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CHAPTER 4

Student Misconceptions in Biology

Achieving Understanding

A number of young children were given a log and asked, "Where does the weight of this dry log come from?" They responded, "from the sun, water, the soil, the seed. . ." Harvard and MIT graduates were then asked the same question. Their answers were largely the same as those offered by the youngsters. The university graduates were then asked, "What would you say to someone who said to you that the weight of the tree comes mostly from carbon dioxide in the air?" Among their replies were such comments as: "Really! I would wonder about that. I would wonder how that's possible." "I would disagree because this same volume of air would weigh much less unless it was highly compressed." "I'd say obviously, carbon dioxide is intimately involved in photosynthesis. I'd say carbon is not much of a building block from what I know of biochemistry." "I'd say that's very disturbing and I wonder how that could happen."

A middle school student, Jon, is given lessons about photosynthesis. After the lessons he knows the formula for photosynthesis by heart and is able to write it on the board. When asked what is in the dry log, he estimates that it contains about "70–75% water, and 25–30% other stuff, including bark and minerals from the soil." The interviewer asks if any of the carbon dioxide that goes into the leaves stays in the tree. Jon says, "Uh, maybe a little bit but not too much." His logic is that if oxygen and carbon dioxide had weight, we couldn't breathe; and if these gases have no weight, then carbon dioxide cannot possibly contribute to the weight of a tree.

The interviewer gives Jon a block of dry ice to hold with an asbestos glove and tells Jon that this is frozen carbon dioxide. Jon is very surprised as he realizes the block has weight. The interviewer asks what Jon thinks about the weight of CO₂ now. Jon concludes that solid carbon dioxide might have weight but gaseous CO₂ does not.

Excerpts from Schnepps, M. (1997b).

THE NATURE OF MISCONCEPTIONS

Among the most pervasive features of the terrain uncovered by the cognitive paradigm in science education is the presence among many students (in fact, probably among all people) of active misconceptions about natural events. The "blank slate" model of the mind postulated by Locke (Locke, 1891, 1996) encouraged the easy

assumption among educators that students receive instruction as if they were empty vessels, devoid of any ideas of their own.

In fact, we now know that students come to the classroom brimming with ideas about a great many issues and events in the natural world. People are constantly building mental models to make sense of the world around them. Unfortunately, a substantial number of these models are erroneous from the scientific point of view. For example, the common and persistent misconception that carbon dioxide cannot contribute to the weight of a tree has been extensively studied (Haslam & Treagust, 1987; Wandersee, 1984; Anderson, Sheldon & Dubay, 1990; Gravett & Swart, 1997). The identification and description of such naive ideas represents a major stream of activity in science education research.

Within the research community, a profusion of names has been suggested to refer to such conceptions, reflecting the dynamic and unsettled nature of the field. Many investigators prefer the designation 'alternative conceptions,' since it is value-neutral and demonstrates respect for student ideas. Other proposed names range from the simple — "naive ideas," "prescientific ideas," "preconceptions," and "conceptual primitives," to the complex — "limited or inappropriate propositional hierarchies" or LIPHS (Wandersee, Mintzes, and Novak, 1994). The present chapter prefers to adopt an eclectic approach in which varying terms are employed according to their nuances and context. The primary term employed here, however, remains "misconception," selected to underscore the cognitive transformation required in order to achieve the scientific view.

The discovery of the fertile field of students' conceptions suggests a modification to Ausubel's dictum (1963, 1968), "Ascertain what the student knows, and teach accordingly." With the recognition that what the student "knows" consists in part of ideas that conflict with scientific beliefs, Ausubel's admonition might more appropriately be stated, "Ascertain what the student misunderstands, and teach accordingly." This injunction, however, turns out to be more difficult to put into practice than it may at first appear to be.

The purpose of this chapter is to elucidate the nature of preconceptions, and to suggest ways in which mapping devices such as circle diagrams, concept maps, mind maps, and SemNet can be employed as a kind of bridge to enable students to make the transition to the scientific view.

Wandersee, Mintzes, and Novak (1994) have reviewed more than 3,000 studies of misconceptions in science. They distilled eight propositions that represent the consensus of investigators. These are summarized (in a different order from the original) and elaborated upon below.

First, learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events. To a large extent, these alternative conceptions are widely shared, often held by 20% or more of a given student population. Science teachers are largely unaware of the existence of these ideas in students' minds.

Second, the alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries. Many similar conceptions are found in students and in the general population worldwide.

Third, alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers. The fact that these naive conceptions are widely shared across both space and time is a tribute to their sensibility. They are logical conclusions drawn from limited data. Further, they underscore the point that many scientific ideas are counterintuitive. Scientific understandings represent hard-won insights into the workings of the world.

Fourth, alternative conceptions have their origins in a diverse set of personal experiences including direct observation and perception, peer culture and language, as well as in teachers' explanations and instructional materials. They are a product of active sense-making (see also Chapter 5).

Fifth, for the reasons described below, alternative conceptions are tenacious and resistant to extinction, especially by conventional teaching strategies. Where such conceptual conflicts are concerned, students often require compelling evidence – they truly need to be convinced. Simply being told is not sufficient reason for them to dismantle their well-established belief systems. The students' own ideas are so well established and so satisfying to them that they tend to be reluctant to replace them with scientific ideas. The scientific ideas may be rejected because they seem foreign, silly or unbelievable, as well as because of the emotional attachment students have to their own ideas. In other cases, the scientific ideas may be altered or misinterpreted so they can appear to be consistent with the student's ideas.

Sixth, to complicate matters further, teachers often subscribe to the same alternative conceptions as their students. As noted above, nonscientific conceptions are not limited to students; they are as natural to human beings as breathing. We all have them. They occur because most people, scientists included, do not employ the scientific method in their everyday efforts to make sense of the world. Nor do most people have access to the accumulated wisdom of every field. Humans simply draw the best conclusions they can on the basis of what is usually their limited knowledge.

Seventh, learners' prior knowledge interacts in profound ways with knowledge presented in formal instruction, resulting in a diverse set of unintended learning outcomes. Many teachers assume that "I told them, they heard me, therefore they know it." This, in fact, may be the most widespread misconception in education.

Eighth, instructional approaches that facilitate conceptual change are usually essential for replacing a resistant misconception with a scientific idea. Such approaches are generally difficult to discover and time-consuming to implement. But effective conceptual change strategies are at the heart of inquiry-based science teaching and constructivist learning. They are necessary if the American public is going to acquire even a modest degree of sophistication in scientific thought (see, for example, McComas, 1997).

In summary, alternative conceptions are not idiosyncratic or peculiar to individuals or groups of individuals. On the contrary, they are shared across age, gender, and culture, they appear regularly in the history of science, and they occur in the cognitive structures of many adults. Preconceptions are not arbitrary or random explanations for events, but rather represent a pattern of understanding that is plausible to the learner who is attempting to make sense of the world with limited knowledge.

The review by Wandersee, Mintzes, and Novak (1994) enables us to see the fundamental characteristics that are shared by misconceptions. Other resources which summarize research on misconceptions include Helms and Novak (1983), Champagne, Gunstone, and Klopfer, (1985), Novak (1987, 1993), and Pfundt & Duit (1994).

One positive aspect of misconception research is the attention it has brought regarding the absolute necessity for teachers and researchers to be well-grounded in both content knowledge and pedagogical content knowledge. That is, to be good at what they do, researchers and teachers must know at a deep level both the content being taught and the specific strategies useful for teaching that topic, known as pedagogical content knowledge or PKG.

It is also important to recognize that preconceptions are not exclusively obstacles to learning. Since preconceptions often have some predictive power in certain practical situations, Clement (1982a) suggests that they be thought of as zero-order models which can be modified with appropriate instructional strategies.

The fact that both useful prior knowledge and misconceptions exist in abundance is a reasonable and straightforward consequence of personal knowledge construction and strong verification of constructivist learning theory (Pope, 1982; West and Pines, 1985; Clement, 1982a; Collins & Gentner, 1982; von Glasersfeld, 1987; Fisher, 1991; Gunstone, 1994). Students are actively engaged in making sense of the world around them long before they arrive at the classroom door. If many of their ideas about natural processes are naive and contradictory to scientific ideas, that is merely indicative of the fact that the findings of science are often counterintuitive or otherwise not obvious. Indeed, if everything in nature were just as it first appears, science would hardly be necessary at all.

SOME EXAMPLES OF COMMON MISCONCEPTIONS IN BIOLOGY

Few biology faculty are aware of the obstacles their students face in trying to come to terms with even simple biology ideas. The vignette at the beginning of this chapter describes a well-studied misconception that is highly resistant to change – namely, the belief by many people that an invisible gas, carbon dioxide, cannot possibly contribute carbon to growing plants for making sugars, starches, and cellulose. The problem is that a great many people believe that gases have no weight because we cannot feel the air around us. This primitive belief interferes with the learning of many science ideas in addition to photosynthesis, such as changes of state, conservation of matter, and so on.

As another example, one of us (Fisher) finds that up to 20–25% of her college seniors every semester do not understand what makes up the bubbles in boiling water. They claim that the bubbles contain oxygen and hydrogen, or air, or sometimes a vacuum. Convincing the students that the bubbles contain water vapor is no easy task – again, telling is not enough. This conception comes from a lack of understanding of changes of state, conservation of matter, and also from the common belief that you can see water vapor, but when water evaporates it turns into an invisible gas and therefore is not water vapor.

A third example is the difficulty involved in understanding what it means to be alive (Stepans, 1985; Carey, 1987; Tamir, Gal-Choppin, & Nussinovitz, 1981; Brumby, 1982). Young children often think that plants are not living because they are not mobile, and many older students assume that such life forms as seeds are not alive.

DISCOVERING MISCONCEPTIONS

People who first read or hear about misconceptions imagine that they must come tumbling out of students' mouths in every classroom. If this were the case, students' naive conceptions would have been discovered long ago. On the contrary, several factors conspire to keep teachers from ever knowing what students are really thinking. First, students generally have implicit rather than explicit knowledge, meaning that they are not quite aware themselves what they are thinking or what assumptions they are making. Second, students are not encouraged to say what they are thinking in traditional classrooms, so that even when their knowledge is explicit, students learn to keep it to themselves. Third, the opportunities for students to express themselves in nonverbal ways in today's classrooms are severely limited, since so much testing is now multiple choice and short answer. And fourth, teacher-designed multiple-choice tests offer what the teachers consider to be valid distracters, not what the students think. Most naive conceptions are so far removed from the scientific view that it simply doesn't occur to most teachers to include such ideas in their test items.

Identifying and characterizing naive conceptions generally entails considerable effort. One of the most frequently used techniques for eliciting students' ideas is the clinical interview (Pines, Novak, Posner, & VanKirk, 1978; Osborne & Gilbert, 1980; Ericsson & Simon, 1984). Two other frequently used methods described in more detail below are concept maps and multiple choice tests which incorporate common misconceptions as item distracters. Other approaches have used sorting and word association tasks (Champagne, Gunstone & Klopfer, 1985) and computer simulations (Nachmias, Stavy & Avrams, 1990).

DISTINGUISHING MISCONCEPTIONS FROM OTHER ERRORS

There are many different kinds of cognitive errors such as a slip of the tongue (Brown & O'Neill, 1966), action slips (Norman, 1981), and information processing errors (Fisher & Lipson, 1985). These types of errors are usually easily corrected. As noted above, naive conceptions are set apart from these errors in that they are shared by a significant fraction of students; they are surprisingly resistant to being taught away (especially with traditional, didactic teaching methods); and they often appear in similar frequencies in classrooms around the world.

Resistance to change is their most pronounced feature and the one that is most troublesome to teachers. In many cases naive conceptions are so deeply embedded in an individual's conceptual ecology that contradictory information either bounces off or is modified to fit the preexisting theory. The cognitive upheaval that is necessarily



<http://www.springer.com/978-0-7923-6575-4>

Mapping Biology Knowledge

Fisher, K.; Wandersee, J.H.; Moody, D.E.

2002, V, 217 p., Hardcover

ISBN: 978-0-7923-6575-4