The Cognitive-Situative Divide and the Problem of Conceptual Change

Stella Vosniadou
Cognitive Science Laboratory
Department of Philosophy and History of Science
National and Kapodistrian University of Athens

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Please address correspondence to:
Stella Vosniadou
Department of Philosophy and History of Science
National & Kapodistrian University of Athens
University Campus, A. Ilissia 157 71
Athens, Greece
e-mail: svosniad@phs.uoa.gr

Educational Psychologist, in press

Abstract

In this paper we argue that both the cognitive and situative perspectives need to be modified in order to account for the empirical evidence on learning, taking as a central example the problem of knowledge transfer. Our proposal is that we need an approach that takes as a unit of analysis the individual in a constructive interaction with the world through a variety of mediated symbolic structures, some internal and some external, in rich socio/cultural settings. This should be done without denying that knowledge can be represented in some form in the memory system. While internal mental structures are acceptable in this framework, concepts should not be seen as stable and unchanging but rather, as flexible, malleable, and distributed. In order to explain conceptual change, we should allow for the possibility that what is already known can be radically restructured and that new, qualitative different structures emerge. Teaching for conceptual change, we argue, should utilize but cannot rely solely on cognitive apprenticeship types of methods. Attention must be paid to the appropriate design of curricula and to the acquisition of subject – matter knowledge, together with the development of instructional methods that utilize socio-cultural processes, like classroom discussion, to develop students' metaconceptual awareness and the ability to engage in intentional learning.

The Cognitive-Situative Divide and the Problem of Conceptual Change

The debate between cognitive and situative (or socio-cultural) perspectives has dominated recent theorizing about learning and instruction. In the last few years it has also been transferred in the area of research on learning that is known as *conceptual change.* In this paper we present some thoughts regarding the relationship between the problem of conceptual change and the cognitive-situative divide and sketch a theoretical framework that we believe can be more fruitful in bridging the two perspectives. The problem of conceptual change is the problem of how concepts change with learning and development. The conceptual change approach is a specific proposal as to how we can deal with the problem of conceptual change which will be described in detail later in this paper.

The paper starts with an attempt to clarify how the terms cognitive perspective and situative perspective are used. We argue that the attempt on the part of the situated perspective to move cognition out of the head is in the right direction but that the denial to objectify knowledge altogether is problematic for a theory of learning. We take as a central example in this discussion the problem of knowledge transfer and we argue that neither the cognitive nor the situated perspectives can explain all the empirical evidence around the problem of transfer. We continue with a description of the problem of conceptual change and argue that the revised conceptual change approach we propose can explain why school knowledge does not transfer to everyday situations while at the same time everyday knowledge is ubiquitous and easy to transfer.

We then discuss a set of proposals to soften the boundaries between the cognitive and situative perspectives in a way that is consistent with the conceptual change approach. We argue that this can be done by allowing the possibility of objectifying knowledge while considering knowledge acquisition to result from participation in socio-cultural activities. Conceptual change in this system is the result of a complex process of interaction between individuals and the world through a rich variety of mediated symbolic structures. Further, we propose that teaching for conceptual change cannot rely on the implicit methods of cognitive apprenticeship, but must aim towards developing in students the metaconceptual awareness required for explicit and intentional belief revision through the appropriate use of socio-culturally based practices and carefully designed research-based curricula.

The cognitive-situative divide: Definitional issues

We will use the term *cognitive perspective* as it is defined and explained by Greeno, Collins, and Resnick (1996) in the *Handbook of Educational Research*. We will also use the term *situative* as they do, to refer to what is otherwise known as the socio-cultural perspective to learning. Greeno et al. (1996) define the cognitive perspective on learning as the view that "treats knowing as having structures of information and processes that recognize and construct patterns of symbols in order to understand concepts and exhibit general abilities, such as reasoning, solving problems, and using and understanding language" (p. 18). On the contrary, the situative perspective is defined as the approach that treats knowledge as a process, "an activity that takes place among individuals, the tools and artifacts that they use, and the communities and practices in which they participate" (Greeno et al., 1996, p. 20).

It is interesting to note that Greeno (1989) uses the theoretical construct of conceptual change to characterize the shift from the cognitive to the situative perspective as analogous to the shift from Newtonian mechanics to relativity theory. "Rather than thinking that knowledge is in the minds of individuals, we could alternatively think of knowledge as the potential for situated activity. On this view, knowledge would be understood as a relation between an individual and a social or physical situation. Relativizing the concept of knowledge in this way might be analogous to the shift in understanding of the concept of physical motion in special relativity theory. In Newtonian mechanics, motion was considered as a property of individual bodies, relative only to absolute space. In the theory of special relativity, the motion of an object can be characterized meaningfully only in relation to a frame of reference. We do not yet understand the dependencies of knowledge on its contexts well enough to formulate a relativistic epistemology, but such an epistemology may be needed to provide an adequate framework for analyzing cognition in practice" (Greeno, 1989, p.1).

As it is clear from the above, the main difference between the two perspectives is their position on the ontological status of knowledge. This difference is well captured by the ‘acquisition’ and ‘participation’ metaphors as they have been discussed by Sfard (1998). The cognitive perspective embodies the acquisition metaphor, i.e., defines knowledge as something in the minds of individuals that can be acquired, develop and change. The situatitive perspective, on the other hand, embodies the participation metaphor, i.e., denies the reification of knowledge and defines knowledge in terms of knowing and doing – in terms participation in social and cultural activities, as apprenticeship in thinking (Rogoff, 1990) or as legitimate peripheral participation (Lave & Wenger, 1991).

In contrast to the difference between acquisition and participation, the distinction between individual and socio-cultural forms of learning does not seem to be a defining difference between the two perspectives. While the cognitive perspective has been identified mainly with individual forms of learning, it is not inconsistent with the notions of group learning. Similarly, while the situative perspective has been identified with social forms of participation, this is not necessarily the case. We can think of learning situations where an individual learner is situated in a non-social context. As Hatano and Miyake (1991) note, “even in purely experimental research, the observable behavioural changes are invariably mediated by artifacts (e.g., the experimental equipment in a laboratory)” (p. 273-274).

It may appear that the definitions offered above are too polarized and do not represent current views. Indeed, there are a number of attempts to bring cognitive and situative perspectives closer together. This applies, for example, to the movements to see cognition as *embodied* (Lakoff, 1987; Lakoff & Johnson, 1998), as *distributed* (Hutchins, 1995; Norman, 1991), or as a *‘cognitive-cultural system’* (Nersessian, in press). We agree that much can be done to bridge the two perspectives, and we will discuss some of these proposals later in the paper, when we will also offer our own. For the time being, however, we would like to keep the two perspectives distinct, as defined by Greeno et al. (1996), in order to better explore their relative advantages and disadvantages and understand how they relate to the problem of conceptual change.

Having made clear how the terms cognitive and situative will be used, we will move on to examine, in the next section, some of the empirical findings that necessitated the conceptual shift that brought about the situative perspective as an alternative to the cognitive one, taking as a central example the problem of knowledge transfer.

<u>The cognitive-situative divide and the problem of knowledge transfer</u>

The situative perspective emerged in learning and instruction in part from the attempts by cognitive anthropologists and psychologists to resolve some basic problems of cognitive theory particularly with respect to the treatment of knowledge transfer. It is not possible to cover here all the extensive literature around the problem of transfer. We will only discuss some ethnographic studies of quantitative reasoning which have been instrumental in the formation of the situative perspective (e.g., Carraher, Carraher, & Schliemann, 1985; Lave, 1988; Scrnibner, 1984; Ginsburg, 1997).

A set of empirical findings, such as the ones coming from the observations of math problem solving during grocery shopping in a supermarket in the Adult Math Project (Lave, 1988), Scribner's (1984) analysis of working arithmetic in a dairy, and the study of children selling coconuts in Recife, Brazil (Carraher et al., 1985), amongst others, have shown that there is little or no effect of schooling on practical, everyday arithmetic performance. This finding is not consistent with the hypothesis of the cognitive perspective that knowledge is something in people's heads that can be transferred to other situations. In addition, the above-mentioned studies showed consistent discontinuities between individuals' performance in school and work situations. The participants were doing much better in work situations than in school, using qualitatively different, quick, and informal procedures in the everyday settings instead of the formal algorithms taught in school.

More specifically, in test situations that resemble school math, problem solving activity was dependent on pencil and paper and Arabic place-holding algorithms. Problem solvers worked from right to left, using borrowing and carrying routines for addition, subtraction and multiplication. On the contrary, the same individuals solved math problems in the context of supermarket shopping in an entirely different fashion. In everyday math, individuals built solutions to the problems not by retrieving abstract math knowledge, concepts, acquired at school, but rather by making use of the components of the specific environmental situation in which they found themselves. They used left to right calculation (decomposing a number into hundreds, tens and ones, starting with the largest and working through to the smallest), re-composition, and rounding. They often stopped part way through the calculating process and used means other than math to solve a problem. They found it much easier to operate on ratios that were evenly divisible into smaller units, and used other techniques not found in test situations (Lave, 1988).

According to Lave (1988), these findings show that the activities of individuals are situated in rich social and physical contexts which have to be taken into consideration in any analysis of human cognition. Other researchers also found the above mentioned findings challenging for cognitive theory. According to Greeno, “an important limitation of current models and the cognitive principles that they embody is their inability to account for performance that is highly situated. In cases that are being studied increasingly, knowledge and the structures of situations are so tightly bound together that it seems best to characterize knowledge in a relation between the knowing agent and the situation, rather than as something that the agent has inside of himself or herself. Current cognitive models lack this relational character.” (Greeno,1988, p.27-28). These researchers turned to treatments of cognition and culture within the epistemological perspectives of phenomenologists, Marxists, and poststructuralists in order to offer a new analysis of thinking that emphasizes the social and cultural character of human thought.

The situative perspective, so developed, is good in explaining situations of everyday reasoning where reasoning is context-dependent and where there is a marked absence of transfer of knowledge acquired in school settings. It becomes problematic, however, in its inability to account for all other instances of learning where transfer is observed. Indeed, the very notion of transfer is problematic in a theoretical framework that denies any objectification of knowledge. If knowledge is defined strictly as participation in culturally relevant activities in socio-cultural contexts, then there is nothing stable enough to transfer from one specific situation to another. Proponents of the situative perspective have tried to deal with this issue in their theories either by denying that transfer is a legitimate phenomenon in learning or by providing some account of it in terms of constraints or affordances that remain invariant from one learning situation to another (Greeno et al., 1996).

I agree with Sfard (1998) on the inadequacy of both of the above mentioned attempts. However, any theory that cannot explain transfer is a very inadequate theory of learning. It is not possible to conceptualize learning if not in terms of some change in what is already known. There must be some invariant properties of the learner to make this possible. The interaction between prior knowledge and new information is in the heart of all constructivist approaches to learning. The last 30 or so years of cognitive psychology research have demonstrated beyond any possible doubt the effects of prior knowledge, positive or negative, on reasoning, text comprehension, language communication, problem solving, memory, and knowledge acquisition (see Bransford, 1979; Bransford, Brown & Cocking, 2000). And, as Anderson, Reder, and Simon (1997) point out in their debate with Greeno (1997) in the *Educational Researcher,* both camps seem to agree on the following: (1) Learning need not be bound to the specific situation of its application, rather it is possible for instruction to generalize from classroom to real world situations, (2) Knowledge can indeed transfer between different sorts of tasks, (3) Abstract instruction can be very effective, and (4) Instruction need not take place only in complex social situations (p. 18).

To conclude, it appears that neither the cognitive nor the situative perspectives are capable by themselves to account for all the empirical findings around the problem of knowledge transfer. The cognitive perspective cannot account for the fact that there is no or little transfer from school tasks to everyday math knowledge. The situative perspective, on the other hand, is not capable of explaining transfer altogether. In the next section we will introduce the conceptual change approach and explain how this approach can provide some new insights with respect to the problem of transfer.

The conceptual change approach

The conceptual change approach attempts to provide an answer to the problem of conceptual change with learning and development. Every theory of learning must provide an answer to the problem of how concepts change and most theories do that by assuming that learning is cumulative and domain general. In contrast, the conceptual change approach is a constructivist approach that assumes that knowledge is organised in domain-specific, theory-like structures, and that knowledge acquisition is characterized by theory changes (see Vosniadou, in pres a, for a more detailed discussion of these issues).

The foundations of this approach can be traced in the attempts by cognitive developmental psychologists and also by science educators to draw an analogy between students' conceptual development with philosophers' attempts to explain theory change in science, (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992). Although the conceptual change approach is very much related to physics education, it is not restricted to physics but makes a larger claim about learning that transcends many domains and can apply, for example, to mathematics (Verschaffel & Vosniadou, 2004), biology (Hatano & Inagaki, 1994), and psychology (Wellman, 2002). Recently the term 'controversial conceptual change' has been used to refer to the debates surrounding certain topics such as evolution and environmental changes, or are related to political and ideological differences and peace education.

As mentioned earlier, the beginnings of the conceptual change approach can be traced in the attempts of science educators to use Thomas Kuhn's explanations of theory change in science as a major source of hypotheses concerning the learning science. Researchers like Viennot (1979), Driver and Easley (1978), and McCloskey (1983) realized that students bring to the science learning task alternative frameworks, preconceptions or misconceptions that are robust and difficult to extinguish. They saw an analogy between theory change in science and the need for students to change their alternative frameworks and replace them with the scientific concepts instructed at school (Posner, Strike, Hewson, & Gertzog, 1982). According to Posner et al. (1982) there are four fundamental conditions that need to be fulfilled before conceptual change can happen: (1) there must be dissatisfaction with existing conceptions, (2) there must be a new conception that is intelligible, (3) the new conception must appear to be plausible, and (4) the new conception should suggest the possibility of a fruitful program. This theoretical framework became the leading paradigm that guided research and instructional practices in science education for many years.

On the basis of this 'classical conceptual change approach', the child is like a scientist, the process of science learning is a rational process of theory replacement, cognitive conflict is a major instructional strategy for producing conceptual change, and conceptual change is like a gestalt shift that happens over a short period of time.

Over the years practically all of the above mentioned tenets of the 'classical conceptual change approach' were seriously questioned. Criticisms coming from the situative perspective pointed out that conceptual change cannot be seen as an individual, internal, cognitive process but as a social activity that takes place in a complex socio-cultural world and that the surrounding situational, cultural, and educational contexts should be taken into account (Hatano, 1994; Caravita & Hallden, 1994; Saljo, 1999). Motivational theorists also criticized the classical conceptual change approach, pointing out that it represents 'cold' cognition and does not take into consideration affective and motivational variables (Pintrich, Marx, & Boyle, 1993; Sinatra & Dole, 1998).

Other aspects of the conceptual change approach were also criticized. For example, it was pointed out that conceptual change is a slow and gradual process and not a dramatic, gestalt shift that happens over a short period of time (Caravita & Hallden, 1994), and that misconceptions are not always well formed and/or resistant to change (Smith, diSessa, & Rochelle, 1994). It was argued that cognitive conflict is not a successful instructional strategy for producing conceptual change as students tend to patch up local inconsistencies in a superficial way (Chinn & Brewer, 1993; Smith et al., 1994; Vosniadou, 1999). Finally, it was pointed out that science learning does not require the replacement of 'incorrect' with 'correct' conceptions, but the ability on the part of the learner to take different points of view and understand when different conceptions are appropriate depending on the context of use (e.g., Pozo, Sanz, & Gomez, 1999; Spada, 1994; Vosniadou, in press b).

In view of the above-mentioned criticisms and based on empirical findings and theoretical approaches coming from cognitive developmental studies (e.g., Carey, 1985; Hatano & Inagaki, 1994; Keil, 1992), Vosniadou (2002, 2003, in press b; Vosniadou & Verschafel, 2004) proposed a modified interpretation of conceptual change which we call the *framework theory* approach.

The framework theory approach also considers conceptual change as domain specific theory change. Unlike the classical approach, however, the theories that need to be changed are not students' misconceptions, but the naïve, intuitive, domain-specific theories constructed on the basis of everyday experience under the influence of lay culture. In this respect, it draws heavily on domain specific approaches in cognitive developmental research (Carey, 1985; Gallistel, Brown, Carey, Gelman, & Keil, 1991; Wellman, 2002; Keil, 1992, Inagaki & Hatano, 2002).

Cognitive developmental research has shown that the knowledge acquisition process starts soon after birth and that infants organize the multiplicity of their sensory experiences under the influence of everyday culture and language into narrow but relatively coherent explanatory frameworks (such as for example, a naïve physics and a naïve psychology) that allow distinct types of explanations and predictions and embody causal notions and ontological and epistemological commitments, known as 'naïve theories' (see Carey, 1985; Spelke, 1991). The term 'theory-like' is used to denote a relatively coherent body of domain-specific knowledge that can give rise to prediction and explanation, and not an explicit, well-formed and socially-shared scientific theory. The importance of the assumption that early knowledge is organized in naïve theories lies in the fact that theory-like structures are generative. As such, they make it possible for even very young children to make predictions about the properties and behavior of unfamiliar entities, or about the reactions of familiar entities to novel situations, and thus to function more efficiently in everyday life (see also Hatano & Inagaki, 1994).

Naïve theories develop through continuing experiences under the influence of lay culture. This development can proceed either in the direction of enriching existing knowledge structures or towards restructuring them (Carey, 1985; Vosniadou & Brewer, 1987). Theory-like structures allow the possibility that developmental change is theory change and this is exactly what conceptual change is meant to be. There is substantial evidence that knowledge is organized in theory-like structures and that it undergoes radical re-organisations that can be described as theory-changes during learning and development (e.g., Carey, 1985; Inagaki & Hatano, 2002; Wellman, 1990; Vosniadou, 2003).

Conceptual change can happen either through the use of bottom-up, implicit and additive mechanisms, or through the use of top-down, deliberate and intentional learning mechanisms, assuming of course, a continuous interaction between an individual and a larger, surrounding cultural context. Examples of the former can be mechanisms like the Piagetian assimilation and accommodation, the use of similarity-based analogical reasoning (Vosniadou, 1989), internalization (Vygotsky, 1978), or even the appropriation of cultural practices of the situated theorists (Rogoff, 1990).

Examples of the latter are the deliberate use of analogy and models, the use of thought experiments, mathematization, etc., (see Vosniadou, in press b; Nersessian, 1992).

The use of simple, bottom-up, additive mechanisms is capable of producing spontaneous developmental conceptual changes, assuming that new knowledge is coming in through observation and/or from the culture. For example, everyday experiences with plants, such as watering plants, seeing them become bigger, or noticing that they can die, can lead children to understand that plants are similar to animals in certain properties, such as feeding, growing, and dying. These similarities can eventually make children consider plants as living things, rather than as inanimate objects, despite the fact that they lack self-initiated movement. This category change can be described as branch jumping (Thagard, 1988), or as an ontological shift (Chi, 1992), and represents a considerable re-organization of the concept of living thing (Carey, 1985).

The use of bottom-up, implicit, additive mechanisms is not very productive however, in producing 'instruction-induced conceptual change'. Instruction-induced conceptual change is the kind of conceptual change that requires systematic instruction in order to be achieved. Science concepts like the concepts of force and energy, of heat and of photosynthesis, require many years of instruction in order to be understood. This is the case because scientific knowledge has developed over hundreds of years of scientific discovery into rather elaborate, counter-intuitive theories, that differ in their concepts, in their structure, and in the phenomena they explain from the explanations children construct on the basis of their experience. Thus, the process of learning science appears to require from children to understand a complex and counter-intuitive scientific theory which represents a completely different explanatory framework from their naïve theories. In this process, the use of implicit, additive mechanisms is bound to produce hybrid or synthetic models (Vosniadou, in press a; Vosniadou, in press b).

The teaching of science usually takes place in the school context by teachers who often use inappropriate curricula and do not understand the magnitude of the difficulties students experience. In these situations, it appears that instruction-induced conceptual change becomes a slow process during which the new, counter-intuitive, scientific, information is assimilated to naïve physics, destroying its coherence and creating misconceptions. Many of these misconceptions are *synthetic models*, formed as learners assimilate the scientific information to an existing but incompatible knowledge base, implicitly and without metaconceptual awareness (Vosniadou, 2003, in press a; Vosniadou & Brewer, 1992, 1994).

For example, by the time children go to school they have available a set of naïve explanations of the day/night cycle according to which night happens when the sun goes down behind the mountains or into the sea or disappears behind clouds, while at the same time, the moon comes up. These explanations are embedded within a naïve physics according to which the earth is a stable, supported, stationary, physical object on which people live and that the sky, sun, moon and other solar objects are located above its top. This explanatory framework is very different from the currently accepted scientific view according to which the earth is a solar object, located in a heliocentric solar system, revolving around the sun, and rotating around its axis.

Empirical studies (e.g., Vosniadou & Brewer, 1992, 1994) have shown that students often misinterpret the scientific explanatory framework in ways that increase its fit with their naïve physics. For example, it appears that as long as they think of the earth as a flat, stable, and supported physical object, students cannot understand that it moves (except for an earthquake-like movement), or that this movement is causally related to the day/night cycle. It is only when they have understood the spherical shape of the earth that students can change their initial model of the day/night cycle. In other words, their prior knowledge about the earth constrains the acquisition of new knowledge.

When students have understood that the earth is an astronomical object, they are more capable of understanding the scientific interpretation of the day/night cycle. Even then, however, they are likely to form various misconceptions, which reveal implicit synthetic attempts towards a reconciliation of the new information with prior knowledge. One of the synthetic models we have obtained is the model of the earth as a stationary sphere with the sun revolving around it. In this model, day/night is caused by the sun's 24 hour revolution around the earth. According to another model, the earth rotates in an up/down fashion while the sun and the moon are stationary and located at diametrically opposite sides around this up/down rotating earth. In this model, there is day when our side of the earth faces the sun and night when our side of the earth faces the moon (as it rotates up/down). In all of the above we can observe intrusions of aspects of everyday knowledge that inhibit the understanding of the scientific explanation (see Vosniadou & Brewer, 1994).

Some researchers working from a situative perspective dismiss the above-mentioned findings. They consider the evidence for students' misconceptions to be a methodological artifact, caused by flaws in studies conducted from a cognitive perspective that focuses on unobservable, inside-the-head, mental structures. They claim that these difficulties disappear when thinking and reasoning is analyzed from a discursive point of view and as a tool dependent activity (e.g., Schoultz, Saljo and Wyndhamn, 2001, Nobes et al. 2003, 2005).

However, a series of empirical studies that attempted to replicate the above-mentioned studies (Vosniadou, Skopeliti, & Ikospentaki, 2004, 2005) did not obtain the same findings. Children do produce fewer misconceptions when cultural artifacts and forced-choice questionnaires are used, but they still have considerable difficulty in understanding the spherical shape of the earth and the day/night cycle.

Other empirical studies have also shown that synthetic models can be observed in many subject-matter areas, from astronomy and mechanics, to history, economics, and mathematics (Gelman, 1990; Vosniadou & Brewer, 1992, 1994; Vosniadou & Ioannides, 1998; also Stafylidou & Vosniadou, 2004; Christou & Vosniadou, 2005). In mathematics, for instance, children use their prior knowledge about natural numbers to misinterpret fractions as consisting of two independent integers and order them from smaller to bigger focusing either on the nominator or on the denominator. Or, using again their knowledge about natural numbers, fail to understand the dense structure of rational numbers, thinking that there are no other numbers between two decimals like 0.05 and 0.06 (Vamvakoussi & Vosniadou, 2004; in press).

The framework theory approach to conceptual change just described (see also Vosniadou, 2003; in press b), avoids many of the criticisms of the classical approach (see Smith et al., 1994). First, the focus is not on misconceptions as unitary, faulty conceptions but on an intricate knowledge system consisting of different conceptual elements organized in complex ways. Second, the distinction is made between naïve explanations, based on everyday experience and lay culture and those that result from learners' attempts to synthesize new, scientific information with existing knowledge. We consider synthetic models not to be stable misconceptions forming alternative theories, but dynamic, situated, and constantly changing representations that adapt to contextual variables or to the learners developing knowledge. Third, 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 that can guide instructional interventions. Last, we consider conceptual change not as the replacement of an incorrect naïve theory with a correct one, but rather as an opening up of the conceptual space through increased metaconceptual awareness, creating the possibility of entertaining different perspectives and different points of view (see Vosniadou, in press b).

The conceptual change approach and the problem of transfer

The cognitive developmental, *framework theory approach* to conceptual change described above may have some relevance problem of transfer. Coming back to the differences between everyday reasoning and reasoning in school settings discussed earlier, we saw that there are some empirical findings indicating that there is little or no transfer from mathematical school tasks to everyday life and work situations. Of course these findings should be interpreted with a great deal of caution. Most people manage to transfer the operations of simple arithmetic learned in school to everyday situations. The real problems appear when the knowledge acquired in school concerns concepts that are a little more advanced or counter-intuitive. In this latter case, we observe a different phenomenon, namely, a great deal of transfer of everyday knowledge inhibiting the understanding of science and math concepts and causing misconceptions or synthetic models. This is transfer in the opposite direction from the one expected by Lave (1988).

In other words, it appears that there is an asymmetry in the direction of knowledge transfer. While there is little transfer of scientific or mathematical knowledge obtained in school to everyday situations, knowledge acquired in everyday settings seems to be ubiquitous and ready to be transferred to other settings (see also Hatano & Inagaki, 1994). This asymmetry in transfer cannot be explained by the cognitive or by the situated perspective, but it is quite consistent with the conceptual change approach to learning.

According to the conceptual change approach, school knowledge maybe difficult to learn and transfer to other situations, because it represents a different explanatory framework-- different in its concepts, in its structure, and in the phenomena it explains -- from the naïve theories students have implicitly constructed on the basis of their everyday experience. The acquisition of this type of knowledge requires considerable knowledge re-organization which is difficult to achieve. As a result, most of the time, what students learn at school are superficial facts that are easily forgotten.

The conceptual change approach can also explain why everyday knowledge transfers to school like tasks, causing misconceptions in science and mathematics (e.g., Gelman, 1990; Novak, 1987; Vosniadou & Verschaffel, 2004; Vosniadou, 2006). As mentioned earlier, many such misconceptions have been interpreted to result from the implicit use of bottom-up, additive mechanisms in a situation where the new information has a different structure from existing knowledge. These implicit but nevertheless constructive attempts can be seen as instances of negative transfer where the existing, everyday knowledge stands in the way of understanding the new scientific explanatory framework.

It may be objected, from the point of view of the situative perspective, that the conceptual change approach's cognitivist view of concepts as well-formed theory-like structures cannot explain the phenomena regarding the situativity of knowledge earlier described and the tendency on the part of individuals to use procedures and strategies that exploit the affordances of the contexts in which they are embedded. We agree with the above criticisms and believe that this is an area where the cognitive perspective and the conceptual change approach need to be revised.

Many conceptual change researchers would agree that theory-like structures should be seen as more flexible and easily influenced by the contexts in which they are embedded than is currently the case (see Hatano, 1994; Caravita & Halden, 1994; Saljo, 1999). On the other hand, most conceptual change researchers would also agree that the situative perspective would need to be revised to allow for the possibility of knowledge to be represented in some form in the memory system. In the next section we will present some preliminary thoughts about how to achieve these modifications and thus narrow the gap between the cognitive and situative perspectives.

Bridging the Cognitive and Situative Perspectives

Acquisition via participation

Hutchins (1995) uses the term 'cognition in the wild' to refer to treatments of cognition in its natural habitat, i.e., to put cognition back in the social and cultural world, without denying its representational nature. We find that this approach is in the right direction because it attempts to capture the dynamic and social nature of the process of knowing without denying the influence of internal, mental representations. As mentioned earlier, knowledge must be represented in some form in the memory system, be it in the form of propositional representations or in neural networks, with the possibility that these representations will be activated, reconstructed, or recalled in particular situations to accomplish cognitive tasks.

In a very interesting discussion of the problems of cognitive science, Hutchins (1995) explains what he calls the 'attribution problem' in cognitive science. He argues that cognitive scientists in their interest to create a cognitive, working model of humans that runs in a computer attributed all the structures and processes required to produce intelligent behavior to symbolic, mental entities inside the head. "Originally, the model cognitive system was a person actually doing the manipulation of the symbols with his or her hands and eyes. The mathematician or logician was visually and manually interacting with a material world. A person is interacting with the symbols and that interaction does something computational. This is a case of manual manipulation of symbols. Notice that when the symbols are in the environment of the human, and the human is manipulating the symbols, the cognitive properties of the human are not the same as the properties of the system that is made up of the human in interaction with these symbols. The properties of the human in interaction with the symbols produce some kind of computation. But that does not mean that the computation is happening inside the person's head." (p. 361).

According to Hutchins, "the physical-symbol-system architecture is not a model of individual cognition. It is a model of the operation of a socio-cultural system from which the human actor has been removed." The computer, he claims, "was not made in the image of the person. The computer was made in the image of the formal manipulations of abstract symbols. And the last 30 years of cognitive science can be seen as attempts to remake the person in the image of the computer" (p. 363).

Hutchins goes on to propose that we re-embody cognition by softening the boundaries between the inside and the outside, or between the individual and context. "Humans are adaptive systems continually producing and exploiting a rich world of cultural structure. The proper unit of analysis for talking about cognitive change includes the socio-material environment of thinking. This system includes a web of coordination among media and processes inside and outside the individual task performers. The definition of learning given here works well for learning situated in the socio-material world, and it works well for private discoveries made in moments of reflective thought." (p. 290).

What we find particularly attractive in Hutchins' proposal is that, unlike other socio-cultural theorists, he does not deny that knowledge is something that can be acquired and change. The problem, he claims, is not in the proposition of cognitive science that humans are processors of symbolic structures but that cognitive science has forgotten "how we got to be symbol manipulators and how we work as participants in socio-cultural systems, rather than assume it as an act of faith." (p. 372). He argues that internal structures exist in the form of symbolic representations but that they were created as a consequence of interaction with symbolic materials.

The above agree with our proposal that there is no conflict between acquisition vs participation, but rather, that knowledge can be acquired through participation in socio-cultural activities. This position has important implications for learning and instruction. In the situative perspective learning is defined in terms of strengthening practices of participation in communities of learning. In contrast, Hutchins (1995) defines learning neither as something that happens only inside an individual, nor as something that happens only outside, in terms of practices of participation. Rather, learning is "the adaptation of structure in one part of a complex system to organization in the other parts. Some parts are re-organised inside the skin. The question of individual learning now becomes a question of how that which is inside a person might change over time as a consequence of repeated interventions with these elements of cultural structure" (p.290). We find this a much more acceptable definition of learning that the one offered by either the cognitive or situative perspectives alone.

Distributed cognition and the role of mental models

Some researchers working within the situative perspective have argued that we should not investigate concepts as internal mental processes that ‘reside inside our heads’ but as ‘elements of discourses that are used in various practices in society’ (Ivarsson, Schoultz, & Saljo, 2002, p. 79). As described earlier, however, the internal-external divide is not necessary. There is an important role that both external and internal representations can play in learning. Recent experiments in our lab (Vosniadou, Skopeliti & Ikospentaki, 2005) have shown that when children are asked generative questions in the area of observational astronomy, and when there is no external representation available, they are very likely to generate an internal mental model of the earth which they then use to reason from. However, when an external representation such as a map or a globe is provided, they are much more likely to reason on the basis of the externally provided model rather than generate their own. We have interpreted these findings to suggest that the cognitive system is distributed and capable of reasoning on the basis of both internal and external models.

Other researchers have also argued for a distributed cognitive system that can generate internal representations of the environment when necessary, but can also use salient resources in the environment, such as cognitive artifacts, in a non-reductive way. Various kinds of external representations such as tools and cultural artifacts, diagrammatic representations and computer visualizations can serve as cognitive artifacts. It appears that people are capable of manipulating these external representations directly, without creating internal representations of them, during reasoning and problem solving (Hutchins, 1995; Norman, 1991; Nersessian, in press; Zhang, 1977; Stenning, 2002).

In this distributed cognitive system, mental models continue to play an important role. In previous work we have argued that the ability to form mental models is a basic characteristic of the human cognitive system and that even young children can construct mental models which have predictive and explanatory power and can be used as mediating mechanisms for the revision of existing knowledge and the construction of new ones (Vosniadou, 2001). Nersessian (in press) argues that model-based reasoning involves the construction or retrieval of a model that can lead to the derivation of novel inferences that can lead to generative problem solving and advancements in science.

The ability to form mental representations of the environment is important because it can help to de-situate cognitive activity. Greeno (1988), for example, argues that models "behave similarly to the objects in the situations that are represented, so that operations on the objects in the model have effects like those of corresponding operations in the situations. Mental models of this kind incorporate features of the situation that can go beyond the knowledge that the individual can state in propositions or other explicit forms, and that the representations of situations formed as mental models can be constrained by principles that are either known or considered as hypotheses" (p. 28).

Not only we can form mental models of the physical environment, we can also use these representations as a basis for the creation of tools and artifacts that can then in turn used as external, prosthetic devices in thinking. The situated perspective emphasizes the importance of cultural artifacts and the role they play as facilitators of thinking. But it does not explain how human culture created these artifacts in the first place. Model-based reasoning is the key to understanding how humans construct the rich cultural environments that mediate our social and intellectual life. Cultural mediating structures range from symbolic systems like language, mathematics, reading, writing, etc., to artifacts like pencil and paper, calculators and computers. But even traffic lights, supermarket layouts, or categorization systems can be considered as symbolic structures that mediate our activities (see Bowker & Starr, 1999).

Individuals can form mental models not only of their everyday, physical experiences but also of the cultural artifacts they use. As Hutchins (1995) points out, "we can be instructed to behave in a particular way. Responding to instructions in this way can be viewed simply as responding to some environmental event. We can also remember such an instruction and tell ourselves what to do. We have in this way internalized the instruction." In a similar way we can use internalize a cultural artifact like a globe and use it, in its absence, as a mental model on the basis of which we can reason.

A globe is a sophisticated cultural representation of the earth different from that provided by everyday experience. Cultural artifacts like maps and globes can be internalized and used in instrumental ways in revising representations based on everyday experience. As mentioned earlier, our studies of children's reasoning in astronomy provide important although preliminary information about how individuals can construct mental representations that are neither copies of external reality nor copies of external artifacts, but creative synthetic combinations of both. This suggests that the cognitive system is flexible and capable of utilizing a variety of external and internal representations to adapt to the needs of the situation (Vosniadou et al., 2004, 2005).

Mental models can play an important role in conceptual change exactly because they can be a point where new information enters the cognitive system in ways that can modify what we already know. They can bring together representations based on physical reality with cultural representations based on scientific explanations of physical reality and cultural artifacts. They can be the basis on which children or scientists can conduct thought experiments and simulations that can help them see the differences between alternative representations or test the implications of principles or theories (see also, Nersessian, in press; Clement, in press).

Implications for Instruction

Problem of Authenticity

As discussed earlier, the situated perspective challenged the traditional assumption that knowledge is an object that can be transferred to the minds of individual students through verbal, transmission-based instruction. This challenge resulted in a critical examination of current practices of teaching in the subject-matter areas. One important problem that emerged concerns the lack of authenticity in traditional school activities. According to Brown, Collins and Duguid (1989), "Too often, the practices of contemporary schooling deny students the chance to engage in relevant domain culture. Archetypal school activity is very different from what we have in mind when we talk of authentic activity, because it is very different from what authentic practitioners do. Classroom activity takes place in the culture of schools. This hybrid activity limits students' access to the important structuring and supporting cues that arise from the context. What students do tends to be ersatz activity." (Brown et al., 1989, p.34). In order to deal with the lack of authenticity it has been suggested that subject-matter can be taught in situations that resemble real life contexts, and that cognitive apprenticeship can be the main instructional method for fulfilling this goal. Cognitive apprenticeship uses methods such as observation, coaching and modeling to teach the cognitive skills required to handle complex tasks (Collins, Brown, & Newman, 1989).

However, cognitive apprenticeship did not succeed in dealing with the problem of authenticity that it set out to solve in the first place. This is because in cognitive apprenticeship the tasks and problems do not arise from the demands of culturally authentic and socially shared activities in the context of the workplace, as it does in traditional apprenticeship situations. Rather, it must find a way to create a culture of expert practice for students to participate in and aspire to, as well as device meaningful benchmarks and incentives for progress." (Collins et. al., 1989, p. 459).

One possible solution to this problem is to propose that the purpose of schools is to enculturate students into the cultures of the subject-matter areas they are taught in school, i.e., into the culture of mathematicians, physicists, writers, historians, etc. This is a road that some researchers have taken. But as Brown, Ash, Rutherford, Nakagawa, Gordon, and Campione (1993) correctly note, this is a rather romantic suggestion. Practitioners of these subject domains do not usually populate schools, particularly when we are referring to primary and secondary education. History teachers or mathematics teachers are not usually practicing historians or mathematicians. Not to mention the impossibility of being simultaneously emerged in the different cultures of all the disciplines covered in primary and secondary schools.

Another possible solution is to create learning experts, "a breed of intelligent novices" (Brown, Bransford, Ferrara, & Campione, 1983), students who, although they may not possess the background knowledge needed in a new field, know how to go about gaining that knowledge. However, we believe that it is very risky to suggest that it is possible to create intelligent novices without substantial subject-matter knowledge.

We agree with Bereiter (1997) that cognitive apprenticeship becomes empty when its purpose is to practice cognitive skills in the absence of substantial knowledge building, and where the domain knowledge is secondary to the skills to be learned. This is also problematic from the point of view of the conceptual change approach. Because new information in science and mathematics is often counter-intuitive and comes in conflict with what is already known, special attention has to be paid to the design of appropriate research-based curricula. In these curricula, the concepts of science cannot be presented as facts but by providing appropriate explanations designed to answer students' possible questions and misunderstandings. This means that knowledge must be seen not only as a process but also as a product, an object to be taught (see also Kirschner, Sweller and Clark, 2006, and Vosniadou, 2005; Vosniadou, Ioannides, Dimitrakopoulou, & Papademitriou, 2001).

Behind all of this lies a considerable confusion between process and product when the product of activity is knowledge. As Bereiter (1997) argues, when the work of a community of practice is that of manufacturing paint, there is no problem in separating the manufacturing process from the product, i.e., the paint. The process of manufacturing paint is a situated activity embedded in the relevant contexts and cultural practices but the product paint is not. Paint itself is not situated. It can be used in many different situations and for many purposes.

One can make the same argument about knowledge as the product of a situated activity. This argument is difficult to understand because unlike the previous situation where the product is paint, in the situation of schooling the product is knowledge. Students produce knowledge objects (ideas, explanations, conjectures, theories), and so on that can be written up and communicated inside and outside the classroom. Bereiter (1997) and also Bereiter and Scardamalia (1989, 1993), focus on the tangible knowledge objects students produce through the use of electronic media and make these objects the focus of their knowledge building environments.

We agree with Bereiter and Scardamalia's argument for knowledge building, and we propose that both students' ideas and subject-matter knowledge should be brought back in the curriculum. The knowledge that has been produced by science and mathematics is something objective and tangible that can be communicated, to individuals who do not necessarily plan to be practicing historians, scientists, or mathematicians. Effective instruction should pay attention both to the processes of knowledge building and its products.

<u>Motivation, metaconceptual awareness and intentional learning</u>

In bridging the cognitive and situative approaches an effort should be made to address adequately the contribution of individuals' in the process of understanding and producing new knowledge. We agree with Hatano (1994) that "although understanding is a social process, it also involves much processing by an active individual mind." The individual is very much a participant in the learning process, and teachers should worry about developing the motivation needed for students to engage in the substantial efforts to required for school learning, particularly in situations where conceptual change is needed.

Also important are considerations about how to develop students' metaconceptual awareness, epistemological sophistication, and intentional learning (see Sinatra & Pintrich, 2003; Mason, 2003; Vosniadou, 2003). Conceptual change cannot be achieved without the development of intentional learners who have the the metaconceptual awareness needed to understand the difference between their naïve beliefs and the scientific concepts to which they are exposed, and are capable of producing the top-down, deliberate and intentional mechanisms that scientists use for hypothesis testing and conscious belief-revision (e.g. see Nersessian, 1990; Sinatra & Pintrich, 2003; Vosniadou, 2003).

However, the development of motivation and metacognition cannot be achieved by cognitive means alone, without extensive socio-cultural support. Dialogical interaction, argumentation, social collaboration, and classroom discussion around carefully designed. research-based curricula and meaningful practices in the school context are the means of creating prolonged comprehension activity. It is through these kinds of socio-culturally based practices that students need to be guided by teachers to a new form of explicit, intentional learning that has the potential to bring about conceptual change (see also Hatano & Inagaki, 1991, 2003; Vosniadou, 2003, in press a).

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