ON THE NATURE OF NA VE PHYSICS

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Abstract

The argument will be advanced in this paper that na ve 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 na ve 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 na ve 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. Na ve 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 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

[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).

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.

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, & D' 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.

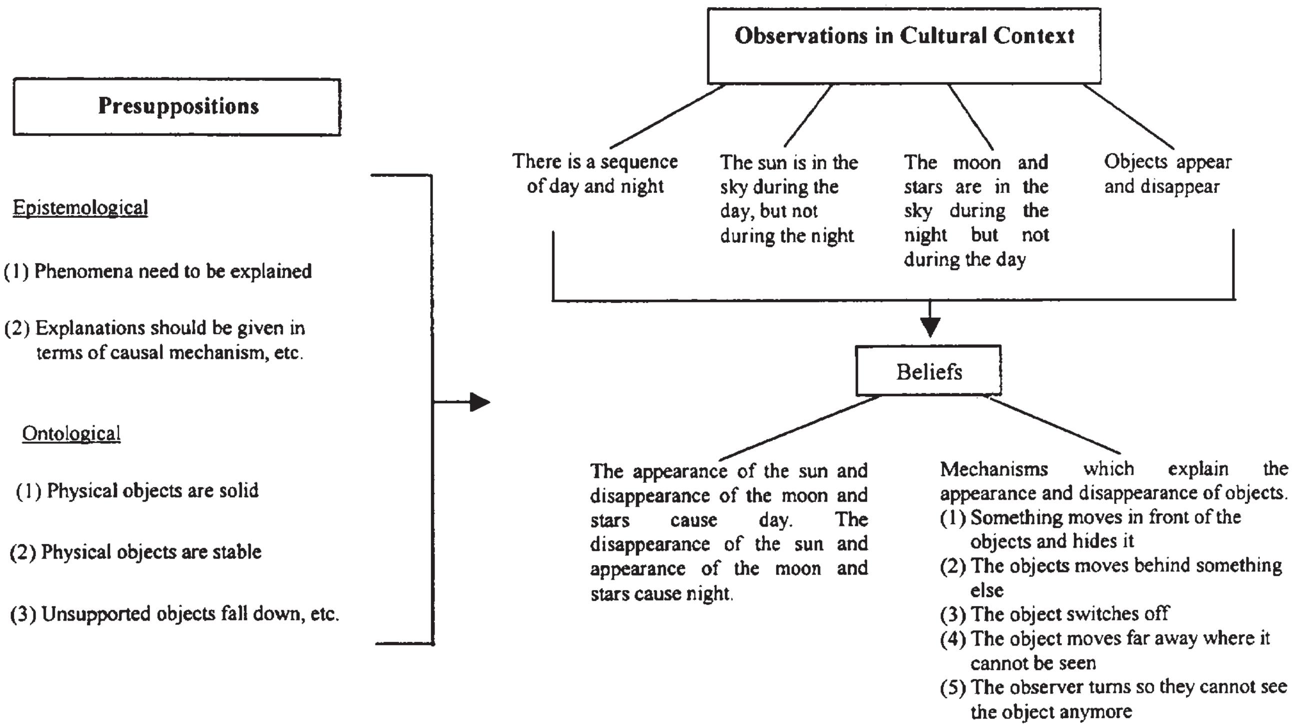
More specifically, we assume that in physics children's initial explanatory framework (their "framework theory") consists of certain basic ontological and epistemological presuppositions about the nature of physical objects and the way they function in the physical world. Some of the ontological presuppositions 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 our 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 Vosnidou 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

Figure 1: Hypothetical Conceptual Structure Underlying Children's Initial Explanations of the Day/Night Cycle



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 not on single conceptions but on rich knowledge systems that are composed of many constituent elements.

The main difference between the present proposal and that of diSessa is in our views of development. It appears that diSessa believes that p-prims are basically unstructured or loosely organized in the conceptual system of the novice. It is through instruction and exposure to the scientific theory that p-prims lose their self-explanatory status and become organized in larger theoretical structures such as physical laws. According to diSessa this change in the function of p-prims is a major change from "intuitive to expert physics".

In our view, to the extend that knowledge elements such as p-prims could be postulated to operate in our conceptual system, they become organized in knowledge structures much earlier on than diSessa believes. If this is so, the process of learning science is not one of simply organizing the unstructured p-prims into physics laws but rather one during which they become re-organised into a scientific theory. This is a slow, gradual process, precisely because we are dealing with many knowledge elements.

One could argue that our position is really not very different from the traditional misconceptions position criticised by Smith et al (1993). But this is not the case. Our position meets all the criticisms of Smith et al (1993). First, we are not describing unitary, faulty conceptions but a knowledge system consisting of many different elements organized in complex ways. Second, we make a distinction between initial explanations prior to instruction and those that result after instruction and which we call synthetic models. Synthetic models are not stable but dynamic and constantly changing as children's developing knowledge systems evolve. Finally, our theoretical position is a constructivist one. It can explain how new information is built on existing knowledge structures and provides a comprehensive framework within which meaningful and detailed predictions can be made about the knowledge acquisition process.

In the pages that follow we will report the results of a study that investigated the development of the meaning of the term *force*.

3. THE DEVELOPMENT OF THE MEANING OF *FORCE*

If the arguments made earlier are correct, then the development of the *meaning of force*[2] should start with a small number of relatively coherent interpretations of *force* revealing aspects of the explanatory framework within which the meaning of *force* is embedded. In the process of learning science these initial meanings should change as aspects of the scientific theory are assimilated into the framework theory creating *synthetic meanings* (or misconceptions). This prediction is very different from what the knowledge in pieces hypothesis would predict. If naive physics is fragmented then we should see increasing systematicity and coherence in the development of the meanings of *force* after instruction. Before continuing, it should be mentioned here that the study was conducted in the Greek language and that in Greek there is only one word – dynamis – that is used as an equivalent for the two English words *force* and *strength.*

The subjects of this study were all Greek students ranging in age from 4 to 16 years. In individual interviews they were asked to answer verbally a 27 items questionnaire developed after extensive pilot work. The questionnaire is shown in Table 1. Simple questions inquired about the existence of *forces* on simple objects in various kinetic states (stationary or moving). The comparison questions asked children to compare *forces* applied in situations that differed in some critical respect (i.e., in the size of objects being compared, the size of the people pushing the objects, etc.). Questions about *force* were phrased either using the scientific form "Is there a *force* exerted on the x? Why?" (group I) or the colloquial form "Is there a *force* on the x? Why? " (group II)[3]. Analysis of the data revealed no statistically significant differences between these two groups and therefore the data were collapsed into one set. All results mentioned in this paper are made on the basis of the combined data from both group I and group II.

[2] We refer to the "meaning of force" rather than the "concept of force" because the present study investigated students' interpretations of the term force. There are different psychological theories regarding the meaning of words (semantic feature or network theories, image theories, etc). We have adopted the position that the meaning of a term such as force can be best thought of as a "theory" consisting of an interconnected set of beliefs and presuppositions. The Meaning of the term force may be only part of the concept of force.

[3] The kindergarten children were asked the questions in the colloquial form only, because they did not understand the scientific form. All the other children were divided in two groups, one group received the simple question, in the scientific form and the other in the colloquial.

Table 1a: The Questionnaire Used in the ***Force*** *Study-Simple Questions*

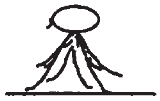
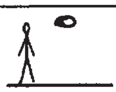
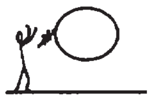
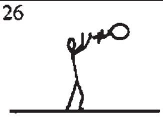
Simple questions: *Group I*: Is there a force exerted on the stone/balloon? Why? *Group II*: Is there a force on the stone/balloon? Why?			
Set I: Stationary objects			
Question 1  The stone is standing on the ground	Question 2  The stone is standing on the ground	Question 3  The balloon is standing on the ground	Question 4  The balloon is standing on the ground
Set II: Stationary objects being on the top of a hill			
Question 5  The man is pushing the stone	Question 6  The man is pushing the stone	Question 7  The man is pushing the balloon	Question 8  The man is pushing the balloon
Set III: Stationary objects being on the top of a hill			
Question 11  The stone is standing on the top of a hill, but is not stable. If someone pushes it will fall down	Question 12  The stone is standing on the top of a hill, but is not stable. If someone pushes it will fall down	Question 13  The balloon is standing on the top of a hill, but is not stable. If someone pushes it will fall down	Question 14  The balloon is standing on the top of a hill, but is not stable. If someone pushes it will fall down
Set IV: Falling objects			
Question 18  The stone is falling to the ground	Question 19  The stone is falling to the ground	Question 20  The balloon is falling to the ground	Question 21  The balloon is falling to the ground
Set V: Objects that have been thrown by a man			
Question 23  The man threw this stone	Question 24  The man threw this stone	Question 25  The man threw this balloon	Question 26  The man threw this balloon

*Table 1b: The Questionnaire Used in the **Force** Study-The Comparison Questions*

<table>
<tr><td colspan="6">Comparison questions:
Group I: -Is there a force exerted on these stones? (If "no" of "force exerted only on one of the stones":)-Why? (If "yes":) –Is there the same force exerted on these stones? (If "same":) –Why (If "different":) –Which of the two forces is greater? Why?
Group II: -Is there a force on these stones? (If "no" of "force only on one of the stones":)-Why? (If "yes":) –Is there the same force on these stones? (If "same":) –Why (If "different":) –Which of the two forces is greater?</td></tr>
<tr><td colspan="3">Set II: Stationary objects which are pushed by a human agent

Question 9 

The same man is trying to move two different stone. The first stone is greater than the second. He cannot move neither the first nor the second stone</td><td colspan="3">Question 10 

A man and a child are trying to move two similar stones. Neither the man nor the child can move the stone</td></tr>
<tr><td colspan="2">Set III: Stationary objects being on the top of a hill

Question 15 

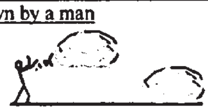
These two stones are similar. The first stone is standing on the top of a hill, but it is not stable. If someone pushes will fall down. The other stone is standing on the ground</td><td colspan="2">Question 16 

These two stones are similar. Each of them is standing on the top of a hill. The first hill is higher than the second. Neither stone is stable. If someone pushes them they will fall down</td><td colspan="2">Question 17 

These two stones are similar. Each of them is standing on the top of a hill. The hills are of the same height. The first stone is not stable. If someone pushes it will fall down. The second stone is very stable.</td></tr>
<tr><td colspan="6">Set IV: Falling objects

Question 22 

These two stones are similar. The first stone is falling to the ground. The other stone is standing on the ground.</td></tr>
<tr><td colspan="6">Set V: Objects that have been thrown by a man

Question 27 

These two stones are similar. The man has thrown the first stone, which is moving in the air. The other stone is standing on the ground</td></tr>
</table>

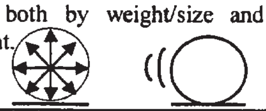
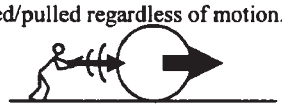
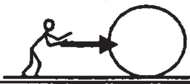
Based on previous work in this area, it was hypothesized that *force* would be interpreted as a property of physical objects and that it may be related to an object's weight and size (Piaget, 1972). Much of recent science education research has shown that the currently accepted Newtonian framework for *force* is very difficult to be acquired and that there is a persistent misconception according to which *force* is related to the movement of inanimate objects (e.g., Nersessian & Resnick, 1989, Osborne & Freyberg, 1985, Clement, 1996, Ministrel, 1982). Based on this prior work, it was hypothesized that the students in the present study would also find it difficult to understand the currently accepted scientific interpretation of *force*. More specifically was hypothesized that *force* would be related to movement, and that various other *synthetic meanings of force* (or *combinations of meanings)* may be created.

Vosniadou and Brewer (1992,1994) have argued that when children are exposed to science instruction, they assimilate aspects of this instruction that are inconsistent with prior knowledge to their existing mental representations, forming *synthetic meanings*. It was therefore expected that as children would start receiving systematic instruction on the Newtonian theory, they would construct synthetic meanings of *force*, although we were not exactly clear about the exact form these meanings would take.

Children's responses to the questions were scored twice: first for the questions comprising each of the five sets of questions (question set level, QSL) and second for all the questions combined (overall level, OL). At the first level, students' responses to each set of questions were scored as a group, on the basis of a scoring key containing a set of categories for each set of questions. Following the scoring at the set of questions level, we tried to see if we could find evidence in the data for the consistent use of a small number of explanatory structures or meanings of *force* by the individual subject in our sample. The scoring at this, overall level, was done on the basis of a second scoring key which outlined the pattern of expected responses for each meaning. Agreement between two independent judges who used the scoring key to score all the responses was high (between 90% and 95%). All disagreements were resolved after discussion.

The results of the second scoring revealed that the majority of the students were systematic and internally consistent in responding to our questions. It was possible to explain the responses given by 88.6% of the students by assuming that they were consistent in using one out of a small number of meanings of *force*. These meanings of force appear in Table 2.

Table 2: Meanings of Force as a Function of Grade

Models	Kind/ garten	4th grade	6th grade	9th grade	Total
1. INTERNAL FORCE: There is an internal force within objects affected by weight/size only. 	7 (46.7%)	4 (13.3%)	- (0%)	- (0%)	11 (10.5%)
2. INTERNAL FORCE AFFECTED BY MOVEMENT: There is an internal force within objects affected both by weight/size and by position/movement. 	2 (13.3%)	2 (6.7%)	- (0%)	- (0%)	4 (3.8%)
3. INTERNAL and ACQUIRED FORCE: There is an internal force affected by weight/size and/or position. In addition there is an acquired force within moving objects only. 	4 (26.7%)	10 (33.3%)	9 (30%)	1 (3.3%)	24 (22.9%)
4. ACQUIRED FORCE: There is an acquired force within moving objects only. 	- (0%)	5 (16.7%)	11 (36.7%)	2 (6.7%)	18 (17.1%)
5. ACQUIRED FORCE and FORCE OF PUSH/PULL: There is an acquired force within moving objects. There is a force exerted on all objects being pushed/pulled regardless of motion. 	- (0%)	- (0%)	5 (16.7%)	10 (33.3%)	15 (14.3%)
6. FORCE OF PUSH/PULL: There is a force only on objects being pushed/pulled regardless of motion. 	- (0%)	- (0%)	- (0%)	1 (3.3%)	1 (1%)
7. GRAVITATIONAL and OTHER FORCES: Force of gravity. Force of push/pull when objects are being pushed/pulled. Acquired force when objects are moving 	- (0%)	3 (10%)	1 (3.3%)	16 (53.3%)	20 (19%)
8. Mixed	2 (13.3%)	6 (20%)	4 (13.3%)	- (0%)	12 (11.4%)
Total	15 (14,3%)	30 (28.6%)	30 (28.6%)	30 (28.6%)	105 (100%)

The observed meanings can be grouped in two categories: Those that appear to be based on everyday experience and show no influences from the scientific theory, and those that have been influenced by the scientific theory. Following Vosniadou and Brewer (1992, 1994) we will call the first group of meanings "initial" and the later "synthetic". There were no meanings of *force* in the present sample that showed a complete understanding of the scientific concept of force.

There seemed to be two initial meanings of force: *internal force* and *acquired force*. As was mentioned earlier the majority of the kindergarten children (46.7%) used the *internal force meaning* according to which *force* is exerted either on all objects because they have weight, or only on "heavy or big objects"[4]. There was also an additional interpretation according to which there is more *force* exerted on heavier objects. In all these interpretations, *force* is conceptualised as an internal property of physical objects and is considered to be affected only by their weight and/or size. We hypothesize that children interpret observations such as that big/heavy people/objects can cause damage on other people/objects, or can resist the push/pull of other objects, and relate these descriptions to the presence of *force*. It appears that the meaning of *force* for these children is closer to what is expressed by the word *strength*.

As shown in Table 2, between the ages of 8 to 12, the *internal force meaning* is replaced by the *acquired force* meaning. In the *acquired force* meaning the criterion for deciding whether a *force* has been exerted or not, is *movement.*[5] The students talk about objects being pushed or pulled by agents but they do not assign a *force* to them unless they move. The *acquired force* meaning, which is the most stable interpretation of *force* in the students in our sample, is similar to the "internal motor" idea of *force* reported by Piaget (1972), to the "*force* of mass" reported by Viennot (1979), and to the "impetus" notion reported by McCloskey (1983), Clement (1982), and diSessa (1988).

The finding that the great majority of the younger children used one of two well defined initial meanings of *force* (or one of two combinations of them as will be discussed later), in a logically consistent way, supports the view that they are guided by an explanatory framework.

The presence of the combined meanings *internal force affected by movement* and *internal and acquired force*, provide a great deal of information regarding the process of conceptual change, and more specifically, regarding the emergence of the *acquired force* meaning from the original *internal force* theory. It appears that children become sensitive to movement and the relationship between movement and *force* early on[6], but have difficulty explaining this relationship. In the context of the *internal force* meaning, the natural interpretation of the movement of an inanimate object is to consider it as "weakness", i.e., as failure of this object to resist to the push/pull of other objects, and thus to lack of *force*, or less *force*. This is exactly the

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[4] This is a qualitative not a quantitative understanding of "heavy" or "big".

[5] In this study only inanimate objects were used, than we can say that this change of meaning applies to the inanimate objects. We do not know what happens in the case of animate objects.

[6] About half of the kindergarten children were placed in one of these two synthetic meanings (see Table 2).

interpretation of movement present in the meaning *internal force affected by movement*. From the point of view of the *acquired force* meaning, however, the movement of an inanimate object is, of course, an indication that a *force* is being exerted. So, from this point of view, the *acquired force* can be conceptualized as an additional force that is combined with the *internal force* to produce greater force. This is the interpretation of movement present in the synthetic meaning *internal and acquired force*. This interpretation of *force* was a very popular one not only with kindergarten children but also with 4th and 6th grade children as well.

However, there is an internal inconsistency that characterizes the synthetic *internal and acquired force meaning*. If we think of an object that has been set in motion by an agent as having an *acquired force*, such an object cannot be thought of as having an *internal force* also, because if it did, the agent should not have been able to move it (following the logic of the argument given by the children placed in the *internal force* meaning). It is maybe the realization of the internal inconsistency implicit in this synthetic attempt that this synthetic meaning is eventually abandoned in favor of the *acquired force meaning*. It is not uncommon in the developmental literature to have cases where conceptual change occurs from the need to solve internal inconsistencies (e.g., Vygotsky, 1962; Karmiloff-Smith, & Inhelder, 1974).

In the *acquired force meaning, force* has been differentiated from *weight*, at least in the case of inanimate objects. So, inanimate objects may have weight as an internal property, but *force* is an acquired property related to the push/pull of a (usually animate) agent, when that push/pull causes the inanimate object to move. Again, cases of differentiation of two concepts from a parent concept have been reported by Piaget (1972) and Smith, Carey & Wiser (1985), while similar phenomena have also been observed in the history of science (Kuhn, 1977).

It is also very interesting to observe that most of the children placed in the mixed category did so because they were caught between *the internal* and *acquired force meanings* and were unsure about how to interpret movement. Ten of the twelve children placed in the mixed category sometimes interpreted movement in the context of the *internal force meaning* - as an indication of "less" *internal force* - and sometimes in the context of the *acquired force meaning* - as an indication for the application of an external *force* (see Table 14 that presents all cases of inconsistency obtained).

While the first four meanings of *force* do not show an influence of the Newtonian theory presented through instruction, the remaining three do show such an influence. As in the case of astronomy studies conducted earlier (Vosniadou & Brewer, 1992; 1994) these synthetic meanings result from the assimilation of scientific information into the existing explanatory framework, which in the present case is the *acquired force meaning*.

The students who used the *acquired force and force of push/pull* meaning interpreted *force* as an acquired property of moving inanimate objects but added to it the *force* of *push/pull* (in the case where an animate agent was shown to exert a *push/pull force*). These students show some progress towards the scientifically accepted meaning, to the extend that they interpret the push/pull action of an animate agent as *force* exerted, (regardless of whether the push/pull results in the movement of the affected object or not). This meaning is synthetic because the *force of push/pull* is added to the existing *acquired force meaning*. Moreover, the *push/pull force* does not appear to be conceptualized in ways consistent with the scientific theory (*force* as interaction between two objects), but in ways that show a confusion between *force*, *effort*, and *internal strength or energy*[7].

Finally, another synthetic meaning is the *gravitational and other forces* meaning. The *gravity meaning of force* starts to appear first in the case of falling objects (Question 22) and thrown objects (Question 27 - with *acquired force*) and then generalizes to stationary objects as well. In the majority of the responses in our sample, gravity was mentioned as a *force* that operates both in the case of moving and of stationary objects, except in the case of push/pull. It appears that in the later case children focus on the push/pull action and forget about gravity.

In summary, it appears that children start with a meaning of *force* which is not differentiated from weight (*force* as an internal property of big/heavy objects). This meaning is spontaneously replaced by a different meaning according to which *force* is the acquired property of objects that move (*acquired force* meaning). The *acquired force* meaning is well in place in the conceptual system of the 11-12 year old child (6th grader) and is not substantially changed through instruction until the age of 15 (9th grade). Under the influence of instruction, children add the *force of push/pull* and the *force of gravity* to the already existing *acquired force* meaning creating various synthetic meanings.

4. CONCLUSIONS

The results of the present study add further support to the arguments made by Vosniadou (1994) and Vosniadou and Brewer (1992, 1994) that children construct a narrow but coherent explanatory framework that guides the process of acquiring knowledge about the physical world from early on. The great majority of the younger children in this study, were consistent in their interpretations of the situations where they thought *force* was exerted. Overall, a small number of meanings of *force* were obtained. All these meanings of *force* were constrained by the underlying presupposition that *force* is a property (inherent or acquired) of physical objects. This is similar in many respects to the finding by Reiner, Slotta, Chi and Resnick (in press) that naive conceptions of force are tied to the notion that force is a property of material substances (see previous discussion about the differences between the two positions, however)

The results of the present study add to the existing literature showing that there is considerable conceptual change happening in childhood (in biology-Carey, 1985; Hatano & Inagaki, 1987; Keil, 1989; Springer & Keil, 1989; in the nature of matter - Smith, Carey & Wiser, 1985; in heat and temperature- Wiser, 1987; in astronomy- Vosniadou & Brewer, 1992; 1994). Unlike our previous studies in astronomy, where the observed changes in the concept of the earth and in explanations of the day/night

[7] See Megalakaki, Ioannides, Vosniadou, & Tiberghien, (1997).

cycle were the product of instruction, the finding of the present study show that considerable change can happen prior to the beginnings of systematic instruction. More specifically, the change from the *internal force* to the acquired *force* meaning of *force* can be conceptualised as spontaneous conceptual change. The meaning of *acquired force* is a different explanatory framework for interpreting the situations where *force* has been exerted, than that of *internal force*. It is a different explanation, addressed to different phenomena (e.g., the motion of inanimate objects), and where the individual concepts have been radically modified (differentiation between *force* and *weight*). Nevertheless, this conceptual change still happens in the context of an explanatory framework where *force* continues to be categorized as a *property* of physical *objects*.

The effects of instruction, while considerable, do not succeed in producing radical changes in the established *acquired force meaning*. The results of the present study show that the meanings of *gravitational force* and *force of push/pull* are added on to the existing explanatory framework, destroying its coherence and distorting the scientific concept. This finding is consistent with the argument that the knowledge acquisition process starts with the formation of a relatively coherent, but narrow explanatory framework which, however, fails to be replaced by another coherent explanatory framework after instruction. Instruction in Newtonian mechanics is assimilated into the dominant *acquired force meaning*, creating synthetic meanings or internally in consisted (mixed) interpretations of *force*.

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