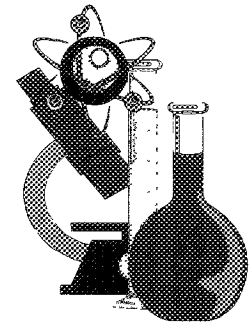

Constructivism: Science Education's "Grand Unifying Theory"

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People often see the teaching community as faddish—every year a different approach is "in." One decade "individualized instruction" is the way to go, and the next decade teachers are told to teach with "cooperative learning." In science education, discovery learning was popular in the 1960s, then came inquiry, then STS (science/technology/society). Today, inquiry and discovery are back again. In this article I try to make rhyme and reason of all these changes through the concept of constructivism. The strength of constructivism is that it unifies trendy teaching strategies. Many so-called fads in education turn out to have a firm, research-supported foundation in constructivist learning theory.

What Is Constructivism?

Constructivism has become a popular term in education circles during the last few years. In truth, the word currently has multiple meanings. It refers to a philosophical view about the nature of reality and perception, is a theory about how people learn, and—more and more often—represents an array of teaching strategies.

Constructivism as Philosophy

Constructivist philosophers are somewhat akin to idealist philosophers. Constructivists argue that we make (construct) our own world view and knowledge. To them, there is no certain way to know that observers are all observing the same things. Experiences and viewpoints, they argue, affect how everyone perceives the world; "reality" is a personal construction. What we hold to be true will be based on what "works" for us. For many constructivists, ideas are not held to be absolutely true or false—because there is no way to know if everyone's ideas about the nature of reality are congruent. Rather than talking about what is scientifically "true," constructivists talk about what is generally agreed upon by the majority of the scientific community.

Constructivism as Learning Theory

A number of people who view themselves as constructivists would not necessarily espouse the ideas in the previous paragraph. Rather, they consider constructivism to be an explanation about learning, or a set of teaching practices. As such, they do not believe one must adopt a particular philosophical position about the nature of reality as part of constructivism. This point has become rather controversial in some science education circles. The controversial aspects relate to the extent to which our perceived ideas of reality are affected by the times and cultures in which we live. For example, would reality be perceived differently by people living hundreds or thousands of years ago, in places where peoples' ideas about God, the devil, life, and death were all different from yours, even if they were observing the same situation as you today? (A discussion of the nuances of the debate here would only detract from my intent to explore the broad realms of constructivism; thus I will avoid explicit discussion throughout this article regarding philosophical positions about the nature of reality.)

Constructivism Applied to the Classroom

Constructivism posits that before coming to your class students have had a multitude of unique experiences. As such, individual students bring with them personal beliefs and knowledge about how the world works—that is, they have lots and lots of scientific ideas. However, some of these intuitively held ideas differ from those accepted by the scientific community.

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Some people express that point more bluntly: Students, they say, come to class with many *wrong* ideas about science. The key point, though, is that students are far from being "empty vessels" waiting to be filled with new knowledge. And, the knowledge they already have is difficult to change.

From the viewpoint of constructivist learning theory, then, science teaching involves trying to help students *change their beliefs* to be more in line with those held by the scientific community. Teaching is about helping students understand how and why scientifically accepted explanations explain and predict what will happen in a given situation better than their intuitive ideas. That view contrasts with the view that teaching is a matter of giving students knowledge and that learning consists of absorbing information.

This rather abstract notion calls for an example. Students graduating from M.I.T. were interviewed for the video series *Minds of Their Own*. The students are asked if they could light a flashlight bulb, given only the bulb, a battery, and a single piece of wire. Most students believe they can light the bulb by placing one end of the wire on the positive pole of the battery, and the other end of the wire on the light bulb's tip. The bulb, of course, does not light. A complete electrical circuit requires a connection from one end of the battery, through the bulb's filament, to the other end of the battery. Remarkably, these students' ideas mirror those of young children.

Why would students think something like this? Perhaps because the place most students have seen flashlight bulbs is in flashlights. And in a flashlight, one would notice the tip of the bulb touching an end of the battery. In addition, it makes sense (to most people) to think that the electrical energy would leave the battery, travel through the wire, and go up to the bulb's filament. This explanation makes sense and seems to work—except for several hours of science class(es) somewhere in students' lives. If the only evidence one has that does not support a firmly held idea is something heard in school, then it is quite easy to forget what was heard in school (as soon as the quiz is finished!).

Here is another example of students' misconceptions. In biology, evolution via natural selection is a central explanatory idea. And adaptation is a key concept in understanding evolution. In biology's history, for many years there was debate about whether Darwin's ideas or those of Lamarck were a better explanation for evolution. Today, of course, more people accept the ideas of . . . Lamarck! Yes, that's right—Lamarck. Let us take a look at the different explanations.

When asked why cheetahs can run so fast, most people respond by saying cheetahs evolved that way because it helps them catch their prey (or they need to run fast to catch prey). Similarly, if asked why certain fish that live deep under the ocean's surface in underwater caves no longer have eyes, people will respond by saying the fishes' eyes disappeared because they didn't need them anymore. These are small examples, but when probed about what they mean, students of all ages express similar beliefs: organisms adapt to their surroundings out of a sense of need. In other words, they are saying that adaptation is a directed activity—that organisms do not change randomly.

The currently accepted scientific belief (the position taken originally by Darwin), however, is that organisms do change (mutate) randomly and those changes that remain in a population—those naturally selected—ultimately help the organisms survive and reproduce.

Why would students hold the belief that organisms do not change randomly? A better question might be, why would they *not* think this? After all, lots of learning comes through the news they see on television or read in the newspaper. After a disaster, how often is it reported that the local people are adapting to their new lives without water, electricity, and other resources? Or stories about how people learn to adapt after losing a limb or similar physical change? In all these cases the word *adapt* is used to mean something different than the biological definition of the word. Students have science for an hour or less per day; during the other twenty-three hours of the day *adaptation* is defined as something that individuals do out of a sense of need. Is it any wonder that students would interpret the concept of adaptation similarly in a high school biology class?

Understanding Teaching and Learning through Constructivist Eyes

The question many science teachers would ask at this point is, "So, what should I do about my students' misconceptions?" We can begin to answer that question by thinking about what it takes to get someone to change his or her mind about a belief (a tall challenge!). For teachers, the task is made even harder with the added realization that we are talking about beliefs that students may not even be aware they hold. Generally speaking, though, getting students to change their minds involves three things:

- being sure the students are clear in their understanding of their own ideas,
- helping students understand the problems with their beliefs, and
- presenting alternate beliefs that work better for them personally. (Posner, Strike, Hewson, and Gertzog 1982, 211)

With this kind of framework in mind, it is easy to understand why research supports certain teaching strategies. What follows are examples of major recommendations and strategies (known perhaps as "fads" to the uninformed), along with their rationale and sug-

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gestions for implementation, as seen from a constructivist perspective.

1. We now have the National Science Education Standards, which define effective science teaching using constructivist tenets:

> The Standards call for more than "science as process," in which students learn such skills as observing, inferring, and experimenting. Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. *They identify their assumptions, use critical and logical thinking, and consider alternative explanations.* In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills. [emphasis added] (NRC 1996, 2).

The science education standards describe a classroom that probably includes hands-on activities, but activities that are neither cookbook nor confirmation-style laboratories. If students are simply following set procedures, they are not required to use or test their previous knowledge. Their ideas are not challenged. What is needed, instead, is a classroom where students are engaged occasionally in open-ended activity in which they try using their previous knowledge to answer questions. In doing so, they will sometimes begin to see flaws in their thinking and be more ready for alternative explanations. Open-ended activities also give teachers greater opportunity to speak to students, ask questions, and better understand their students' intuitive scientific ideas.

2. *Cooperative learning* hinges on a constructivist viewpoint. We see how valuable cooperative learning can be when students talk with each other about their ideas. Sometimes, simply trying to explain one's viewpoint to others is enough to cause learners to see problems with their explanations. Other times, other students can ask challenging questions or present alternate viewpoints. Challenging questions help people understand the flaws in their ideas, and if the questions come from peers they may be seen as less threatening than if they come from a teacher.

3. *Questions* and *wait time* in science class support constructivism. Questions are the major ways to find out what students think and to help stimulate their thinking in ways that lead to conceptual change. From a constructivist perspective, open-ended questions are particularly valuable. Statements or questions such as "Tell me about what you are thinking" or "What have you noticed?" are nonthreatening ways to get a better sense of how students understand a topic. The goal is to understand how students see the world so that the teacher can go on to challenge student misconceptions. Such questions, however, are not always easy for students to respond to. That's where wait time comes in. After asking a challenging question, the teacher needs to allow the student some time to think.

4. From the constructivist perspective, *demonstrations* are at their best when, again, they encourage students to think about their preconceived ideas or challenge those ideas. Two particular types of demonstrations are noteworthy:

- *Discrepant events.* In a discrepant event, results are different from those expected by many students. A common example is the demonstration introducing concepts of buoyancy in which students observe that a peeled orange sinks, whereas an unpeeled orange floats.[1] Students are challenged to explain what they see. Thinking is challenged.
- *Predictions.* When the teacher asks students to make predictions about what will happen *before* the event takes place, it forces students to access their previous knowledge. Seeing whether their predictions are accurate is a way for students to test their understandings. In addition, the teacher can also ask students, "Why do you think that will happen?" In that way the teacher gets a better understanding of how some students understand the phenomenon in question.

5. An in-depth discussion of the place for *lectures* and *textbooks* in a constructivist classroom would require a volume of its own. However, three overarching principles can guide practice. First, lectures and textbooks, by themselves, are ineffective ways to challenge or change student thinking about a topic. Second, lectures and texts are better suited for a time when students are aware of their ideas about a topic, and aware of problems with their ideas. In other words, lectures and texts will be most appropriate when students are ready for a new idea to replace their current ideas. Third, the best way for students to learn from lectures or texts is by actively relating what they are learning to other things.

6. *Assessment* is framed by constructivism. Assessment is traditionally thought of as comparing how students perform in terms of each other or a set standard, usually via multiple choice or other questions requiring relatively short student responses. That kind of assessment is important in any classroom. In addition to more classical forms of testing, though, students engaged in inquiry activities may be assessed other ways. The term *authentic assessment* generally refers to assessing students while they are doing noncontrived tasks, such as laboratory experiments, or are involved in other real-life problem-solving situations. Effectively assessing what, how, and why students are doing those things involves practices such as open-ended questions and grading students while they are working on an activity.

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Applying Constructivist Ideas to Real Classrooms

As educators, we must determine how to make the transition from classical instruction to instruction that makes good use of constructivist ideas. To be sure, it should be a gradual process. Often, neither teacher nor student is comfortable, familiar, or experienced with the kinds of teaching implied by the theory of constructivism. Making changes slowly, taking time to develop new skills, and giving students time to adapt (in a Lamarckian sense!) to new ways of being taught help ensure a smooth transition. Specifically, to make their classrooms more supportive of constructivism, science teachers should

1. provide lab activities before discussing the results students are expected to find;
2. discuss labs before lecturing on their topics;
3. remove lab data tables so that students generate or organize information;
4. change tests to require more concept application by students;
5. use a questioning strategy that encourages students to reveal what they're thinking;
6. have students invent the procedure to answer a lab question; and
7. put students into situations where groups debate, discuss, research, and share.

Taken together, the changes ultimately describe a classroom well in line with recommendations from the National Science Education Standards, as well as the science education community. Far from being faddish, the teaching practices supported by constructivism represent the best practices of science teachers since time immemorial!

NOTE

1. Although the inside of an orange is denser than water, the orange's peel is not. The orange with its peel is still less dense than water, and the orange floats. Students sometimes talk about the phenomenon with an analogy—they say the peel acts like a life preserver for the fruit inside!

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