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Conceptual Change and Education

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Key Words

Conceptual change · Instruction-induced conceptual change · Sociocultural constraints · Synthetic models

Abstract

In order to understand the advanced, scientific concepts of the various disciplines, students cannot rely on the simple memorization of facts. They must learn how to restructure their naive, intuitive theories based on everyday experience and lay culture. In other words, they must undergo profound conceptual change. This type of conceptual change cannot be achieved without systematic instruction that takes into consideration both individual, constructivist and sociocultural factors. Teachers must find ways to enhance individual students' motivation by creating a social classroom environment that supports the creation of intentional learners who can engage in the deep and enduring comprehension activities required for the revision of conceptual knowledge.

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Going beyond the teaching of simple literacy and arithmetic, one of the most important missions of education is to enable students to understand the ways of thinking of the various disciplines, particularly disciplines such as the physical sciences and mathematics. Yet, this is the area where schools fail most. An overwhelming body of educational research has documented repeatedly students' misconceptions, mainly in science, but also in other areas, such as mathematics, history, economics and biology. We claim that this is the case because schooling has been unable to deal with the problem of *conceptual change.*

In order to understand the advanced scientific concepts of the various disciplines, students cannot rely on the simple memorization of facts or the enrichment of their naive, intuitive theories. They need to be able to restructure their prior

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knowledge which is based on everyday experience and lay culture, a restructuring that is known as *conceptual change*. How can this restructuring take place? What can schools do to make conceptual change easier and more accessible to most students?

In this short essay, we would like to outline some of the basic tenets of the conceptual change approach and describe their implications for the design of instruction, drawing heavily on the pioneering work of Giyoo Hatano. The discussion will touch on certain critical, theoretical issues, such as domain specificity, naive theories, the nature and mechanisms of conceptual change, the importance of the social and cultural environment, and of course the role of education.

What Exactly Is the Conceptual Change Approach in Development and Learning?

The conceptual change approach in development and learning is a constructivist approach that rests on certain fundamental assumptions, such as that knowledge is acquired in domain-specific, theory-like knowledge structures and that knowledge acquisition is characterized by theory changes. We will examine these assumptions in greater detail below.

Domain Specificity

Most theories of learning and development, such as piagetian and vygotskian approaches, information processing, or sociocultural theories are *domain general*. They focus on principles, stages, mechanisms, or strategies that are meant to characterize all aspects of development and learning. In contrast, the conceptual change approach is a domain-specific approach. It examines distinct domains of thought and attempts to describe the processes of learning and development within these domains. Many cognitive developmental psychologists see domain specificity through the notion of domain-specific constraints on learning [Keil, 1994].

There is a great deal of debate in the literature as to whether domain-specific constraints should be seen as hardwired and innate as opposed to acquired, and as having representational content or not [Elman et al., 1996]. Hatano and Inagaki [2000] suggested that constraints are innate domain-specific biases or preferences that mitigate the interaction between a learning system and the environment. They also introduced the notion of 'sociocultural constraints.' They argue that sociocultural factors can also guide learning and development by restricting the possible range of alternative actions thus leading the learner to select the most appropriate behavior [Hatano & Miyake, 1991; Keil, 1994].

Finally, some domain-specific approaches focus on the description of the development of expertise in different subject matter areas, such as physics [Chi, Feltovitch, & Glaser, 1981], mathematics [Mayer, 1985; Van Lehn, 1990] or chess [Chase & Simon, 1973], without necessarily appealing to innate modules or constraints.

The conceptual change approach can be applied to any of the above conceptualizations of domain specificity, focusing on the description and explanation of the changes that take place in the content and structure of knowledge with learning and development. Domain-specific approaches should be seen as complementary rather than contradictory to domain-general approaches. It is very likely that both domain-general and domain-specific mechanisms and constraints apply in development and learning [Keil, 1994].

Naive Theories

A basic characteristic of the conceptual change approach is the assumption that domain-specific knowledge is organized in the form of *theory.* The term theory is used here to denote a relatively coherent body of domain-specific knowledge characterized by a distinct ontology and a causality that can give rise to explanation and prediction [Inagaki & Hatano, 2002].

The importance of the assumption that early knowledge is organized in the form of naive theories lies in the fact that theory-like structures are generative. As such, they make it possible for children to formulate explanations and predictions and to deal with unfamiliar problems. Hatano and Inagaki [1994] discuss in detail the everyday functionality of naive biology, such as that it allows children to make predictions about the properties and behavior of unfamiliar entities and about the reactions of familiar animate entities to novel situations, thus enabling young children to make sense of everyday biological phenomena.

The Nature of Conceptual Change

The processes of knowledge acquisition with development can proceed either in the direction of enriching existing knowledge structures or towards restructuring them [Carey, 1985; Vosniadou & Brewer, 1987]. Theory-like knowledge 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 cognitive development is indeed characterized by theory changes. For example, in the domain of biology, cross-sectional developmental studies show that the biological knowledge of the 10-year-old is qualitatively different from that of the 4- to 6-year-old child [Carey, 1985; Hatano & Inagaki, 1997], although there is considerable disagreement as to how exactly this development proceeds. Theory changes in the domain of biology have been described in terms of three fundamental components: (1) the ontological distinctions between living/nonliving and mind/body; (2) the modes of inference that children employ to produce predictions regarding the behavior of biological kinds, and (3) the causal-explanatory framework children employ – e.g., intentional or vitalistic as opposed to mechanistic causality [Carey, 1985; Inagaki & Hatano, 2002].

Similar reorganizations of conceptual knowledge across early childhood years can be found amongst others in children's theory of mind [Wellman, 1990], theory of matter [Smith, Carey, & Wiser, 1985], and in astronomy [Vosniadou & Brewer, 1992, 1994]. Our work in observational astronomy has shown that considerable qualitative changes take place in children's concept of the earth between the ages of 4–12. Preschool children think about the earth as a stable, stationary and flat physical object located in the center of the universe. On the contrary, most children at the end of the elementary school years think of the earth as a spherical astronomical object, rotating around itself and revolving around the sun in a heliocentric solar system. In this process, a significant ontological shift takes place in the concept of the earth which is categorized as a *physical object* by the majority of first-graders but as a *solar object* by the majority of sixth-graders [Vosniadou & Skopeliti, 2005]. Similar ontological shifts have been pointed out by Chi [1992].

In what we may call the 'classical conceptual change approach,' these changes are considered the result of a rational process of theory replacement, by a thinking (like a scientist) child, which takes place in a short period of time – like a gestalt-type switch. Over the years, practically all of the above-mentioned tenets of this 'classical conceptual change approach' have been subjected to serious criticisms [Vosniadou, Baltas, & Vamvakoussi, in press]. It appears that the process of conceptual change is usually a slow and gradual one rather than a dramatic gestalt-type shift, by learners who, unlike scientists, lack metaconceptual awareness of their beliefs and of the process of change [Vosniadou, 2003]. Most importantly, it has become clear that conceptual change is not only an internal cognitive process but one that happens in broader situational, cultural, and educational contexts, and that it is significantly influenced and facilitated by social processes [Hatano & Inagaki, 1997].

Mechanisms of Conceptual Change and the Role of Education

We would like to draw a distinction between bottom-up, conservative, additive and largely unconscious mechanisms and top-down, radical, deliberate, and intentional learning mechanisms. Examples of the former are the piagetian mechanisms of assimilation and accommodation. Examples of the latter can be mechanisms like hypothesis testing, the deliberate use of analogy and modeling, the use of external representations, or the use of thought experiments [Nerserssian, 1992].

The use of simple, bottom-up, additive mechanisms is adequate for what we shall call 'spontaneous conceptual change.' Spontaneous conceptual change is the kind of conceptual change that takes place naturally with development and learning in the context of lay culture. 'Instruction-induced conceptual change,' on the other hand, is the kind of conceptual change that requires systematic instruction in order to be achieved. Science concepts like the concepts of force, energy, and heat or the concept of photosynthesis usually require years of instruction before they are completely understood. We claim that instruction-induced conceptual change requires the deliberate use of top-down, intentional learning mechanisms to be achieved.

Let us examine, for example, the piagetian mechanisms of assimilation and accommodation. These simple mechanisms together with the extensive use of similarity-based analogical reasoning [Carey, 1985; Vosniadou, 1989] can lead to significant changes that can be described as 'theory changes' assuming of course that new knowledge is coming in through observation or from everyday culture. Everyday experiences with plants, such as watering plants – seeing them become bigger or noticing that sometimes they die – can lead children to understand that plants are similar to animals in certain properties like feeding, growing, and dying. These similarities can eventually make children consider that plants are living things, rather than inanimate objects, despite the fact that they lack self-initiated movement. Similarly, Inagaki [1990] showed that kindergarteners who were actively engaged in raising fish had much richer conceptual and procedural knowledge about goldfish, compared to children of the same age without such experience. But most importantly, the goldfish raisers started using the knowledge about goldfish as a source for analogies about the behavior of unfamiliar animals, suggesting significant reorganizations in the knowledge base.

Unlike spontaneous conceptual change, the use of such bottom-up, largely unconscious, additive, mechanisms is not very productive in the case of instruction-induced conceptual change; on the contrary, it leads to the formation of misconceptions. This is because in the latter case the learner is confronted with a scientific concept which presents a new explanatory framework that differs from his/her naive theory in its structure, in the phenomena it explains and in the individual concepts that comprise it. When we have two different explanatory frameworks, the simple addition or deletion of beliefs will necessarily produce hybrid or synthetic models.

Let us take the case where a child is simply told that the earth is a sphere (and maybe shown the globe) without any further explanation. This information comes in conflict with the child's naive model of the earth, based on everyday experience – namely, that the earth is flat, as well as with his belief in an up/down gravity (i.e., that physical objects, including the earth itself, need to be supported otherwise they will fall 'down'). Our studies have shown that in such situations, the use of simple, assimilatory types of mechanisms can give rise to a number of different synthetic models. Some possible synthetic models are the 'dual earth model' according to which there are two earths: a flat, supported and stable earth on which people live, and a spherical, rotating earth, which is a 'planet' up in the sky; another is the disc model according to which the earth is round but flat at the same time [Vosniadou & Brewer, 1992].

Synthetic models are created because children change some but not all of their beliefs about the earth that need to be changed if the scientific model is to be understood, using the bottom-up, additive mechanisms described earlier. They happen because the children do not have explicit knowledge of their own beliefs and therefore they understand neither the contradictions between their naive theories and the scientific explanations to which they are exposed, nor the distortions of the scientific view which they create.

In order to avoid the construction of such synthetic models, students must (1) become aware of the inconsistencies between their naive theories and the scientific ones, and (2) use the top-down, conscious and deliberate mechanisms for intentional learning mentioned earlier. In other words, instruction-induced conceptual change requires not only the restructuring of students' naive theories but also the restructuring of their modes of learning and the creation of metaconceptual awareness and intentionality [Sinatra & Pintrich, 2003; Vosniadou, 2003].

According to Hatano and Inagaki [2003], the creation of such intentional learners cannot be achieved without sociocultural support, without paying adequate attention to the social and cultural factors that are necessary to promote and facilitate instruction-induced conceptual change. While many researchers before him have stressed the importance of sociocultural factors in learning and cognition, Hatano's work is unique because he has been able to formulate a position that combines sociocultural with individual, constructivist approaches and relate it to the problem of conceptual change.

An important limitation of sociocultural (or situative) perspectives [Lave, 1996; Rogoff, 1998] is that they only consider the internalization or appropriation of existing cultural practices, tools, and artifacts and do not pay adequate attention to the active role of the individual mind in understanding or constructing new knowledge. As Hatano [1994] aptly expresses discussing the work of another of the Japanese colleagues [Kobayashi, 1994]:

> although understanding is a social process, it also involves much processing by an active individual mind. It is unlikely that conceptual change is induced only by social consensus. The post-change conceptual systems must have not only coherence but also subjective necessity. Such a system can be built only through an individual minds' active attempts to achieve integration and plausibility. (p. 195)

Hatano, together with his colleague Kayoko Inagaki, have conducted a number of educational studies in order to show how individual cognitive mechanisms can combine with sociocultural constraints to promote instruction-induced conceptual change [Hatano, 1998; Hatano & Inagaki, 1991; Inagaki, Hatano, & Morita, 1998]. They paid particular attention to the use of classroom dialogue which they believed can foster individual cognitive change through constructive processes. Most of these studies are conducted using the Japanese science education method known as Hypothesis-Experiment-Instruction originally devised by Itakura [1962]. This method was utilized extensively by Hatano and his colleagues and it is a promising method for achieving exactly the kind of metaconceptual awareness required by students for the deliberate and intentional belief revision needed for instruction-based conceptual change.

The design of Hypothesis-Experiment-Instruction consists of presenting students with a multiple-choice problem with conflicting alternatives, some of which represent common misconceptions held by students. This method creates the necessary conditions for producing cognitive conflict. Hatano believes that cognitive conflict is important in inducing 'cognitive' or 'epistemic' motivation among students to evaluate their prior knowledge but may not be enough to create conceptual change. In order to amplify students' motivation, a teacher needs to create a sociocultural environment that favors prolonged comprehension activity and conceptual change, a 'collective comprehension activity' [Hatano & Inagaki, 1991].

One way a teacher can provide the sociocultural environment to encourage collective comprehension is to ask students to participate in dialogical interaction, which is usually whole-class discussion. Whole-classroom dialogue can be effective because it ensures on the one hand that students understand the need to revise their beliefs deeply instead of engaging in local repairs [Chinn & Brewer, 1993], and on the other hand that they spend the considerable time and effort needed to engage in the conscious and deliberate belief revision required for conceptual change [Miyake, 1986]. Often in these discussions, students break up in smaller groups that compete with each other in discovering the correct solution and supporting it with the best arguments. This division of labor creates what Hatano calls 'partisan' motivation which amplifies 'cognitive' motivation and enhances deep comprehension and the likelihood of conceptual change [Hatano & Inagaki, 1991].

It is not possible to reproduce in this short paper all the information in the rich educational studies through which Hatano and Inagaki have studied the sociocultural environments that foster instruction-induced conceptual change in the school context. Their studies have established some of the fundamental principles that need to be taken into consideration so that social interaction and group activity in classroom settings can result in considerable knowledge advancement and restructuring at the level of the individual. More work is needed to explore the different ways in which conceptual change can be effectively induced by combing cognitive and sociocultural factors [Hatano & Inagaki, 2003].

Concluding Remarks

There is currently a divide in educational research, with cognitive theorists focusing on intermental, individual, cognitive mechanisms as opposed to intermental, social mechanisms that are the focus of sociocultural theorists. The work of Hatano is a bright example of how the two research lines can be combined together and complement each other in order to provide some of the fundamental principles for the design of learning environments to deal with one of the most important problems in education, the problem of instruction-induced conceptual change.

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