Chapter 12

Conceptual Change in Physics and Physics-Related Epistemological Beliefs: A Relationship under Scrutiny

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Introduction

There is a diversity of theoretical and conceptual approaches to the construct of 'epistemological beliefs.' This is reflected by the fact that the construct is assigned different terms in the literature, such as personal epistemology, epistemic beliefs, ways of knowing, epistemological perspectives, epistemological reflection, epistemological thinking, epistemological theories, epistemological resources, etc. This diversity indicates that what we call 'epistemological beliefs'[1] may not be the same in all relevant studies, or at least, that the boundaries of the construct may differ (Hofer & Pintrich, 1997; Pintrich, 2002). As Pintrich points out,

> the key issue concerns what should be considered as the core or essence of personal epistemology and what should be left out of the definition or considered as related but distinct constructs. (Pintrich, 2002, p. 390)

The present chapter draws on the more conventional definition of epistemology, as the study concerning "the nature and limits of claims to know" (Harre, 2002), and suggests that personal epistemological beliefs cluster in two general areas: the nature of knowledge, including structure and stability of knowledge, and the nature of the process of knowing, including source and justification of knowing (see also Hofer & Pintrich, 1997). We consider personal epistemological beliefs as individually held *theory-like* structures, namely, systems of beliefs that are nonetheless interconnected (see also Hofer & Pintrich, 1997).

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[1] We have decided to keep the term epistemological beliefs, since this is widely used by researchers in the field, until there is some consensus on a new terminology.

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This theoretical position is in line with the conceptual change approach adopted here, and suggests that personal epistemology forms initially a narrow but relatively coherent set of beliefs regarding the nature of knowledge and the process of knowing, which is based on the limited range of children's initial experiences and information they receive from lay culture. This set of beliefs becomes gradually more differentiated as experience and/or cultural information accumulates, gradually changing some beliefs, but not others, and connecting them to different contexts of use. It should be mentioned that the term *theory-like* is used to denote an explanatory structure that can generate explanations and predictions, but which, unlike a scientific theory, is not explicit, well formed or socially shared. It is assumed that most individuals are not metaconceptually aware of their epistemological beliefs.

The *theory approach* to epistemological beliefs adopted in the present study can be seen as a bridge between the *developmental approach* (according to which epistemological beliefs form a rather coherent, developmental structure that does not allow for within-stage of development variation (e.g., Baxter Magolda, 1992; Belenky, Clinchy, Golberger, & Tarule, 1986; King & Kitchener, 1994; Kuhn, 1991; Perry, 1998)), and the *multidimensional approach* (according to which personal epistemology is a system of rather orthogonal, uncoordinated dimensions, that are more or less independent, developing not necessarily in synchrony (e.g., Schommer, 1990, 1994; Schommer, Crouse, & Rhodes, 1992)). Conceptualizing epistemological beliefs as theory-like structures helps us understand better how they can be acquired and changed, how they can influence individuals' learning in areas such as physics, and how it is possible to have different epistemological beliefs in different disciplines (Buehl, Alexander, & Murphy, 2002), since it allows for general and domain-specific beliefs to co-exist in an interconnected network (see also Hofer, 2000; Hofer & Pintrich, 1997), which is nonetheless contextually bound.

Regardless of the conceptual and theoretical approach to the construct, changes in epistemological thinking have always been conceptualized as involving an 'upward' movement from dualistic/absolutist and objectivist views to more and more relativist, subjectivist, contextual, constructivist, and evaluative perspectives of knowledge and knowing (Hofer, 2002; Hofer & Pintrich, 1997; Pintrich, 2002). In this context, physics-related epistemological beliefs have been seen to change in a variety of specific ways. Songer and Linn (1991) focus on what they call 'productive science views.' According to their suggestion, scientific knowledge is a dynamic, socially constructed set of ideas, that progresses through either evolutionary or even revolutionary changes in perspective and, therefore, it is controversial, particularly in periods preceding discoveries, and is relevant to the lives of individuals and societies. Smith, Maclin, Houghton, and Hennessey (2000), following Carey and Smith (1993), describe the preferred, constructivist, epistemology of science as

> an epistemology in which students are aware of the central role of ideas in the knowledge acquisition process and of how ideas are developed and revised through a process of conjecture, argument and test. (Smith et al., 2000, p. 350)

Driver, Leach, Millar, and Scott (1996) think that the more complex and presumably more mature epistemological views are characterized by 'model-based reasoning.'

According to this view, students must understand that scientific inquiry involves evaluation of theories in light of new evidence, and that there may be multiple explanatory models, involving theoretical entities that cannot be observed. Also, description is clearly differentiated from explanation. Finally, other researchers emphasize that students' views about the nature of scientific knowledge and knowing are strongly influenced by context (see also Elby & Hammer, 2001; Leach, Millar, Ryder, & Sere, 2000). We will use the term 'constructivist epistemology' to refer to a set of epistemological beliefs that have more or less the contextual, constructivist, and evaluative characteristics described above, having, however, in mind, that the context-dependence of epistemological beliefs challenges the across-context generalizations about the nature of knowledge and knowing.

A constructivist personal epistemology is positively related to skills and attitudes important for learning. Previous studies have demonstrated the relationship of the construct with comprehension, learning, academic performance, and conceptual change. For example Ryan (1984), following and extending the work of Perry (1998), investigated the effect of epistemological development on comprehension and metacomprehension. He found that students who are relativists in their beliefs about knowledge, i.e., who perceive knowledge as context dependent, are more successful in comprehension monitoring and tend to use high-level comprehension strategies, as opposed to dualists (who perceive knowledge as factual, right or wrong). The latter are more likely to study for recall of facts from texts. Beliefs concerning the structure of knowledge, that is, considering knowledge as an accumulation of discrete, concrete, knowable facts, have been found to be related to poor text comprehension in such areas as the social and physical sciences. They have also been found to affect the comprehension and related problem solving of statistical text in a negative way (Schommer, 1990; Schommer et al., 1992). Beliefs concerning the stability/certainty of knowledge, that is, viewing knowledge as unchanging, attaining/approximating absolute truth, have been found to negatively affect the interpretation of controversial evidence (Kardash & Scholes, 1996) and tentative text (Schommer, 1990).

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Epistemological Beliefs and Physics Understanding

There is some empirical evidence that supports the position that a constructivist physics epistemology facilitates physics understanding. Songer and Linn (1991) found that secondary students who viewed science as a dynamic process of developing and changing ideas, and also considered interpretation and integration of ideas as strategies that facilitate learning, were more likely to understand concepts in thermodynamics and to integrate them around scientific principles, than students who viewed science as an accumulation of true and unchanging facts. Qian and Alverman (1995) investigated the influence of secondary students' epistemological beliefs on learning counter-intuitive science concepts from a refutational text (Newton's first law vs. the 'impetus' theory). Their results showed that epistemological beliefs were strongly related to what they call 'conceptual change learning' regarding projectile motion. More specifically, the students who believed in simple-certain knowledge and quick learning were less likely to change their positions on projectile motion after reading an expository refutational text, compared to the students who viewed knowledge as complex and evolving and learning as a time-consuming process.

In our previous work we investigated the relationship between Greek secondary school students' physics-related epistemological beliefs and physics understanding (Stathopoulou & Vosniadou, 2006). The beliefs of 394 Greek 10th-grade students were measured through a specially designed paper and pencil questionnaire, the Greek epistemological belief evaluation instrument for physics (GEBEP). The results revealed four dimensions underlying students' beliefs: *structure of knowledge*, *construction & stability of knowledge*, *attainability of truth*, and *source of knowledge*. In a subsequent study we selected 38 students with the highest scores in all the dimensions underlying the GEBEP (the constructivist epistemological beliefs group) and 38 students with the lowest scores (the less-constructivist epistemological beliefs group). These 76 students were administered a reliable instrument for measuring their conceptual understanding of Newtonian dynamics, the force and motion conceptual evaluation instrument (FMCE) (Thornton & Sokoloff, 1998). The design of the FMCE is based on results received by the extant science education research on students' 'misconceptions.' FMCE has been administered to many thousands of secondary and university students in the US. It has also been used extensively in our research lab with secondary and university physics students in Greece. Thus, substantial information is available that allows us to know, on the basis of the students' performance on this test, when they can be said to have understood Newton's three laws, in other words, to have achieved conceptual change regarding force and motion.

The results showed that beliefs regarding the nature of physics knowledge and the process of knowing are related to conceptual change in physics. More specifically, students' epistemological beliefs concerning the *structure* as well as the *construction and stability of physics knowledge* were found to predict high scores in the FMCE, suggesting a deep understanding of Newtonian dynamics. Furthermore, the results showed that only the students in the constructivist epistemological beliefs group achieved a deep conceptual understanding of Newtonian dynamics. As shown in Figure 12.1, only 11 students out of

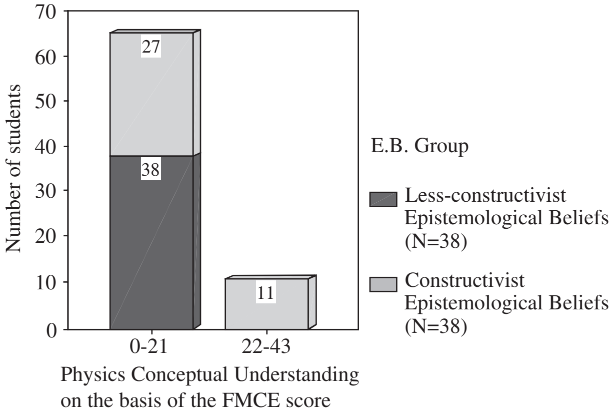

Figure 12.1: Only 11 students, all of whom were found to hold constructivist physics-related epistemological beliefs, were found to secure high scores on the force and motion conceptual evaluation (FMCE) instrument.

the 76 were found to have high scores in the FMCE and all of these students had constructivist physics-related epistemological beliefs. We have interpreted these results to suggest that a constructivist physics epistemology may be a necessary, although not sufficient, condition for conceptual change in dynamics (Stathopoulou & Vosniadou, 2006).

In a third study, we studied three 10th-grade students in the context of a computer supported collaborative learning (CSCL) environment[2] implemented in the instruction of Newtonian dynamics (Mol, Stathopoulou, Kollias, & Vosniadou, 2003). These three students had strong less-constructivist beliefs regarding the source of knowing in physics, which limited their ability to a more effective use of the CSCL environment. For example, they believed that they should rely on the authority of the teacher to tell them which was the correct answer and, as a result, they had great difficulty resolving inconsistencies and disagreements by themselves through argumentation. Their epistemological beliefs prevented them from relying on themselves and developing the more reflective approach necessary in order to resolve, in a principled way, differences of opinion regarding physics knowledge.

Why may Epistemological Beliefs Facilitate Conceptual Change?

In their influential model of conceptual change as a rational process, Posner, Strike, Hewson, and Gertzog (1982), suggested four conditions[3] for a successful conceptual change to take place in the learner's *conceptual ecology*. The term *conceptual ecology* was used to describe the learner's existing interrelated networks of concepts that influence the selection of a new concept playing a central and organizing role in thought. Among these, personally held 'epistemological commitments,' namely, assumptions or views concerning the nature of knowledge and knowing were considered as playing an important role. In a 'revisionist' approach of the initial overtly rational model of conceptual change, Strike and Posner suggested that "motives and goals and their institutional and social sources need to be considered" (1992, p. 162) as well, in attempting to describe a learner's evolving *conceptual ecology* and understand the construct's impact on conceptual understanding.

The need to incorporate variables of motivational and affective character, such as personal beliefs and attitudes,[4] into models of conceptual change is stressed by cognitive/developmental psychologists who also go beyond an approach that emphasizes the overtly rational nature of conceptual change (e.g., Pintrich, Marx, & Boyle, 1993; Pintrich, 1999; Dole & Sinatra, 1998; Gregoire, 2003; Sinatra, 2005). Hofer and Pintrich (1997) suggested that epistemological beliefs functioning as implicit theories interacting with the educational context can influence academic achievement indirectly by affecting goal orientation. In other words, epistemological beliefs can give rise to certain types of learning goals, such as mastery, performance, and completion goals, which in turn, can function as guides for cognitive and metacognitive strategy use.

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[2] The research was performed as part of the European Project ITCOLE (http://www.euro-cscl.org/site/itcole)

[3] That is, dissatisfaction with the current concept and also the ineligibility, plausibility, and fruitfulness of the new concept.

[4] For example, beliefs about the nature of knowledge, and knowing, beliefs about learning, about the role of self as learner, goal orientation, motivation to engage in academic tasks, interest/values.

The conceptual change approach adopted in this study considers that, in many cases, the construction of a scientific concept, such as the concept of force, requires students to radically reorganize prior knowledge (Carey, 1985, 1992; Vosniadou, 1999, 2002, 2003; Vosniadou, in press). This is the case, because by the time they are exposed to systematic science instruction, students have already constructed an initial *naïve physics* based on their everyday observations and cultural experience. This *naïve physics* is very different from the scientific theories to which they are exposed at school and can stand in the way of learning physics. We explain the phenomenon of 'misconceptions' observed in physics classrooms, at all levels of education, as resulting from students' attempts to add the new, to-be-acquired information to an incompatible knowledge base, thus forming *synthetic models* (Ioannides & Vosniadou, 2002; Vosniadou, 1999, 2002). We believe that conceptual change is a slow and gradual process that not only involves cognitive factors but is also influenced by motivational and affective variables, such as personal beliefs and attitudes, as well as by the physical and social/cultural environment (Dole & Sinatra, 1998; Pintrich, 1999; Sinatra, 2005; Vosniadou, 2002, 2003).

According to our theoretical position, physics-related epistemological beliefs can influence the knowledge acquisition process directly or indirectly, just like ontological presuppositions and other beliefs of a motivational and affective character can do. They can influence both the kinds of new information that is picked up from the physical and socio-cultural context and the way in which this information is interpreted (Vosniadou, 1994, 2002, 2003; Vosniadou & Brewer, 1994). For example, beliefs in simple and/or certain knowledge may affect the learning process directly by focusing students' attention on factual information, while beliefs in complex and/or evolving knowledge may cause students to focus more on patterns of relationships and their change over time. Figure 12.2 presents a skeletal theoretical framework for conceptualizing the relationship between physics-related epistemological beliefs and physics conceptual understanding.

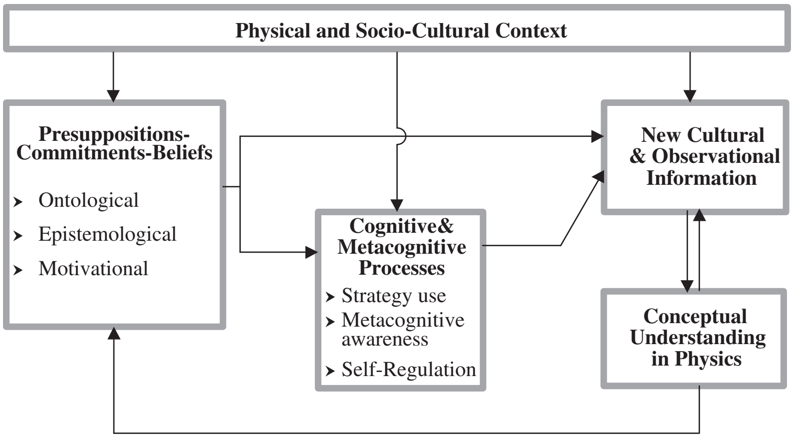

Figure 12.2: A skeletal theoretical framework for conceptualizing the relationship between (physics-related) epistemological beliefs and physics conceptual understanding.

Epistemological, ontological, and motivational beliefs may also affect students' achievement indirectly, by influencing students' learning goals, study strategies, and self-regulation, as discussed earlier. For example, the belief in simple knowledge may lead to the selection of rehearsal strategies to strengthen memorization and recall of piecemeal factual information. The skeletal framework presented in Figure 12.2 is based on prior work by Vosniadou regarding conceptual change in physical science (e.g., Vosniadou, 1994, 2003), and also takes into consideration some current suggestions about the role of motivational and affective as well as social/cultural variables (Pintrich, 1999; Pintrich et al., 1993; Strike & Posner, 1992).

A Case Study: How do Study Strategies Intervene?

In the pages that follow we present preliminary results from a case study which attempted, through in-depth interviews, think-alouds, and observations, to understand the indirect effect of physics-related epistemological beliefs on physics understanding. The in-depth interviews were administered to 10 students, who were selected out of the 76 students in the Stathopoulou and Vosniadou (2006) study that investigated the relationship between physics-related epistemological beliefs and physics understanding. These 10 students were selected on the basis of their scores in the GEBEP, as well as in theFMCE. Five of the students had high scores in all dimensions underlying the GEBEP and also high scores on the FMCE, thus comprising the group of students who were considered to hold constructivist physics epistemologies and to have achieved an in-depth understanding of physics. In contrast, the remaining five had low scores in all dimensions underlying the GEBEP and also low scores on the FMCE, thus comprising the group of students considered to hold less-constructivist physics epistemologies and to have poor/superficial physics understanding.

It was hypothesized that the approach to learning and studying adopted by the students, that is, deep vs. superficial (e.g., Entwistle, this volume; Entwistle & Tait, 2000), and the related selection of study strategies, may intervene in the relationship between personal physics-related epistemological beliefs and conceptual change in physics. More specifically, we hypothesized that a constructivist physics personal epistemology is more likely to guide students to the adoption of a deep approach to studying, and therefore, to facilitate physics understanding, than a less-constructivist epistemology. Of course, the relationship between personal epistemology and physics understanding is likely to be a reciprocal one. As students develop a deeper understanding in physics their personal physics-related epistemologies would be likely to change. On the basis of these hypotheses, the five students who were found to score high on both the GEBEP and the FMCE were expected to adopt a deep approach to studying, as opposed to the remaining five students, with low scores on both the GEBEP and the FMCE, who were expected to adopt a superficial approach to studying.

Following Entwistle (e.g., Entwistle, this volume; Entwistle & Tait, 2000), a deep approach to learning and studying involves goals of personal making of meaning, and accordingly, deep strategy use, such as integration of ideas, looking for patterns and underlying principles, examining in detail evidence and logic, and monitoring of understanding. It also involves metaconceptual awareness, that is, awareness of one's own beliefs. A deep approach to learning and studying may also involve some performance goals, such as time management and organized studying that do not contradict the goal of personal making of meaning. In contrast, a superficial approach to learning is characterized by performance orientation, lack of purpose, and superficial strategy use, such as memorization of facts, and syllabus boundness. It is also characterized by lack of metaconceptual awareness.

Method

Participants

Ten 10th-grade Greek students participated in this study, six of whom were boys and four were girls. As mentioned earlier these students were selected from a pool of students that participated in the Stathopoulou and Vosniadou (2006) study on the basis of their scores on the GEBEP and the FMCE. Five of the students were selected because they had achieved high scores in all dimensions underlying the GEBEP and also high scores on the FMCE, whereas the remaining five were selected because they had achieved low scores in all dimensions underlying the GEBEP and also low scores on the FMCE.

Materials and Procedure

The interview started with a discussion with each participating student about the nature of physics knowledge, the role of teachers, textbooks, peers and the self in learning physics, and about the role of experience and experiment in the justification of knowing. This was done in order to re-examine the participants' physics-related epistemologies and to reveal aspects of students' approaches to physics learning and studying. The discussion also concerned the interviewees' attitudes towards physics and their study goals and strategies. The second part of the interviews involved discussion, think-alouds, and observation as each student was faced with tasks such as answering questions regarding particular dynamics-related situations, and solving problems in the area of Newtonian dynamics. We wanted in this way to re-examine the depth of students' conceptual understanding of dynamics, but most importantly, to investigate in a context-sensitive way students' approaches to learning and studying and particularly their strategies in the context of a problem-solving task. Some examples of the physics questions and problems that were used during the interviews are shown in Figure 12.3. We selected the particular problems because they targeted some well-known 'misconceptions' of students, such as the 'impetus misconception.'

Each student was interviewed for about two hours. Data regarding students' grades in school physics were also collected.

Results

The analysis of the interviews gave results consistent with those received by the instruments that were earlier used to measure epistemological beliefs and physics understanding (i.e., the GEBEP and the FMCE respectively). More specifically, all five students who were

Identify the forces acting on the ball.

i. Identify the forces acting on the sliding down girl.
ii. In case that the boy on the top of the slide had pushed the girl instantly, do you believe that the same, as previously, forces would act on her, as she slides down the slide? Explain.
iii. Consider the slide as a frictionless inclined plane of given length and angle. If you also know the girl's mass and weight can you find her speed at the bottom of the slide? Explain.

An object with a mass of 2 Kg moves with a speed of 3 Km/h. Can you find the net external force on the object so that it keeps moving in the same direction with the speed of 3 km/h? If yes, find it. If not, what other information should you be given?

Figure 12.3: Some examples of physics questions and problems used in the interviews.

selected because they scored high on both the GEBEP and the FMCE, were indeed found to hold constructivist physics epistemologies and to have achieved conceptual change in Newtonian dynamics, in contrast to the remaining five students who were selected for their low scores on the GEBEP and the FMCE. Further analysis of the interview-data was done for the purpose of identifying patterns of responses pointing to what may be described as *deep approach to studying*, as opposed to *superficial approach to studying*.

Preliminary results showed, as expected, that all five students who were found to hold constructivist physics epistemologies, and also to have achieved conceptual change in physics (in the area of Newtonian dynamics), had adopted what may be considered a deep approach to learning and studying. The remaining five students showed evidence of adopting a superficial approach to learning and studying. The criteria for identifying students' approaches were defined, as mentioned earlier, on the basis of Entwistle's descriptions of a deep as opposed to a superficial approach to learning and studying (Entwistle, this volume; also, Entwistle & Tait, 2000) and are presented in Table 12.1. They were categorized around three dimensions of studying: goals, strategies, and metaconceptual awareness. A deep approach to learning and studying involves goals of personal making of meaning, and deep strategy use, such as integration of ideas. It also involves awareness of one's own beliefs and thus a good sense of understanding or failure to understand. A superficial approach involves performance goals, lack of purpose, and superficial strategy use, such as rote learning. We also assume that this approach is accompanied by low awareness of one's own beliefs.

To illustrate the differences in approaches to learning and studying adopted by students with qualitatively different physics-related epistemological beliefs, two students, John and Michael, were selected as examples. Below we present in greater details results from the interviews of these two students.

A closer look at John and Michael

The two students who served as examples in the present study, John and Michael, were very different in terms of their personal physics epistemologies and their conceptual understanding of dynamics, but both had very high grades in school physics. Comparable performance in school physics was important for selecting the two students because controlling this variable has the potential to help us understand better the influence of physics-related epistemological beliefs on physics understanding. John had scored high on all the factors underlying the GEBEP and also impressively high (40 out of 43) on the FMCE, while Michael had scored low on all the factors underlying the GEBEP and also very low (6 out of 43) on the FMCE. In what follows, we present excerpts from the transcribed interviews with the two students in order to clarify the differences in their approaches to learning and studying. We will focus on the three criteria used to identify students' approach to learning and studying, described in Table 12.1.

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Table 12.1: Criteria for identifying students' approach to learning and studying.

Approaches to learning and studying	**Criteria**		
	Goals	**Strategy use**	**Metaconceptual awareness**
Deep approach	Meaning-making	Integrating ideas	Being aware of one's own beliefs
Superficial approach	Performance orientation or lack of purpose	Rote learning	Not being aware of one's own beliefs

Goals: Meaning Making vs. Performance Orientation John appears to seek personal making of meaning, by trying to work things out for himself, to relate them to what he already knows.

> John: *Physics is relatively difficult for the average student because (…) you have to learn things, not by rote, but to learn, to put them in your mind. You need time to consolidate things…*
> Interviewer: *What do you mean by saying "to put them in your mind" and "to consolidate things"?*
> John: *I mean to relate them, that is, you don't need to have [separate] laws for force and motion, and later other for energy and other for momentum. If you don't relate them you can't learn them really good.*

His meaning seeking is demonstrated by the fact that he monitors his performance and takes corrective steps when he realizes failures in understanding:

> John: *[Sometimes] you realize that something is missing, or that you haven't really understood [something]. You have to go back, I mean, I don't know what most students do, but I will go back, because if I haven't understood, I can't go on.*

Michael, on the other hand, appears to be performance-oriented in the sense that he worries not really about understanding for himself, but rather, about doing what, he thinks, the physics teacher expects of him. This seems to be his major concern and having the teacher's approval is what he is after. This is rather clear in the following excerpt:

> Michael: *When the physics teacher asks something, regardless of whom he asks, I say the answer to myself and if I was quicker in answering [than the other student], and the answer was correct, I believe that it is OK. I'm sure that I know that.*
> Interviewer: *Is this enough to be sure that everything is OK? Is there anything else [about your learning] to worry about?*
> Michael: *(laughing) No, no, no, and if the teacher tells you, which is not usual, "you're doing well, keep working" then, I believe, that you are at a good level.*

Strategies: Integrating Ideas vs. Rote Learning

John appears to adopt the deep strategy use such as integration of ideas on the basis of some organizing principles. He also admits that he finds it rather intriguing to try to relate ideas and to play around with ideas.

> John: *Our mind can remember a lot of things, but you cannot overload it, so, you can keep in your mind some basic formulas that you can easily store in your memory (…) You can relate different parts of a theory.*

> *Thus you can relate formulas with other things that may help you to reproduce any formula needed (…) Formulas derive from theory. It's easier to remember the formulas if you understand the theory. (…) [You know that linear velocity in uniform circular motion is equal to* $2\pi R/R$ *rather than* $2\pi T/R$*] because you remember from theory that linear velocity equals the arc length divided by the [corresponding] time. You know that the length of a circle is* $2\pi R$ *and the corresponding time equals the period* T*, thus…*

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And later, when he was asked to identify the forces exerted on a girl sliding down a slide and to find her speed at the bottom of the slide he said:

> John: *(having drawn the forces, in the scientifically accepted way, without difficulty) Right… her speed. Let me see, I can work either with kinematic equations or with energy (He starts working with kinematics, suggesting that there is friction between the slide and the girl).*
> Interviewer: *Suggest the friction is negligible.*
> John: *Then I would work with energy.*
> Interviewer: *I see, [in that case] you would prefer a different way.*
> John: *I don't mind actually, both ways are good.*

Also, in another instance:

> John: *[You may engage yourself in solving a problem that is not an assignment and looks strange or intriguing, because] it is the curiosity to deal with something that may not come to an end but you want simply to play around with this, to try this out.*

In contrast, Michael appears to adopt superficial strategy use, such as rehearsal and memorization:

> Michael: *I have my own way, I mean with some formulas that are difficult [to remember] I find some key words and I keep them in mind so that when is needed I can remember exactly what it was about. Or by writing formulas, if you write them many times, I believe that your hand is getting used [to writing them] and at the moment you must write them it is easier, they come back in memory.*

Later, answering a question concerning what he does when he simply cannot remember a formula; for example, how he can decide whether the linear velocity in uniform circular motion is equal to $2\pi R/T$ or to $2\pi T/R$ he said:

> Michael: *I believe that if you have learned a formula well, from my personal experience, because I'm good with formulas and I can remember them, hum I'm familiarized…, but I believe that if my mind gets stuck,*

> *the student will try to recall it; if he doesn't, he will try to solve the problem and (…) he will get such a result that he will understand that something's wrong.*
> Interviewer: *This is what you do?*
> Michael: *I am sure that I will write the formulas [right], because I know them, I mean, it is so easy to write them if you have learnt them (…) I have no trouble with formulas. I write the formula and everything goes right, the problem is easily solved (…). The problem goes itself, for me it is something that you can learn, what to do first, second, third, and the problem is solved like that. I mean it's so easy.*

In another instance Michael was given the mass and the speed of a moving object and was asked to find the net force on the object in case it kept moving in the same direction with the same speed.

> Michael: *I usually have more data given. I believe that I should have been given a force F so that I could find the resultant force in the x direction, to find in the vertical direction that the weight equals the [normal force] N and then to find the friction, classical methodology. Something is missing. I believe that I should be given the F.*

Being Metaconceptually Aware vs. Not Being Metaconceptually Aware Another important aspect of a deep approach to learning is awareness of one's own beliefs. Being aware of one's own beliefs, means being also able to recognize different points of view. John is aware of his own beliefs and of the change in his beliefs. For example, he knows that he has abandoned the 'impetus misconception,' that is, that there must be always a force in the direction of the movement (McCloskey, 1983; Gunstone & Watts, 1985; Vosniadou, 2002; Ioannides & Vosniadou, 2002). Thus, when John is asked to identify the forces on a ball that was hit by a football player he says:

> John: *Now there is no force from the football player, it is away from him, the only force is its weight. Yes there is no force [from the football player], there is a velocity that was acquired when it was in contact with him, when he exerted a force on the ball.*
> Interviewer: *Is this a spontaneous response? I mean, are there any cases when you are about to say that there is also an acquired force and then you say "no there isn't [such a force]"?*
> John: *Yes, I haven't got away [from this belief] completely, but when I think about it I understand that there isn't such a force, since there is no contact [with the football player]. I mean with a first thought, I may be confused, but with a second, no I don't.*

Michael, on the other hand, is not aware of his own beliefs and their development. The following dialogue, when he was also asked to identify the forces on a ball that was headed by a football player is revealing, as it shows that he is not aware of his failure to understand:

> Michael: *This body has definitely a weight and we can see its direction and put another force F (he draws a force F in the direction of the ball's movement)*
> Interviewer: *I can see why you say "there is definitely its weight" it is like saying that the ball is in the field of gravity, but why do you think there is also this force F?*
> Michael: *We can see that he hits the ball with his head and now the ball is free [to move]*
> Interviewer: *Yes, the ball is not in contact with his head isn't it?*
> Michael: *(crossing out the force F) Yes it has left his head.*
> Interviewer: *I see that you cross out the force F.*
> Michael: *Yes, because I made a mistake, there is not such a force; there is its weight and a backward force. We can say that it is the reaction from the air that slows down the ball.*
> Interviewer: *If we consider this force negligible Michael, how does it move?*
> Michael: *It slows down, ah we said [it is] negligible, hum it falls freely?*
> Interviewer: *It moves downwards, vertically?*
> Michael: *Let's say this is the ground, right? It will move…I forgot, I don't remember how it moves.*

Later, when Michael was faced with the problem concerning the girl sliding down a slide he drew a force in the direction of the movement and when he came to a dead end due to the lack of information about such a force, he wondered whether he should cross out that force.

In short, John, the student with a constructivist physics-related epistemology, and the one showing evidence of in-depth physics understanding, adopted a deep approach to learning and studying as exemplified by his tendency to seek personal meaning-making, to actively monitor his understanding, to integrate ideas and also, to be aware of his own beliefs and of changes in his beliefs. The opposite, that is, the adoption of a superficial approach to learning and studying, was found for Michael, the student with a less-constructivist physics epistemology who showed evidence of poor conceptual physics understanding. Michael appeared to be performance-oriented, to rely on memorization of what has to be learned and rote learning, not to be concerned about integrating ideas and finally, not to be aware of his own beliefs.

Discussion

The study presented in this chapter provided preliminary evidence that the adopted approach to learning and the consequent selection of study strategies may intervene in the relationship between epistemological beliefs and conceptual change. Of the 10 students investigated, the five who held constructivist physics epistemologies and had achieved conceptual change in dynamics, adopted a deep approach to learning and studying. They were all oriented to personal meaning-making through the selection of deep study strategies. This process paralleled an increasing metaconceptual awareness of their beliefs. In contrast, the remaining five students who had less-constructivist physics epistemologies and were far from having achieved deep conceptual understanding of dynamics, showed evidence of a superficial approach to learning and studying. They were performance-oriented and preferred the selection of superficial study strategies, while no evidence of substantial metaconceptual awareness was found. The examples of John and Michael helped us to better understand these differences.

The findings of the present study are in line with Entwistle's (this volume) suggestion that the development of *conceptions of knowledge* (dualistic vs. relativistic) parallels the development of *conceptions of learning* (reproducing vs. seeking meaning), and that this is a process of increasing metacognitive awareness. They also agree with the hypotheses emerging from the suggested theoretical framework according to which epistemological beliefs may either facilitate or constrain the knowledge acquisition process directly, both through guiding attention to certain information and through influencing intentions regarding knowledge construction and revision, as well as indirectly through certain mediating cognitive, metacognitive, and/or motivational factors, such as goal orientation and study strategies (e.g., Vosniadou, 1994, 2003, in press; Sinatra & Pintrich, 2003; Mason, 2003; Pintrich, 1999; Dole & Sinatra, 1998; Sinatra, 2005).

AQ4

Students' belief that physics knowledge is a piecemeal collection of factual information, rather than a complex system of interrelated concepts, may make them more likely to 'early foreclose' (Kruglanski, 1989) their critical thinking in the process of learning (Pintrich et al., 1993; Pintrich, 1999; Qian & Alverman, 1995). It is also possible that students with such a predisposition may be precluded from deep information processing and from developing useful metacognitive skills. They would thus be expected to use superficial strategies (e.g., memorization of facts and formulas) instead of deeper strategies (e.g., organization and integration on the basis of principles). Such strategies lead to inert knowledge and prevent successful transfer. At the metacognitive level, they would be expected not to be aware of the need for information management and evaluation of learning outcomes. In any case, a significant impact on conceptual change in physics would be expected. Schommer et al. (1992) also suggested that belief in simple, as opposed to complex, knowledge may influence both students' selection of cognitive strategies during the process of learning and their standards for judging learning outcomes.

With regard to the finding that students' beliefs in unchanging physics knowledge are also related to a superficial physics understanding, it could be argued that this may be the case because such a belief may constrain the evaluation and filter the interpretation of tentative and controversial information that does not concur with existing knowledge (Schommer–Aikins, 2002; Qian & Alverman, 1995). Students, who believe that physics knowledge does not change, may prefer to avoid 'threatening' new information, rather than examining and changing their existing conceptions. Similar explanations have been provided in the literature to account for the way students respond to anomalous data in conditions of cognitive conflict (e.g., Chinn & Brewer, 1993; Chinn & Malhotra, 2002; Mason, 2000).

Finally, the results of our studies also suggest that epistemological beliefs maybe better predictors of conceptual change in physics than grades in physics (Stathopoulou &

Vosniadou, 2006). As we saw, the two students who served as examples in the present study, John and Michael, were very different in terms of their personal physics epistemologies and their conceptual understanding of dynamics, but both had very high grades in school physics. Previous studies with Greek 1st-year university physics students have also shown that about half of them could not answer in the scientifically accepted way all the FMCE questions concerning the three Newton's laws of motion, despite the fact that they took demanding entrance examinations and were selected on the basis of their high grades in school physics (Mol, Stathopoulou, & Vosniadou, 2004). This may be the case, because high grades can result not only from in-depth physics understanding but also from such factors as efficient use of rules, formalistic and algorithmic approach to problem-solving, adaptation to the teacher's preferred techniques, rote learning, or what could be called a 'strategic approach' to learning and studying (Entwistle & Tait, 2000). Thus, it seems reasonable to suggest that a student with a deep conceptual understanding in physics would be expected to have high grades in school physics but the opposite may not necessarily be the case.

To conclude, it appears that epistemological beliefs influence conceptual change in a variety of different ways. Understanding these ways involves more than an approach to conceptual change as an overtly rational process. The conflict between what is already known and the new, to-be-acquired information creates a learning situation in which affective and motivational variables can play an important role (Dole & Sinatra, 1998; Gregoire, 2003; Pintrich et al., 1993; Pintrich, 1999; Sinatra, 2005; Vosniadou, 2003). The relationship between epistemological beliefs and conceptual change is likely to be, to some extent, a reciprocal one (Pintrich, 2002). Since personally held beliefs about knowledge and knowing (in physics) are themselves subject to change, it is rather reasonable to suggest that deeper understanding (in physics) may provide feedback that influences epistemological beliefs.

The exact processes through which epistemological beliefs change is not addressed in this study, but it is definitely an issue that needs careful investigation. A number of researchers emphasize the importance of constructivist instruction in facilitating the development of personal epistemologies (e.g., Bell & Linn, 2002; Carey & Smith, 1993, Roth & Roychoudhury, 1994; Smith et al., 2000). As noted earlier, conceptualizing epistemological beliefs as theory-like structures can help us understand better the mechanisms of their change by drawing on various cognitive mechanisms, as well as on motivational and affective variables that are involved in conceptual change models (e.g., Dole & Sinatra, 1998; Gregoire, 2003; Pintrich, 1999; Pintrich et al., 1993; Sinatra, 2005; Vosniadou, 1994, 2003).

References

Baxter Magolda, M. B. (1992). *Knowing and reasoning in college: Gender-related patterns in students' intellectual development*. San Francisco, CA: Jossey-Bass.

Belenky, M. F., Clinchy, B. M., Golberger, N. R., & Tarule, J. M. (1986). *Women's ways of knowing: The development of self, voice, and mind.* New York: Basic Books.

Bell, P., & Linn, M. C. (2002). Beliefs about science: How does science instruction contribute? In: B. K. Hofer, & P. R. Pintrich (Eds), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 347–363). Mahwah, NJ: Lawrence Erlbaum Associates.

Buehl, M. M., Alexander, P. A., & Murphy, P. K. (2002). Beliefs about schooled knowledge: Domain specific or domain general? *Contemporary Educational Psychology*, *27*, 415–449.

Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MA: MIT Press.

Carey, S. (1992). The origin and evolution of everyday concepts. In: R. N. Giere (Ed.), *Cognitive models of science* (pp. 89–128). Minneapolis, MN: University of Minnesota Press.

Carey, S., & Smith, C. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist*, *28*(3), 235–251.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research*, *63*(1), 1–49.

Chinn, C. A., & Malhotra, B. A. (2002). Children's responses to anomalous scientific data: How is conceptual change impeded? *Journal of Educational Psychology*, *94*(2), 327–343.

Dole, J., & Sinatra, G. (1998). Reconceptualizing change in the cognitive construction of knowledge. *Educational Psychologist*, *33*, 109–128.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Buckingham: Open University Press.

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education*, *85*(5), 554–567.

Entwistle, N., & Tait, H. (2000). Patterns of response to approaches to studying inventory across contrasting groups and contexts. *European Journal of Psychology of Education*, *15*(1), 33–38.

Gregoire, M. (2003). Is it a challenge or a threat? A dual-process model of teachers' cognition and appraisal processes during conceptual change. *Educational Psychology Review*, *15*(2), 147–179.

Gunstone, R., & Watts, M. (1985). Force and motion. In: R. Driver, E. Guesne, & A. Tibergien (Eds), *Children's ideas in science*. Milton Keynes, England: Open University Press.

Harre, R. (2002). *Cognitive science. A philosophical introduction*. London: Sage.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology*, *25*, 378–405.

Hofer, B. K. (2002). Personal epistemology as a psychological and educational construct: An introduction. In: B. K. Hofer, & P. R. Pintrich (Eds), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 3–14). Mahwah, NJ: Lawrence Erlbaum Associates.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88–140.

Ioannides, C., & Vosniadou, S. (2002). The changing meanings of force. *Cognitive Science Quarterly*, *2*(1), 5–62.

Kardash, C. M., & Scholes, R. J. (1996). Effects of pre-existing beliefs, epistemological beliefs and need for cognition on interpretation of controversial issues. *Journal of Educational Psychology*, *88*, 260–271.

King, P. M., & Kitchener, K. S. (1994). Developing reflective judgement: *Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco, CA: Jossey-Bass.

Kruglanski, A. W. (1989). *Lay epistemics and human knowledge: Cognitive and motivational bases*. New York: Plenum Press.

Kuhn, D. (1991). *The skills of argument*. Cambridge: Cambridge University Press.

Leach, J., Millar, R., Ryder, J., & Sere, M. G. (2000). Epistemological understanding in science learning: The consistency of representations across contexts. *Learning and Instruction*, *10*, 497–527.

Mason, L. (2000). Role of anomalous data and epistemological beliefs in middle students' theory change on two controversial topics. *European Journal of Psychology of Education*, *15*, 329–346.

Mason, L. (2003). Personal epistemologies and intentional conceptual change. In: G. M. Sinatra, & P. R. Pintrich (Eds), *Intentional conceptual change* (pp. 199–236). Mahwah, NJ: Lawrence Erlbaum Associates.

McCloskey, M. (1983). Naive theories of motion. In: D. Gentner, & A. L. Stevens (Eds), *Mental models*. Hillsdale, NJ: Erlbaum.

Mol, A., Stathopoulou, C., Kollias, V. P., Vosniadou, S. (2003, July). Gradual learning of science in a CSCL environment and the quest of epistemologically sophisticated learners. Paper presented at the 3rd IEEE International Conference on Advanced Learning Technologies (ICALT'03), Athens, Greece.

Mol, A., Stathopoulou, C., & Vosniadou, S. (2004). Consistency versus fragmentation in Mechanics. In: S. Vosniadou, C. Stathopoulou, X. Vamvakoussi, & N. Mamalougos (Eds), *Abstracts of the 4th European symposium of the European association for research on learning and instruction on conceptual change: Philosophical, historical, psychological and educational approaches* (pp. 133–135). Athens: Gutenberg Press.

Perry, W. C., Jr. (1998). Forms of intellectual and ethical development in the college years: A scheme. San Francisco, CA: Jossey-Bass.

Pintrich, P. R. (1999). Motivational beliefs as resources for and constrains on conceptual change. In: W. Schnotz, S. Vosniadou, & M. Carretero (Eds), *New perspectives on conceptual change* (pp. 33–50). Oxford: Elsevier.

Pintrich, P. R. (2002). Future challenges and directions for theory and research on personal epistemologies. In: B. K. Hofer, & P. R. Pintrich (Eds), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 103–118). Mahwah, NJ: Lawrence Erlbaum Associates.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, *63*(2), 167–199.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception. Toward a theory of conceptual change. *Science Education*, *66*(2), 211–227.

Qian, G., & Alvermann, D. (1995). Role of epistemological beliefs and learned helplessness in secondary school students' learning science concepts from text. *Journal of Educational Psychology*, *87*(2) 282–292.

Roth, W. M., & Roychoudhury, A. (1994). Physics students' epistemologies and views about knowing and learning. *Journal of Research in Science Teaching*, *31* (1), 5–30.

Ryan, M. P. (1984). Monitoring text comprehension: Individual differences in epistemological standards. *Journal of Educational Psychology*, *76*(2), 248–258.

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology*, *82*, 498–504.

Schommer, M. (1994). An emerging conceptualization of epistemological beliefs and their role in learning. In: R. Garner, & P. Alexander (Eds), *Beliefs about text and instruction with text* (pp. 25–40). Hillsdale, NJ: Erlbaum.

Schommer–Aikins, M. (2002). An evolving theoretical framework for an epistemological belief system. In: B. K. Hofer, & P. R. Pintrich (Eds), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 103–118). Mahwah, NJ: Lawrence Erlbaum Associates.

Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology*, *84*(4), 435–443.

Sinatra, G. M. (2005). The "warming trend" in conceptual change research: The legacy of Paul Pintrich. *Educational Psychologist*, *40*(2), 107–115.

Sinatra, G. M., & Pintrich, P. R. (2003). The role of intentions in conceptual change learning. In: G. M. Sinatra, & P. R. Pintrich (Eds), *Intentional conceptual change* (pp. 1–18). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Smith, C. L., Maclin, D., Houghton, C., & Hennessey, M. G. (2000). Sixth-grade students' epistemologies of science: The impact of school science experiences on epistemological development. *Cognition and Instruction*, *18*(3), 349–422.

Songer, N. B., & Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*, *28* (9), 761–784.

Stathopoulou, C., & Vosniadou, S. (2006). Exploring the relationship between physics-related epistemological beliefs and physics understanding. *Contemporary Educational Psychology*, XXX. **AQ5**

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In: R. A. Duschl, & R. J. Hamilton (Eds), *Philosophy of science, cognitive psychology and educational theory and practise* (pp 147–176). New York: State University of New York Press.

Thornton, R. K., & Sokoloff, D. R. (1998). Assessing student learning of Newton's laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula. *American Journal of Physics*, *66*(4), 338–352.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, *4*, 45–69.

Vosniadou, S. (1999). Conceptual change research: State of the art and future directions. In: W. Schnotz, S. Vosniadou, & M. Carretero (Eds), *New perspectives on conceptual change*. Oxford: Elsevier.

Vosniadou, S. (2002). On the nature of naive physics. In: M. Limon, & L. Mason (Eds), *Reconsidering conceptual change: Issues in theory and practice* (pp. 61–76). Dordrecht, The Netherlands: Kluwer.

Vosniadou, S. (2003). Is intentional learning necessary for conceptual change? In: G. Sinatra, & P. Pintrich (Eds), *Intentional conceptual change*. Hillsdale, NJ: Erlbaum.

Vosniadou, S. (in press). Conceptual change and education. *Human Development.* **AQ6**

Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science*, *18*, 123–183

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