CHAPTER 1

HOW DO PEOPLE LEARN?

1. INTRODUCTION

Years ago while teaching junior high school math and science, two events occurred that made a lasting impression. The first occurred during an eighth grade math class. We had just completed a chapter on equivalent fractions and the students did extremely well on the chapter test. As I recall, the test average was close to 90%. The next chapter introduced proportions. Due to the students' considerable success on the previous chapter and due to the similarity of topics, I was dumbfounded when on this chapter test, the test average dropped below 50%. What could have caused such a huge drop in achievement? The second event occurred during a seventh grade science class. I cannot recall the exact topic, but I will never forget the student. I was asking the class a question about something that we had discussed only the day before. When I called on a red-haired boy named Tim, he was initially at a loss for words. So I rephrased the question and asked again. Again Tim was at a loss for words. This surprised me because the question and its answer seemed, to me at least, rather straightforward, and Tim was a bright student. So I pressed on. Again I rephrased the question. Surely, I thought, Tim would respond correctly. Tim did respond. But his response was not correct. So I gave him some additional hints and tried again. But this time before he could answer, tears welled up in his eyes and he started crying uncontrollably. I was shocked by his tears and needless to say, have never again been so persistent in putting a student on the spot. However, in my defence, I was so certain that I could get Tim to understand and respond correctly that it did not dawn on me that I would fail. What could have gone wrong?

Perhaps you, like me, have often been amazed when alert and reasonably bright students repeatedly do not understand what we tell them, in spite of having told them over and over again, often using what we believe to the most articulate and clear presentations possible, sometimes even with the best technological aids. If this sounds familiar, then this book is for you. The central pedagogical questions raised are these: Why does telling not work? Given that telling does not work, what does work? And given that we can find something that does work, why, in both psychological and neurological terms, does that something work? In short, the primary goal is to explicate a theory of development, learning and scientific discovery with implications for teaching mathematics and science. The theory will be grounded in what is currently known about brain structure and function. In a sense, the intent is to help teachers better understand effective teaching methods as well as provide both psychological and neurological level explanations for why those methods work.

We begin with a brief look at three alternative views of how people learn. This will be followed by a discussion of initial implications for higher-order cognition and for math and science instruction. Chapter 2 will introduce neural network theory with the intent of explaining learning in neurological terms. Subsequent chapters will expand on these and related ideas in the context of math and science instruction and in the context of scientific discovery.

2. EMPIRICISM, INNATISM AND CONSTRUCTIVISM

An early answer to the question of how people learn, known as *empiricism*, claims that knowledge is derived directly from sensory experience. Although there are alternative forms of empiricism espoused by philosophers such as Aristotle, Berkeley, Hume and Locke of Great Britain, and by Ernst Mach and the logical positivists of Austria, the critical point of the empiricist doctrine is that the ultimate source of knowledge is the external world. Thus, the essence of learning is the internalization of representations of the external world gained primarily through keen observation. *Innatism* in its various forms stands in stark opposition to empiricism. Innatism's basic claim is that knowledge comes from within. Plato, for example, argued for the existence of innate ideas that "unfold" with the passage of time. For a more modern innatist view see, for example, Chomsky and Foder (in Piattelli-Palerini, 1980). A third alternative, sometimes referred to as *constructivism*, argues that learning involves a complex interaction of the learner and the environment in which contradicted self-generated behaviors play a key role (cf., Piaget, 1971a; Von Glasersfeld, 1995; Fosnot, 1996).[1] What are we to make of these widely divergent positions? Consider the following examples.

Van Senden (in Hebb, 1949) reported research with congenitally blind adolescents who had gained sight following surgery. Initially these newly sighted adolescents could not visually distinguish a key from a book when both lay on a table in front of them. They were also unable to report seeing any difference between a square and a circle. Only after considerable experience with the objects, including touching and holding them, were they able to "see" the differences. In a related experiment, microelectrodes were inserted into a cat's brain (Von Foerster, 1984). The cat was then placed in a cage with a lever that dispensed food when pressed, but only when a tone of 1000 h2 was produced. In other words, to obtain food the cat had to press the lever while the tone was sounding. Initially the electrodes indicated no neural activity due to the tone. However, the cat eventually learned to press the lever at the correct time. And from that point on, the microelectrodes showed significant neural activity when the tone sounded.

1 A philosophical examination of alternative forms of constructivism can be found in Matthews (1998). Discussion of some of these alternatives will be saved for Chapter 11. For now it suffices to say that the present account rejects extreme forms of constructivism that in turn reject or downplay the importance of the external world in knowledge acquisition.

In other words, the cat was "deaf" to the tone until the tone was of some consequence to the cat! In more general terms, it appears that a stimulus is not a stimulus unless some prior "mental structure" exists that allows its assimilation.

What about the innatist position? Consider another experiment with cats. In this experiment one group was reared in a normal environment. Not surprisingly, cells in the cats' brains became electrically active when the cats were shown objects with vertical lines. Another group was reared to the same age in an artificial environment that lacked vertical lines. Amazingly, the corresponding cells of these cats showed no comparable activity when they were shown identical objects. Thus, in this case at least, it would seem that the mere passage of time is not sufficient for the cat's brain cells to become "operational," i.e., for their mental structures to "unfold."

Next, consider a human infant learning to orient his bottle to suck milk. Jean Piaget made several observations of his son Laurent from seven to nine months of age. Piaget (1954, p. 31) reports as follows:

> From 0:7 (0) until 0:9 (4) Laurent is subjected to a series of tests, either before the meal or at any other time, to see if he can turn the bottle over and find the nipple when he does not see it. The experiment yields absolutely constant results; if Laurent sees the nipple he brings it to his mouth, but if he does not see it he makes no attempt to turn the bottle over. The object, therefore, has no reverse side or, to put it differently, it is not three-dimensional. Nevertheless Laurent expects to see the nipple appear and evidently in this hope he assiduously sucks the wrong end of the bottle.

Laurent's initial behavior consists of lifting and sucking whether the nipple is properly oriented or not. Apparently Laurent does not notice the difference between the bottom of the bottle and the top and/or he does not know how to modify his behaviour to account for presentation of the bottom. Thanks to his father, Laurent has a problem. Let's return to Piaget's experiment to see how the problem was solved.

On the sixth day when the bottom of the bottle is given to Laurent ".... he looks at it, sucks it (hence tries to suck glass!), rejects it, examines it again, sucks it again, etc., four or five times in succession" (p.127). Piaget then holds the bottle out in front of Laurent and allows him to simultaneously look at both ends. Laurent's glare oscillates between the bottle top and bottom. Nevertheless, when the bottom is again presented, he still tries to suck the wrong end. The bottom of the bottle is given to Laurent on the 11th, 17th, and 21st days of the experiment. Each time Laurent simply lifts and sucks the wrong end. But on the 30th day, Laurent "...no longer tries to suck the glass as before, but pushes the bottle away, crying" (p. 128). Interestingly, when the bottle is moved a little farther away, "...he looks at both ends very attentively and stops crying" (p. 128). Finally, two months and ten days after the start of the experiment when the bottom of the bottle is presented, Laurent is successful in first flipping it over as he "...immediately displaces the wrong end with a quick stroke of the hand, while *looking beforehand* in the direction of the nipple. He therefore obviously knows that the extremity he seeks is at the reverse end of the object" (pp. 163-164).

Lastly, consider a problem faced by my younger son when he was a 14-month old child playing with the toy shown in Figure 1. Typically he would pick up the cylinder

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