Feature Article

CONSTRUCTIVISM FOR SCIENCE TEACHERS

William W. Cobern, Ph.D.
Arizona State University West
Associate Professor of Science Education
Phoenix Arizona 85069-7100
Voice Mail: 602-543-6334
Fax: 602-543-6350
INTERNET: ICWWC@ASUVM.INRE.ASU.EDU

Constructivism is a concept that in recent years has garnered considerable attention among science education researchers. Essentially, it is a model or metaphor of how learning takes place. Prominent science educators have called it a most promising model and a theoretical shift that may lead to a coalescing of current thought as well as the stimulation of new ideas. I do not believe this is hyperbole. The potential significance of constructivism has already extended beyond research and into the science classroom. References to constructivism appear ever more frequently in the literature, however, often with little or only trivial discussion of the philosophical meaning of constructivism. My purpose in this article is to acquaint teachers with the philosophical roots of constructivist thought enabling them to better understand this expanding literature. First, however, it is necessary to offer a word or two about Piagetian cognitive development theory which has dominated educational thinking for some years now.

The Eclipse of Piagetian Theory

Piagetian cognitive development theory has precipitated enormous amounts of educational research. However, an inability to translate research findings into practice has been a chronic weakness of Piagetian theory. Joseph Novak, an eminent professor of science education, wrote that for years he had been "trying to suggest that the Piagetian paradigm for cognitive development is not the most useful paradigm to guide research in science education nor for planning instructional programs" (1978, p. 591). His arguments remain appropriate. Moreover, cognitive development theory has never quite escaped the charge that it is culturally biased. The difficulty with cognitive development theory lies in a paradoxical relationship between rationality and understanding. Piaget designed a set of clinical interviews based on formal propositions of logic. He inferred levels of cognitive development in terms of rationality from performance on interview tasks. By inference, a person who successfully completes the tasks is able to handle advanced propositions of logic, and therefore, is capable of learning advanced subject matter. To use the jargon of research on reasoning, this person is a rational, logical thinker who uses formal, abstract operations. For use in education research, educators derived from Piaget's clinical interview procedures several paper-and-pen assessments of rational development which can be used with large numbers of students at one time. This latter type of research is typically called research on cognitive development and is the focus of the next comments.

It strikes one's attention when reading the literature in education on cognitive development research that so many studies find that many secondary students and even adults have not reached abstract or formal levels of logic. The research seems to say that many secondary students and adults fail to understand science because they simply have not attained a high enough level of rational thinking. I find this problematic. Clearly the cognitive development researcher must assume that the premises of the assessment procedures are correctly understood by the person being assessed. That a person understands a task or statement, however, can only be determined by observing that the person agrees or disagrees as to (a) what statements are the same as the given one, (b) what the given statement implies, (c) what other statements are contradicted by the given statement, and (d) what is irrelevant to the given statement (Smedslund, 1970). This is exactly where the difficulty lies. If a person cannot think well (if a person is not very rational) that person will not be able to recognize statements that are equivalent in meaning, statements that contradict each other, the implications of a statement, or the things that are irrelevant to the presented statement or problem. Then, if the subject fails to answer the test or interview question properly, the researcher is actually unable to determine whether the subject failed due to a lack of logical skill or due to a failure to understand the premises of the task. The point is that in ordinary situations it is exceedingly difficult, if not impossible, to separate rationality from comprehension. The cognitive development researcher can only proceed by assuming that a subject understands what is going on in the test. But, this is a counter-intuitive and counter experiential assumption. "In conversation we always assume that the other person is logical . . . When our expectations are not fulfilled, we normally attribute it to a lack of understanding . . . but not to genuine illogically on his part . . . logic must be presupposed, since it is characteristic of any activity of any integrated system and is a part of the very notion of a person (Smedslund, 1970, p. 217-218). Smedslund's point is that the researcher is making an assumption that defies commonsense. We have a very well established precedent from everyday life: when a person does not get a thing correct, we don't assume he lacks logic. We assume he has failed to understand and thus we proceed to try another approach to explaining the thing.

The question in education is why would we want to abandon an approach that has served daily life so well? The answer that people give is that children are different. Surely children are at a lower level of rational thinking than adults regardless of what is assumed about understanding. On this premise educators have written what they argue are developmentally appropriate curricula which prescribe what topics can be taught at various ages. Indeed, few would disagree, for example, that the concept "chair" is less abstract than the concept "atom," and therefore more readily understood by young children. But how is it that the concept "atom" is more abstract than the concept "chair?" In cognitive development theory the answer is that acquisition of this concept requires advanced rational thought that children have not yet attained. However, it is also true that "atom" and "chair" are not epistemologically equivalent concepts. A conceptual analysis of "atom" reveals that this concept is built up from a large number of other concepts. In other words, the concept "atom" subsumes a large number of related concepts. Grasping the concept "atom" requires a grasp of the subsumed concepts. In contrast, the concept "chair" subsumes far fewer related concepts, and thus, grasping the concept "chair" requires the grasp of fewer related concepts. Is then the concept "atom" more difficult to understand because its understanding requires an advanced level of rational thought? Or, is it difficult because of the sheer number of subsumed concepts that must be grasped before one can understand the concept "atom"? In the later case, the young child simply has not lived long enough or has not had the requisite experiences needed to build up the prior knowledge necessary for understanding a difficult concept such as "atom." It is not clear that children's thinking differs from adult thinking because children are less rational, rather than because children have less developed conceptual frameworks.

This issue of understanding versus rationality has great importance for the classroom. If the teacher assumes that (say) elementary children are rationally unable to learn certain concepts, the teacher will not teach those concepts. In first grade one teaches about animals, but not about atoms. At first glance it appears that the ability to offer teachers a developmentally appropriate curriculum is a good thing. Unfortunately, such a curriculum can easily put the brakes on teaching. In a developmentally appropriate curriculum, the tendency is to not press beyond a given topic even when that topic has been successfully taught, because the curriculum implies that the teacher should go no further than the prescribed appropriate concepts. Commonsense tells us that success should be a stimulus for further efforts regardless of difficulty, and that the teacher should simply keep going as long as the children are learning. This is exactly what a competent teacher does when the teacher's focus is understanding rather than rationality and cognitive development. Thus, even if one accepts that children are at lower levels of rationality than adults, the value of the influence of cognitive development theory on curriculum is debatable at best.

Cognitive development theory is used to inform instructional practice as well as curriculum, but it is not the stage development aspects of the theory that are used. Instructional practice is informed by Piaget's concepts of accommodation and assimilation. These concepts are clearly about understanding, not rationality. David Ausubel (1968) has demonstrated that the concepts of accommodation and assimilation do not have to be linked with developmental stages. His focus has been to develop a theory of meaningful learning that extends the concepts of accommodation and assimilation rather than switching to concepts of rationality. One of Ausubel's chief ideas is that only personally meaningful learning is true learning. His recognition of the powerful influence that prior learning has on the meaning a student makes of any learning situation sets the stage for constructivism.

The focus of constructivist theory is understanding. In my view, this is one of the primary reasons that constructivism is rapidly replacing cognitive development theory as the foundation for science education research and practice. Moreover, one the attractions of constructivism is its utter simplicity. On reflection, one would almost say the notion is patently self-evident. However, the widespread adoption of the term constructivism has actually created considerable confusion and controversy. For all its simplicity, the term seems to mean different things to different people. Constructivism for some is a rather uncomplicated, pragmatic description of learning that can be turned about and used to guide teaching. For others, constructivism is more a philosophy about knowledge. Those with the more philosophical orientation (they are known as radical constructivists) argue that it is fundamental that cognition is a biological adaptation that serves to or ganize experience for a person but it does lead to the discovery of how things really are (Glasersfeld, 1989). So what is constructivism?

The Uncertainty of Knowledge

In an effort to foster an intuitive grasp of this concept, I prefer not to start with a definition. Rather, what follows is a descriptive narrative. I trust that the narrative, in somewhat inductive fashion, will evoke in the reader an understanding of constructivism prior to hearing a formal definition.

We all wish to know about the world around us, whether we are speaking of the world in physical, social, or even spiritual terms. Science, of course, is the discipline that tells us about the physical world, and in science one's senses are critical. One uses sight, hearing, feel, and taste to learn about physical phenomena. Instruments are used to extend the range of the basic human senses. These instruments can be as simple as an ordinary ruler or as complex as a radio telescope or mass spectrometer. Typically, what we have thought in science is that our senses provide authentic data about the real world. Experimentation keeps subjectivity in check. But is that really how our senses work? Consider that science uses the senses to focus only on what can be measured. For example, a scientist typically is not as interested in the color of an object as he or she is in measurable electromagnetic wavelengths emitted or reflected by the object. If you want to build a color television, knowledge of electromagnetic wavelengths is necessary. However, who can say that a wavelength of 4.0×10^{-7} meters tells us any more about the reality of an object than does blueness? In fact, philosophers of science tell us that the question cannot be answered. Scientists focus on measurable attributes simply because they have chosen to do so—it works for what they want to do.

There is another question that confronts our attempts to understand reality, regardless of the physical attributes on which one chooses to focus. How do we know that what we perceive is what is actually there? As early as 1604, Kepler demonstrated that the physical image on the retina of the eye is actually inverted. Yet that is not how we perceive objects. We perceive them right side up. In other words, even though we see an object upside down, we nevertheless perceive it right side up. So how can we say that what we see is actually what is there? Perception appears to involve interpretation rather than simple transmission. To further illustrate the difference between sight and perception, try to image a person born without functioning sense organs. Somehow the person survives and one day after many years, the person's eyes suddenly start functioning. His eyes would see reflected light just as ours do; but, what would he perceive? A mass confusion of light, a jumble of hues and intensities, a tumult of sensation, all signifying absolutely nothing. He would not recognize a tree in front of him because he could not have had any prior knowledge of the concept of tree. Perception is the act of one who sees, not the passive reception of light reflected by objects. To make this more personal, imagine that you have just removed the cover of your personal computer. Few of us know anything at all about the physical apparatus within a computer casing. Open one up and what we perceive is a confusion of lines, shapes, and colors—signifying nothing. On the other hand, the computer scientist perceives a computer. This illustrates what the modern developments in the philosophy of science have clearly shown, all observation is theory laden.

There are then two profound limitations on scientific knowledge. First, science is limited by its focus on selected attributes to the exclusion of others. This is a choice made by scientists, not a limitation imposed upon science by physical reality. Second, one can perceive an object only when one has preexisting knowledge of what is being examined. The result is that the scientist can never say that he or she has exact knowledge of what reality is like. Rather, the scientist drawing upon previous knowledge interprets experience following rules agreed upon by the community of scientists. A scientist constructs knowledge to fit experience. Instead of a photograph of reality, scientific knowledge is much more like an artist's impressionistic painting of reality. The notion that knowledge is constructed leads some to conclude that all knowledge is inherently subjective. Others take the more conservative position that knowledge can be objective but that all knowledge is fallible.

This essentially means that scientific knowledge is fallible, and this has implications for education. If there were a direct link between the scientist and a physical reality independent of the scientist, one could argue for a direct link between scientific knowledge independent of any knower and the acquisition of scientific knowledge by a learner. This is the viewpoint of naive objectivism. It implies that knowledge can have an existence independent of a knower. It thus implies that the best way to teach is by careful, methodical, detailed explication of scientific knowledge with the expectation that students will learn by receiving (i.e., memorizing) the knowledge. In fact, under the influence of positivism which taught that rationality and objectivity resided in quantitative experimental science, that is exactly how science has been taught for many years. However, if scientific knowledge is a scientist's meaningful construction based on his or her experiences of reality, how can the learning of scientific knowledge be any different? If I cannot know reality for sure, what is it that I am learning when I learn? Essentially, there is no difference between the original derivation of scientific knowledge by a scientist and the learning of scientific knowledge by a student. Both are acts of interpretation. When I learn a science concept, I am constructing a personal understanding of the concept based on what I perceive the textbook, or activity, or teacher to be saying. Just as a scientist interprets experience in light of a personal background of knowledge, I learn by interpretation in light of my personal background of knowledge. In contrast, rote memorization involves no interpretation, is rarely meaningful; and, therefore, most of what students memorize is soon forgotten.

The concepts of construction and meaningful learning help make sense of a widespread occurrence among people. Science education research has shown that people hold many different ideas about such things as motion, force, life, and gravity. People's ideas frequently differ considerably from accepted scientific viewpoints even when the people are students of science. After very careful explication of a concept, students frequently come away with quite different interpretations of the concept. Even graduate level physics students have been shown to have views of the concept "impetus" that vary considerably from what is consider the scientifically orthodox view. This phenomenon prompted David Hawkins to write, "reasonably patient explanation is no cure . . . we are up against something rather deep in the relation between science and common sense; we are up against a barrier to teaching in the didactic mode which has hardly been recognized, or if recognized has been seen mainly as a challenge to ingenuity in teaching rather that as a challenge to a deeper understanding of human learning" (1978, p. 5, 7). What is the barrier? You ask, how do these scientifically unorthodox ideas happen? They happen because learning does not involve photography, but impressionistic artistry. As the learning theorist David Ausubel says, the only real learning is meaningful learning. We have learned something when it makes sense to us. The advanced physics students have a particular impression of what impetus means because that impression makes sense to them. If their impression of impetus does not resemble the teacher's, it is because their impression is a personal construction. If learning occurred by transmission, students would either have the concept or not. What they would not have are idiosyncratic versions of the concept.

Defining Constructivism

The definition of constructivism is carried in its name. Learning is the active process of constructing or putting together a conceptual framework. The philosophical basis for constructivism is epistemological fallibalism. All knowledge is fallible by virtue of lacking exactitude and comprehensiveness. Ultimately, we can never know for sure how close our knowledge actually approximates reality. Rather, knowledge is a meaningful interpretation of our experiences of reality. If the original derivation of knowledge is by meaningful interpretation, then the learning of knowledge must also involve meaningful interpretation. Thus, no one learns by transmission. No one learns in a way analogous to the copying of a computer file from floppy disk to hard drive. We learn by making sense of what is experienced.

As I mentioned at the start, constructivism is a practical idea. Consider the following simple dialogue:

Teacher: I say to you the man is tall.
Student: I hear you say that the man is tall. I think this man is also tall.
Teacher: No, that man is only 2 meters tall.
Student: Okay, I hear you saying that the first man is tall because he is over 2.4 meters
Teacher: Yes, but you are saying the second man is tall because he is over 2 meters.

We might call this dialogue "coming to an understanding" or "clearing the air," or "seeing eye to eye." The dialogue demonstrates three things. It demonstrates that both the teacher and the student are learners. They learn from each other. Second, the dialogue demonstrates that learning is an interpretive process. The student had to interpret the meaning of "tall." The teacher had to interpret the student's response. Third, in order to help the student understand the teacher's intention, the teacher had to come to an understanding of the student's viewpoint, i.e., that student interpreted tall to mean over 2 meters. This, essentially, is the constructivist model of learning. It says to us that learning is always an active process of making sense out of an experience, and that this process is much influenced by what one already knows. Therefore, in any teaching/learning situation it is crucial that the teacher come to a common understanding with the student. Constructivism says to us that learning involves negotiation and interpretation. Therefore, the teacher is advised to engage students in discourse that facilitates the actions of negotiation and interpretation. The discourse may be with the teacher or among students. In this regard, cooperative learning strategies are ideal. Constructivism also implies that activity, or hands-on learning, by itself is not enough. A good inquiry lesson will fail with many students if students are not allowed to engage in negotiation and interpretation of ideas.

There is a further issue to consider. Most people have had the experience of being in a conversation where one would swear that the other person was speaking in an unknown foreign language even though that was not the case. One simply could not make oneself understood by the other person. This failure to communicate happens when the parties bring to the conversation radically different conceptual frameworks, and this is not uncommon in the science classroom. The problem is that the student has no idea what the teacher is talking about. The issue here is contextual constructivism (worldview is a related issue; Cobern, 1994). One of the clearest examples of this in science is the topic of origins. The scientific view of origins has to do with evolutionary mechanisms that speak to the question of how. For many students, however, origins is not about how but about why. Origins is a religious topic rather than a science topic, and these students construct knowledge appropriate to the context that is meaningful to them. The result is a radical schism between teacher and student, which is made only worse when the teacher assails the student's position without ever trying to understand the student. The solution is not to tell the students they are wrong, but for teacher and students to work through the issues together.

Conclusion

In summary, constructivism is a model intended to describe learning. The model suggests:

1. The student is always active when learning takes place.

2. This active process is the process of making sense. Learning does not occur by transmission but by interpretation.

3. Interpretation is always influenced by prior knowledge.

4. Interpretation is facilitated by instructional methods that allow for the negotiation of ideas.

Inquiry activities are powerful specifically when they promote discourse. By the same reasoning, cookbook labs and demonstrations are far less effective. Thus, if students are not talking science, you will find that many are not learning science. As to the different views of constructivism, some educators are content to use the model as a basis for developing teaching strategies. However, Glasersfeld (1989) is right. There are at work here key issues of epistemology and ontology. The model can be used pragmatically, but I do not think that its full potential can be realized without the support of a philosophical framework.*

Suggested Reading

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