

# The Constructivist Perspective: Implications and Teaching Strategies for Science

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The constructivist perspective is becoming a dominant paradigm in the field of cognitive psychology. Research findings resulting from this perspective have profound implications for the way in which science instruction is carried out.

Within the past two decades, a major shift has occurred in how those who study human learning view the nature of the learning process (Witrock, 1985). Research questions which are studied have changed from questions about factors external to the learner, such as teacher variables, personality, clarity of expression, enthusiasm, use of praise, etc. to questions about factors inside the mind of the learner, such as prior knowledge, naive conceptions, memory capacity, information processing capacity, motivation, attention, and cognitive style (Witrock, 1985). This focus upon studies of cognition has resulted in a rapidly growing body of research literature which is beginning to provide unprecedented insights into the nature of the learning process especially those cognitive processes thought to underlie meaningful learning.

The science education research community is contributing greatly to this body of knowledge. Findings from these research efforts have begun to generate important insights about how students acquire meaning and understanding of science concepts both in and out of school and on how prior knowledge can interfere with or enhance student understanding. These insights stem from a key philosophical stance known as the constructivist perspective, and they carry profound implications for instructional practices, practices which some experienced teachers seem to effect intuitively. Unfortunately, however, a vast majority of science programs are textbook driven and thus often fail to capitalize upon more effective instructional practices stemming from these new insights.

## Constructivist Theory

Constructivism can be defined as that philosophical position which holds that any so-called reality is, in the most immediate and concrete sense, the mental construction of those who believe they have discovered and investigated it. In other words, what is supposedly found is an invention whose inventor is unaware of his act of invention and who considers it as something that exists independently of him; the invention then becomes the basis of his world view and actions (Watzlawick, 1984).

The most salient feature of the constructivist perspective then is reflected in Watzlawick's definition. It is the notion that learners respond to their sensory experiences by building or constructing in their minds, schemas or cognitive structures which constitute the meaning and understanding of their world. Individuals attempt to make sense of whatever situation or phenomenon they encounter, and a consequence of this sense making process (a process which takes place within the mind of these individuals) is the establishment of structures in the mind.

These structures or schemas as they are frequently called can be thought of as one's beliefs, understandings, and explanations, in short, one's necessarily subjective knowledge of the world. The first major tenant of the constructivist theory is, "Meaning is constructed by the cognitive apparatus of the learner" (Resnick, 1983). Consequently, it is not communicated by the teacher to student.

To say it another way, meaning is created in the mind of the student as a result of the student's sensory interaction with her or his world. Because it is created in the mind of the learner, it cannot simply be told to the student by the teacher. In the words of Bransford, Franks, Vye, and Sherwood (1989), "Wisdom can't be told."

It is important to note that these mental constructions are often not in accord with those of the community of scientists or those given in textbooks and as such are described variously as misconceptions, alternative conceptions (Viennot, 1979; White & Tisher, 1986), alternative frameworks (Driver & Easley, 1978), homegrown conceptions (Rowe, 1983), and intuitive conceptions (Burbules & Linn, 1988).

The way in which the sensory experiences and cognitive structures interact to result in understanding is best illustrated with a detailed discussion of an example. The well-known Piagetian task, displacement of volume, will be used here. Suppose the thought processes of John (age 12 to 14), a learner who is in the process of trying to understand how the density (he may or may not understand the term) of an object is related to the amount of water it would displace if the object were completely submerged in the water, is examined.

Typically, John has constructed schema from many previous experiences with objects and liquids such as toys, cars, bathtubs, dishpans, sinks, water, milk, juices, boats, etc. These schema have been created, often in an almost unconscious fashion, over a period of several years and they are employed by

him to make predictions about the behavior of objects submerged in liquids.

Two important uses of these structures are that they: (a) provide the learner with the power to utilize his past experience to make predictions and (b) provide a means by which he can develop explanations for these predictions. It is important to note that the predictions and the explanations might be wrong in the sense that they don't agree with those which are generally accepted by the community of scientists at large. To the learner, they make logical sense within the context of the world view he has constructed out of his experience. For example, suppose the learner expects that water will overflow and spill from a bucket full of water when an object is submerged in it. From past experiences with water levels and immersed objects, he knows that the water level will rise when an object is immersed in it.

Suppose now that the learner is handed two metal objects, the same size and shape, one of brass, the other aluminum. He is then asked to make a prediction about the amount of water each would displace if they were submerged. He holds the objects in his hand and notices the brass object is much heavier than the aluminum. He is then asked to place the aluminum object in the graduated cylinder and observe the resulting water level after immersion.

Now, John is asked to make a prediction about the rise in water level which would result from immersing the brass object. John recalls his sensory experience with objects (i.e. the brass was much heavier than the aluminum) and consequently predicts that the brass will displace more water than the aluminum. (His schema tells him the heavier object will displace more water.)

Such a prediction is very common among persons when faced with questions of this sort. How is such a prediction formulated? According to constructivist theory, it arises out of one's schema of submerged objects. The schema which many students invoke in order to formulate such a prediction is usually something like, "The heavier object will displace more water because heavier means bigger, and bigger takes up more space, so the heavier object will make the water level rise more." Many students, however, will simply say, "I don't know why. That's just the way it is" or "I remember we learned it in school."

Now, the description of the interaction between sensory experience and cognitive structure where the learner's predictions are compared with his observations will be addressed. The learner is asked to place the brass object in the graduated cylinder and observe the resulting water level. In other words, he is placed in a situation where he must compare an aspect of his cognitive universe with an aspect of the natural universe. (The reader, no doubt, realizes that the correct schema is that when objects denser than water are submerged, they displace a volume of water equal to the volume of the submerged object.) At this point, it is appropriate to describe a second important tenant of constructivist theory.

The second important tenant is these schema or mental constructions have been created at great cognitive expense, i.e. the construction of meaning is a psychologically active process

which requires the expenditure of mental effort.

As long as the learner's predictions continue to agree with his experience, the schema remains intact. In other words, they are confirmed or more strongly held. In the event prediction does not agree with experience, the learner becomes surprised, puzzled, frustrated, or in Piaget's terms, disequibrated.

In the process of reconciling this conflict between prediction and observation (e.g. internal world and external world), the learner has three options. He can deny the existence of the sensory data, distrust it by claiming it to be invalid, or rationalizing it away. This is called the intact schema option. He can also revise the schema in some way so that the predictions agree with experience. This is called the cognitive restructuring option. These options are two sides of the same coin, i.e. to revise or not revise one's schema. A third option, is apathy. Here, the learner simply disengages himself cognitively. He simply does not accept the responsibility to understand but instead maintains the attitude that, "I don't know why and I don't care (why)".

With the intact schema option, the thinking is something like, "Don't confuse me with facts, my mind is already made up." Here the learner chooses (probably unconsciously) to disbelieve his or her senses or tends to invoke magic or mysticism or in some other way rejects his sensory experience with the world. This first option manifests itself in statements like, "It just looks like it displaces the same amount but it really isn't the same" or "Its magic water" (Linn, 1983) or "Real water doesn't do that." Children, and even adults, actually say such things. Such statements are indications of the tremendous cognitive inertia which must be overcome in order to restructure schema.

There is considerable evidence in the literature which suggests that discarding or restructuring one's schema does not come easily (Champagne, Klopfer, & Anderson, 1980; Eylon & Linn, 1988; Gunstone & White, 1980; Linn & Thier, 1975). Instead it seems, the learner chooses to ignore new sensory data and clings tenaciously to her or his schema.

The second option, cognitive restructuring, is to trust the data (e.g. to accept one's sensory experience) and revise or alter one's schema such that its predictions are more in harmony with what is observed. In such a case, it is said that meaningful learning occurs. This option manifests itself in student statements such as, "Oh! Now I get it" (understands the phenomena) or "I was wrong. It's not the weight but the volume that does it." The gleam in the eye of the learner is readily apparent when the light comes on (the insight is gained). It is of utmost importance to point out that the teacher cannot convey this insight through lecture. The student must construct it in the mind. The teacher cannot modify the student's cognitive structure, only the student can. The teacher can assist students with cognitive restructuring by placing them in situations which result in disequibration. The teacher cannot convey or transmit meaning. The teacher can only transmit

ords. Meaning must be created by the student.

The existence of the first option, intact schema, brings us to a third tenant of the constructivist theory. Cognitive structures are sometimes highly resistant to change, even in the face of observational evidence and/or formal classroom instruction to the contrary (Champagne et al., 1980; Linn, 1983; McDermott, 1984; Whitrock, 1985).

To help visualize the relationships among experience, schema, and meaningful learning, the interaction between ~~cognitive and sensory events is represented with a model~~ (see Figure 1). The model shows the interaction of the learner with the environment, i.e. the connections between the learner's cognitive universe (internal) and the physical universe (external). When the learner is engaged in the processes described in the example, the learner is said to be in a state of active cognitive involvement or the constructivist learning model is activated.

The connection between these two universes takes place through the sensory apparatus and associated neurological, physiological and biochemical mechanisms, in short, the apparatus through which the world around us is experienced. The flow of this sensory data into the structures of the mind is known as assimilation in Piagetian terminology; however, the model shows that when the learner's expectations (predictions) do not coincide with experience (measurements) the result is disequilibrium.

Disequilibrium can result in the modification of one's schema, e.g. the learner restructures his schema such that expectations are more in agreement with one's experience. This schema restructuring process is interpreted as meaningful learning. From this, it can be inferred that restructuring has occurred when learners verbalize phrases such as, "Oh, now I get it; it's not the weight of the brass and aluminum which determines the rise in water level, it's the volume."

In summary, learners construct knowledge through a psychologically active process. These knowledge structures are sometimes highly resistant to change. Finally, disequilibrating experiences can result in modification of these cognitive structures and hence give rise to increases in the learners understanding of the world.

A necessary condition for cognitive restructuring is an opportunity for repeated, exploratory, inquiry-oriented behaviors about an event or phenomena in order to realize that the intact schema option is no longer tenable, and that the only reasonable option is to revise one's cognitive structure so as to be more consistent with one's experience (data, measurements, or observations).

### Implications for Instructional Practices

What are the implications of the constructivist perspective for learning in the science classroom? Science learning is the acquisition of meaning, not the mere rote memorization of information, but rather cognitive restructuring in a direction such that one's internal world is more consistent with one's

empirical data about the external world. Such restructuring clearly implies that learners need abundant sensory experiences with their external world and opportunities for reducing disequilibrium. What are important features of effective science programs in light of the constructivist perspective? Four instructional features which stem directly from the constructivist perspective, have been shown by research to enhance meaningful learning, and are relatively easy to implement in science classrooms are presented below. The features are presented separately; however, in actual practice, they are interwoven in complex ways to create an environment designed to engender meaningful learning.

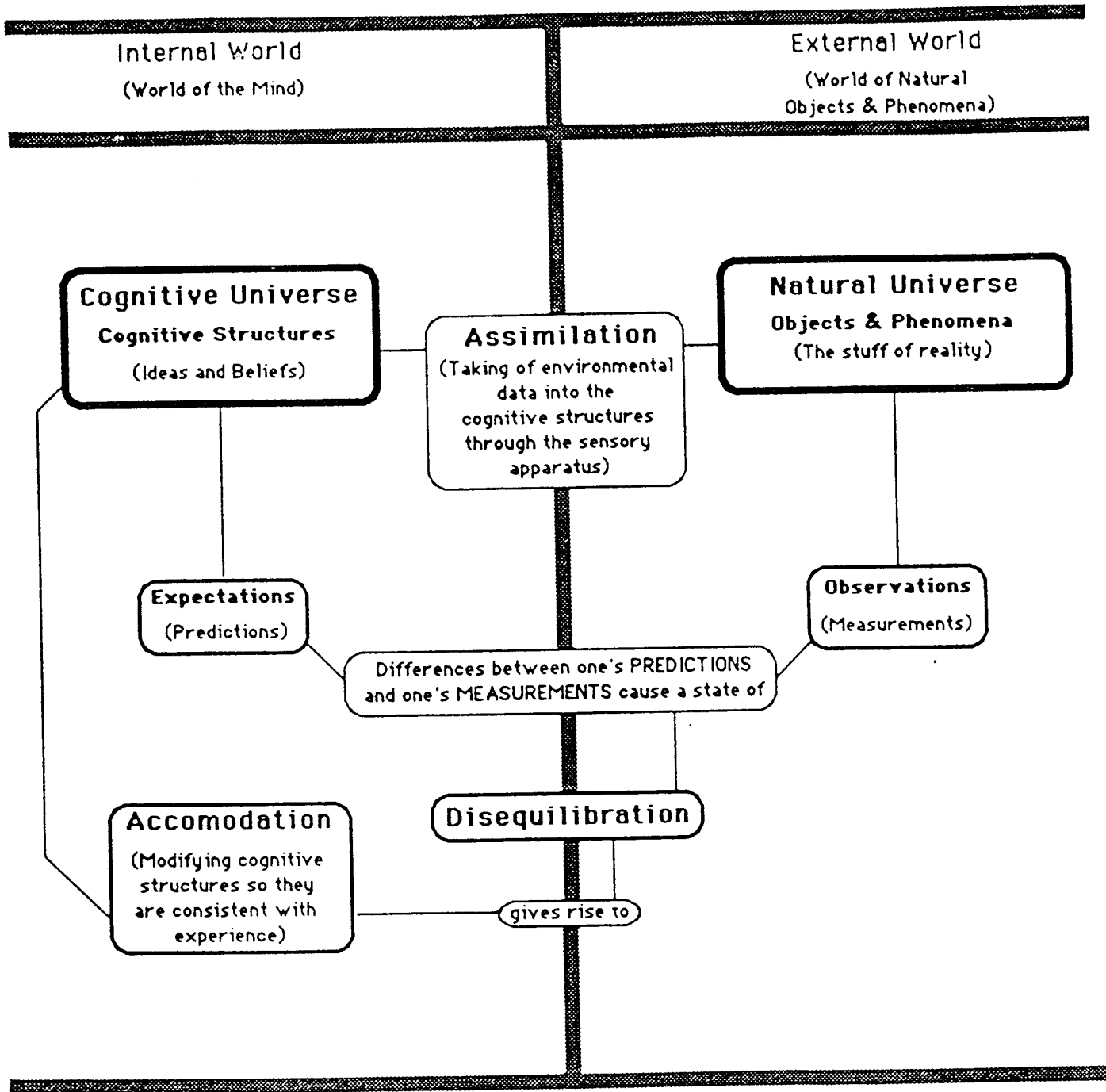
### Hands On, Investigative Labs

First hand, direct sensory experiences (hands on laboratory activities) provide opportunities for learners to experience for themselves (assimilate) the phenomena or materials under study and, as a result of disequilibrating experiences, to modify their schema so as to understand their sensory experiences. The use of manipulative activities has been shown to be far more effective in producing large gains in achievement than merely having students observe or read about a phenomena or event (Wise & Okey, 1983). It is important to note that not all laboratory activities are equally effective in bringing about meaningful learning. Laboratory instruction has long been examined from two points of view: (a) the traditional or verification lab and (b) the investigative or inquiry approach.

In the traditional approach, students are provided a handout, workbook, lab manual, or other printed materials containing the purpose of the experiment and detailed instructions for carrying it out. In this approach (commonly termed cookbook), both the design of experiment and the procedures for carrying it out have been thought out by someone other than the learner. In a sense, then, some of the cognitive work has been done for the student instead of by the student. If the student does not understand the purpose of the experiment, she or he will gain little or no understanding by merely carrying out a set of procedures often in a somewhat rote fashion (Burnett, 1939). When one queries students who are engaged in cookbook lab activities about what their purpose is, what they are learning about, or why they are conducting a particular procedure, they usually respond with, "I don't know" or "The teacher told us to do this." All too frequently, they are simply following instructions, step by step, in a cognitively very passive way, often attending to visual stimuli and conversational topics other than that of the laboratory activity. This passive, robot like mental activity is likely not to produce disequilibrating experiences. Students simply have not relied upon their existing schema's to generate expectations (a product of one's cognitive world) about their (external world) observations.

In the investigative or inquiry approach, the student must, of necessity, utilize her or his schema to formulate an expectation about what is likely to be observed. Further, if the student is

Figure 1. A constructivist learning model.



allowed some involvement in the design of the investigation, she or he must, again, of necessity, formulate a plan for measuring or observing the anticipated outcome. This plan evolves out of and is built upon his understanding of the situation (her or his internal world). This active cognitive involvement sets the stage for assimilation of the external environment and the consequent disequilibrium resulting from the differences in predictions

and measurements. Consequently, in the investigative or inquiry lab, the learner is much more likely to be immersed in an environment rich with opportunities that evoke disequilibrium and hence give rise to the potential for cognitive restructuring. These sorts of outcomes are clearly shown in Raghbir's (1979) study of investigative labs in high school biology as well as in several studies of the learning cycle

model of instruction (Purser & Renner, 1983; Saunders & Shepardson, 1987; Schneider & Renner, 1980; Sheehan, 1970).

inclusion of test items which activate higher level cognitive processes.

### Active Cognitive Involvement

A second feature of classroom environments which enhance meaningful learning is the opportunity for active cognitive involvement of learners. Cognitive activities such as thinking out loud, developing alternative explanations, interpreting data, participating in cognitive conflict (constructive argumentation about phenomena under study), development of alternative hypothesis, the design of further experiments to test alternative hypothesis, and the selection of plausible hypotheses from among competing explanations are all examples of learner activities which activate the constructivist learning model.

### Group Work

Students benefit from working in small groups, both in the conduct of investigations (hands-on lab activities) and in the development of explanations, interpretations, and conclusions about phenomena under investigation (active cognitive involvement). Small-group work tends to stimulate a higher level of cognitive activity among a larger number of students than does listening to lectures and thus provides expanded opportunities for cognitive restructuring.

### Higher-Level Assessment

Like it or not, many students are strongly motivated to learn what they need to know to pass the test or exam. Because many commercial and teacher made tests place a heavy emphasis upon lower-level knowledge, students often do not engage in higher-level learning. The more frequent use of quiz and test questions which tap higher-level cognitive abilities is a very important aspect of learning environments which help insure that students will be more actively involved in meaningful learning. If teachers incorporate suggestions one, two, and three above without utilizing four, there is a strong likelihood that student cognitive activity will remain at a low level, and meaningful learning is less apt to take place.

### Summary

The constructivist perspective holds that meaningful learning or understanding is constructed in the internal world of the learner as a result of her or his sensory experiences with the world (hence, it cannot be told to the student by the teacher) and, that while these understandings or schema tend to resist change, they can change as a result of disequilibrium. The implications for classroom instruction include the ample use of hands-on investigative laboratory activities, a classroom environment which provides learners with a high degree of active cognitive involvement, use of cooperative learning strategies, and the

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6/6

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