mathematics, science, and programming. *Review of Research in Education,* 16, 3-56.

Dewey J. (1938). *Experience and Education*. Kappa Delta Pi.

Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1990). Applying the "cognitive conflict" strategy for conceptual change – some implications, difficulties, and problems. *Science Education,* 74(5), 555-569.

Driver, R., Asoko, H., Leach, J., Mortimer, E., Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher,* 23(4), 5-12.

Edmondson, K.M., & Novak, J.D. (1993). The interplay of scientific epistemological views, learning strategies, and attitudes of college students. *Journal of Research in Science Teaching,* 30(6), 547–559.

Gredler, M. E. (1997). *Learning and instruction: Theory into practice*. New Jersey: Prentice Hall.

Halloun, I.A., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics,* 53(11), 1043-1055

Hennessey, M. G. (1991). Analysis of conceptual change and status change in sixth graders' concepts of force and motion (Doctoral dissertation, University of Wisconsin- Madison). *Dissertations & Theses: Full Text database*. (Publication No. AAT 9128916).

Hewson, P. W. (1981). A conceptual change approach to learning science. *European Journal of Science Education,* 3(4), 383-396.

Hewson, P. W., & Hewson, M. G. (1984). The role of conceptual conflict in conceptual change and the design of instruction. *Instructional Science,* 13(1), 1-13.

Hewson, P. W., & Thorley, N. R. (1989). The conditions of conceptual change in the classroom. *International Journal of Science Education,* 11(5), 541-553.

Hewson, W. P., Tabachnick, R. B., Zeichner, M. K., & Blomker, B. K. (1999). Educating prospective teachers of biology: Introduction and research methods. *Science Education,* 83(3), 247-273.

Howe, A. C. (1993). A Vygotskian Perspective on Teaching for Conceptual Change. In *The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics*, Misconceptions Trust: Ithaca, NY.

Kuhn, T.S. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago: University of Chicago Press.

Martens, M. L., & Crosier, S. (1994). Sharon's story: The usefulness of conceptual change constructs in promoting student reflection. *Journal of Science Teacher Education,* 5(4), 139-145.

Moll, L. (1990). *Vygotsky and education. Instructional implications and applications of sociohistorical psychology.* Cambridge: Cambridge University Press.

Naussbaum, J., & Novick, S. (1982). Alternative frameworks, conceptual conflict and accommodation: Toward a principles teaching strategy. *Instructional Science,* 11(3), 183-200

Novak, J. D. (1988). Learning science and science of learning. *Studies in Science Education,* 15(1), 77-101.

Novak, J. D.(1996). Concept mapping: A tool for improving science teaching and learning. In D. F. Treagust, R. Duit, & B. J. Fraser (Eds.), *Improving teaching and learning in science and mathematics* (pp.32-43), New York: Teachers College Press.

O'Loughlin, M. (1992). Rethinking science education: Beyond Piagetian constructivism toward a sociocultural model of teaching and learning. *Journal of Research in Science Teaching,* 29(8), 791–820.

Pfundt, H. & Duit, R. (1994). *Bibliography: Students' alternative frameworks and science education* (4th ed.), IPN Reports in Brief (Germany: University of Kiel).

Piaget, J. (1978). *The development of thought* (A. Rosin, Trans.). Oxford: Basil Blackwell.

Pines, A. L. (1985). Toward a taxonomy of conceptual relations and the implications for the evaluation of cognitive structures. *In* L. H. T. West and A. L. Pines (Eds.). *Cognitive Structure and Conceptual Change*. New York: Academic Press, Inc.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education,* 66(2), 211-227.

Slavin, R. E. (1988). *Educational psychology: Theory into practice*. Englewood Cliffs: Prentice Hall.

Strike, K. A. & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl & R. J. Hamilton (Eds.) *Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice.* State University of New York: Albany.

Tsai, C.C. (1998). An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education,* 82(4), 473–489.

Von glasersfeld, E. V. (1986). Steps in the construction of others and reality. In R. Trappl (ed.), *Power, autonomy, and utopias: New Approaches toward complex systems* (107-116). London: Plenium Press.

Von glasersfeld, E. V. (1993). Questions and answers about radical constructivism. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 23–38). Washington, DC: AAAS Press.

Vygotsky, L. S. (1978). *Mind in Society: The development of higher psychological process.* Harvard University Press.

Wandersee, J.H., Mintzes, J.J., & Novak, J.D. (1994). Research on alternative conceptions in science. In D. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177–210). New York: Macmillan.

White, R.T., & Gunstone, R.F. (1989). Metalearning and conceptual change. *International Journal of Science Education,* 11(5), 577–586.

Yeany, R. H. (1991). A unifying theme in science education? *NARST News,* 33 (2), 1-3

Yip D. Y. (1998). Identification of misconceptions in novice biology teachers and remedial strategies for improving biology learning. *International Journal of Science Education,* 20(4), 461-477.

Author

Mustafa Çakır is a faculty member in secondary science and mathematics education in Ataturk Faculty of Education, Marmara University, Turkey. Dr. Çakır earned his PhD (2004) and MSc (2000) in Science Education from the Pennsylvania State University. His current research focuses on assisting students in developing understandings of scientific inquiry, nature of science, and relevance of science to society that are consistent with current practice and helping them to develop understandings and skills that are necessary for citizens of 21st century. **Correspondence**: Marmara University, Ataturk Faculty of Education, Goztepe Kampus, 34722, Kadıköy–İstanbul, Turkey. Email: mustafacakir@marmara.edu.tr.