ON THE NATURE OF NAÏVE PHYSICS

STELLA VOSNIADOU

National and Kapodistrian University of Athens, Greece

Abstract The argument will be advanced in this paper that naive physics is neither a collection of unstructured knowledge elements nor a collection of stable misconceptions that need to be replaced, but rather a complex conceptual system that organises children's perceptual experiences and information they receive from the culture into coherent explanatory frameworks that make it possible for them to function in the physical world. The process of learning science appears to be a slow and gradual one during which aspects of the scientific information are added on to the initial explanatory framework destroying its coherence until (and if) it is restructured in ways to make it consistent with currently accepted scientific views.

1. INTRODUCTION

Researchers in science education and cognitive science seem to agree that naive physics exerts a great deal of influence on the way new information is understood and science concepts are acquired, but disagree on how to characterize the exact nature of naïve physics. What kinds of knowledge elements naive physics consists of, how is it organized, and how does it develop? This disagreement has important implications for the teaching of science. Are there persistent misconceptions that represent relatively stable and internally consistent beliefs that interfere with the teaching of science, or is it the case that naïve physics consists of a multiplicity of knowledge pieces that are mainly unstructured and unsystematic? And, is the process of knowledge acquisition in science a process that increases the systematicity of initially fragmented pieces of knowledge or a process of replacing stable and resistant misconceptions with currently accepted scientific theories?

In this paper we will try to outline a different theoretical framework within which this debate can be reframed. We will argue that children start the knowledge acquisition process by organizing the multiplicity of their sensory experiences under the influence of everyday culture and language into narrow but coherent explanatory frameworks that are different from the currently accepted science. Naïve physics thus does not consist of a collection of unstructured knowledge elements or of stable misconceptions but constitutes a complex system that includes perceptual information, beliefs, presuppositions, and mental representations. This knowledge

M. Limón & L. Mason (Eds.), *Reconsidering Conceptual Change. Issues in Theory and Practice*, 61-76.

system represents children's attempts to organize their perceptual experiences and information they receive from the culture into coherent explanatory frameworks. The process of learning science appears to be a slow and gradual one during which elements of the scientific theory become assimilated to the initial explanatory framework destroying its coherence and creating synthetic models. This is the case because currently accepted scientific explanations and concepts have evolved over thousands of years of scientific discovery to become rather elaborate, counter-intuitive theories that differ in their structure and in the phenomena they explain from initial explanations of the physical world based on everyday experience.

In the pages that follow we will describe the misconceptions and knowledge in pieces positions in greater detail. We will continue by discussing the theoretical framework we have developed. An empirical study investigating the development of the meaning of the term *force*[1] will be presented to provide an example of conceptual change as we see it. We will argue that the results of this study add further evidence to those earlier conducted in our lab (Vosniadou, 1994; Vosniadou and Brewer, 1992, 1994) in showing that from an early age children organize their physical experiences in narrow but coherent explanatory frameworks. During development, we observe neither a sudden change from an impetus misconception to Newtonian physics nor the gradual development of more coherent and systematic networks of knowledge. Rather, information received through instruction seems to become assimilated to the initial explanatory framework creating synthetic or internally inconsistent models.

2. THE "MISCONCEPTIONS" VERSUS "KNOWLEDGE IN PIECES" POSITIONS IN SCIENCE EDUCATION

The proposal that the learning of science involves the replacement of persistent misconceptions has its roots in the work of science educators like Novak (1977), Driver and Easley (1978), Viennot (1979) and McCloskey (1983a, 1983b). They were among the first to pay attention to the fact that students bring to the science learning task alternative frameworks, preconceptions, or misconceptions that are robust and difficult to extinguish through teaching. Misconceptions are defined as student conceptions that produce systematic patterns of error. Misconceptions can be the result of instruction or they may originate prior to instruction. Posner, Strike, Hewson and Gertzog (1982) drew an analogy between Piaget's concepts of assimilation and accommodation and the concepts of "normal science" and "scientific revolution" offered by philosophers of science such as Kuhn (1970) and derived from this analogy an instructional theory to promote "accommodation" in students' learning of science. The work of Posner et al. (1982) became the leading paradigm that guided research and practice in science education for many years.

[1] *This study is based on a dissertation submitted by Christos Ioannides and is reported in detail in C. Ioannides and S. Vosniadou, Exploring the Changing Meanings of Force, Cognitive Science Quarterly (in press).*

Smith, diSessa, & Rochelle (1993) have criticized the misconceptions position on the grounds that it presents a narrow view of learning that focuses only on the mistaken qualities of students' prior knowledge and ignores their productive ideas that can become the basis for achieving a more sophisticated mathematical or scientific understanding. Smith et al (1993) argue that misconceptions should be reconceived as faulty extensions of productive knowledge, that misconceptions are not always resistant to change, and that instruction that "confronts misconceptions with a view to replacing them is misguided and unlikely to succeed" (p. 153). Other research has shown that it is very difficult to identify internally consistent misconceptions in mechanics and kinematics in high school or college students who had little exposure to formal physics (e.g. Ranney, 1994)

diSessa (1988; 1993) has put forward a different proposal for conceptualizing the development of physical knowledge. He argues that the knowledge system of novices consists of an unstructured collection of many simple elements known as phenomenological primitives (p-prims for short) that originate from superficial interpretations of physical reality. P-prims appear to be organized in a conceptual network and to be activated through a mechanism of recognition that depends on the connections that p-prims have to the other elements of the system. According to this position, the process of learning science is one of collecting and systematizing the pieces of knowledge into larger wholes. This happens as p-prims change their function from relatively isolated, self-explanatory entities to become pieces of a larger system of complex knowledge structures such as physics laws. In the knowledge system of the expert, p-prims "can no longer be self-explanatory, but must refer to much more complex knowledge structures, physics laws, etc. for justification (diSessa, 1993, p. 114).

We appreciate the efforts of diSessa (1993) and Smith et al (1993) to provide an account of the knowledge acquisition process that captures the continuity one expects with development and has the possibility of locating knowledge elements in novices' prior knowledge that can be used to build more complex knowledge systems. We also agree that we need to move from single units of knowledge to systems of knowledge that consist of complex substructures that may change gradually indifferent ways. Finally, we agree with Smith et al's (1993) urge to researchers to "move beyond the identification of misconceptions" towards research that focuses on the evolution of expert understandings and particularly on "detailed descriptions of the evolution of knowledge systems over much longer durations than has been typical of recent detailed studies (p. 154).

In the last few years we have been involved in a program of research that attempts to provide detailed descriptions of the development of knowledge in specific subject-matter areas mainly of the physical sciences, such as astronomy (Vosniadou and Brewer, 1992; 1994; Vosniadou 1994; 1998), mechanics (Ioannides and Vosniadou, in press; Megalakaki, Ioannides, & Vosniadou, & Tiberghien, 1997), geophysics (Ioannidou & Vosniadou, in press) chemistry (Kouka, Vosniadou & Tsaparlis, in press), and biology (Kyrkos & Vosniadou, 1997).

The above-mentioned studies are all cross-sectional developmental studies investigating the knowledge acquisition process in subjects ranging from 5 to 20 years of age. We have also used the results of our research to develop curricula and instruction that has been tried in schools in Greece (see Vosniadou et al., in press). The results of these studies show that young children answer questions about force, matter, heat, the day/night cycle, etc. in a relatively consistent way revealing the existence of narrow but coherent explanatory frameworks. These explanatory frameworks are usually different in their structure, in the phenomena they explain, and in their individual concepts from the scientific theories to which children are exposed through instruction.

The position we have been developing is similar in many respects to the views developed by Carey (1985), according to which even very young children form "theories" that embody causal notions, allow distinct types of explanations and predictions, reflect basic ontological commitments, and are subject to modification and radical revision. In our work (Vosniadou, 1994; 2000), we have used the term "framework theory" to refer to the conceptual system that young children form to interpret their observations about the physical world, as well as their interpretations of the information provided by the culture. The term "theory" is used relatively freely to denote an explanatory system with some coherence. Unlike Gopnik (1996) it is assumed that this system differs in many respects from a scientific theory. It lacks the systematicity of a scientific theory as well as other characteristics of scientific theories such as their abstractness, and social/institutional nature. It is also assumed that children differ from scientists in important ways, for example in the strategies they use to evaluate evidence (e.g., Kuhn, Amsel, & O'Loughlin, 1988), or in that they lack metaconceptual awareness of their naive theories, and therefore do not seek to verify or falsify them.

While this kind of developmental research has so far concentrated on very young children, the research we have pursued investigates older children and young adults as well, in an effort to find out what happens after they are exposed to systematic science instruction in school settings. Our results show that in the process of learning science, children add or delete beliefs and presuppositions to their explanatory frameworks destroying their coherence, while at the same time distorting the scientific concepts to which they are exposed.

More specifically, we assume that in physics children's initial explanatory framework (their "framework theory") consists of certain basic ontological and epistemological presuppositions about the nature of physical objects and the way they function in the physical world. Some of the ontological presuppositions are that physical objects are solid and stable, that space is organized in terms of the directions of up and down and that unsupported objects fall in a downward direction. Children also seem hold certain epistemological presuppositions, such as that rest is the natural state of inanimate objects and motion needs to be explained, and that entities such as force, heat and weight are properties of physical objects.

Children's continuing observations and the information they receive from the culture are interpreted under the constraints of presuppositions such as the above to create specific explanations of phenomena. For example, as shown in Figure 1, there can be various specific explanations of the day/night cycle such as that the sun goes behind the mountains, or that the sun goes down to the other side of the earth. These specific explanations are embedded within the above-mentioned explanatory framework because the earth is considered to be a physical object (as opposed to an astronomical object), and thus to be constrained by all the presuppositions that apply to physical objects in general. In other words, children assume that on the earth space is organized in terms of the directions of up and down and gravity works in an up/down direction. These presuppositions can stand in the way of children's understanding of the spherical shape of the earth and of the earth's axis rotation, which in turn are necessary for understanding the scientific explanation of the day/night cycle.

It could be argued here that our attempts to explain conceptual change are similar to the explanations proposed by Chi and her colleagues (Chi, 1992; Reinner et al., 2000). Chi argues that misconceptions arise when a person associates the wrong ontology with a scientific concept, such as *force* or *heat*. She notes that many concepts in physics are wrongly associated with a *substance* ontology when in fact they belong to a *process* (or *acausal*) ontology. Chi seems to believe that conceptual change is a radical process that happens in a short period of time.

There are, however, important differences between our position and the one put forward by Chi and her colleagues. Unlike Chi, Vosniadou (1994) argues that conceptual change does not happen suddenly but is a gradual and time consuming process. This is the case because we are dealing with a complex knowledge system that consists of a network of beliefs or presuppositions that take a long time to change. We agree with Chi and her colleagues that conceptual confusions often arise in science learning from the assignment of scientifically incorrect ontological presuppositions to concepts such as force, heat, the earth, etc. However, ontological change is only one of the many kinds of changes that need to take place in the process of changing theories. Furthermore, we believe that Chi's theoretical framework does not provide an adequate account of the nature of ontological categories and their development. There is no theory about where ontological categories come from, how they develop, how new ontological categories are formed and why, etc. In our theoretical framework we try to account for how children slowly construct the explanatory framework within which their observations about the physical world are interpreted (see also Vosniadou, 1994; 1998). Information from infancy studies substantiates our claims that children start from very young to organize their perceptual experiences in conceptual structures, such as the concept of the physical object (e.g., Spelke, 1991). Ontological and epistemological presuppositions are attached to these conceptual structures. Perceptual information, as well as beliefs, and mental representations also constrain the knowledge acquisition process.

Our position is not inconsistent with the view that something like diSessa's p-prims constitute an element of the knowledge system of novices and experts. We believe that p-prims can be interpreted to refer to the multiplicity of perceptual and sensory experiences that are obtained through our observations of physical objects and our interactions with them. In the conceptual system we propose, diSessa's p-prims would take the place of the perceptual information obtained through observation. These perceptual experiences provide the basis for forming beliefs, presuppositions, and mental models. The proposal that the conceptual system consists of different kinds of knowledge elements (such as beliefs, presuppositions and mental models) is also consistent with diSessa's proposal that we need to focus

http://www.springer.com/978-1-4020-0494-0

Reconsidering Conceptual Change: Issues in Theory
and Practice
Limón, M.; Mason, L. (Eds.)
2002, XX, 420 p., Hardcover
ISBN: 978-1-4020-0494-0