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Conceptual Change

Intermediate article

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Conceptual change is the creation and alteration of mental representations that correspond to words. It is an important part of learning in science and everyday life.

INTRODUCTION

Concepts are mental representations corresponding to words. For example, the concept 'dog' is a mental structure that corresponds to the word 'dog' and refers to dogs in the world. Conceptual change is produced by mental processes that create and alter such mental representations. Explaining how conceptual change works is important for understanding the growth of scientific knowledge, the development of children's thinking, and the education of students in fields such as science and mathematics. In each of these kinds of learning, a theory of conceptual change is needed that can answer such questions as the following. What is the nature of the concepts that are learned? What kinds of changes do concepts undergo? What are the mental processes that produce different kinds of conceptual change? It is also interesting to inquire whether the processes of conceptual change in scientists, young children, and students are similar or different.

TYPES OF CONCEPTUAL CHANGE

The simplest type of conceptual change is when people learn a new concept. A more challenging type occurs when existing concepts must be adjusted and reorganized to accommodate new information: in such cases, the meaning of concepts changes in relation to other concepts and the world. In radical conceptual change, the development of knowledge involves a shift in which a collection of important concepts undergo alterations in meaning. In such cases, learning is not simply a matter of accumulating new concepts and beliefs; it also requires substantial revision and restructuring of mental representations.

CONCEPTUAL CHANGE IN SCIENTISTS

The problem of conceptual change in science was first highlighted in Thomas Kuhn's famous book, *The Structure of Scientific Revolutions* (Kuhn, 1962). He challenged the prevailing view that scientific knowledge grows cumulatively by progressively adding to the stock of available theories and concepts. Instead, Kuhn proposed that the development of science often involves revolutionary changes in which one theory or paradigm is replaced by a radically different one. For example, the acceptance of the Copernican theory that the earth revolves around the sun required the rejection of the Ptolemaic theory that the sun revolved around the earth. Replacement was not merely a matter of one theory being substituted for another, but also involved shifts in meaning of the concepts used in the theories. In the Copernican revolution, for example, the concept 'planet' shifted to include the earth and exclude the sun and moon. According to Kuhn, radical differences between theories make it difficult to establish rationally that one is better than another.

Kuhn distinguished between normal science, in which a dominant paradigm is taken for granted, and revolutionary science, in which the dominant paradigm is replaced by a radically new one. The main activity in normal science is puzzle solving, which deals with problems within the scope and constraints of the dominant way of thinking. Scientists pursue normal science until there is an accumulation of anomalies, which are problems that the paradigm fails to solve. For example, in the eighteenth century the prevailing theory of combustion based on phlogiston, a substance supposed to be given off by burning objects, encountered the anomaly that objects gain rather than lose weight during combustion. Scientists attempt to deal with individual anomalies as puzzles to be solved with the tools provided by the paradigm they accept, but the accumulation of anomalies produces a state of crisis in which scientists begin to consider the need for new theories. When a new paradigm is conceived that can solve the problems that were anomalous for the old one, a scientific revolution occurs and a new theory becomes accepted. Kuhn's favorite examples of scientific revolutions include the Copernican revolution, the chemical revolution in which Lavoisier's oxygen theory of combustion replaced the phlogiston theory, and the revolution in physics in which relativity theory was adopted.

Before Kuhn, science was generally viewed as a cumulative process in which new theories built on the successes of previous ones. Kuhn insisted that scientific revolutions are noncumulative episodes in which an older paradigm is replaced by an incompatible new one. He even suggested that the new and old theories are incommensurable with each other, that is, there may be no logical means for objectively choosing between them. A major source of incommensurability is the use by the different paradigms of very different concepts. For example, it might seem that the Newtonian physics and relativity theory both use the concept of mass, but Einsteinian mass can be converted into energy whereas Newtonian mass is conserved. Thus for Kuhn a major aspect of scientific revolutions was radical conceptual change.

In *Conceptual Revolutions*, Thagard (1992) offered a comprehensive account of the kinds of conceptual changes that have occurred in the major revolutions in the history of science. Most scientific revolutions involve the introduction of new concepts, such as Newton's gravitational force, Lavoisier's oxygen, Darwin's natural selection, and Wegener's continental drift. In addition, revolutions usually involve reclassification in which a concept changes its place in the hierarchy of kinds, just as Copernicus reclassified earth as a planet, Darwin reclassified humans as a kind of animal, and the cognitive revolution in psychology reclassified thinking as a kind of computation. Even more radically, the principle of classification sometimes changes, as when Darwin argued that species should be organized into kinds on the basis of evolutionary history rather than similarity. Like many other philosophers of science, Thagard argued that Kuhn had overestimated the conceptual differences between theories, so that conceptual change did not prevent one theory from being rationally preferred to another on the basis of its explanatory power. Nevertheless, he accepted Kuhn's basic contention that new theories often have very different conceptual systems from the ones they replace.

Philosophers and psychologists have discussed the cognitive mechanisms by which new conceptual systems in science are constructed. These include conceptual combination, in which a concept such as 'sound wave' is constructed out of the previously existing concepts 'sound' and 'wave'. New concepts are rarely derived directly from experience, but instead are built up from previously existing concepts. A concept produced by conceptual combination need not be a simple sum of the original concepts, but instead can involve emergent properties. For example, the concept 'blind lawyer' has characteristics not found in either 'blind' or 'lawyer': people use causal reasoning to conclude that a blind lawyer must be courageous.

Another creative mechanism is analogy, in which new scientific concepts are formed by adapting and transforming previous concepts. For example, Darwin's concept of natural selection was based in part on his familiarity with artificial selection practiced by breeders who produced new varieties of plants and animals. Maxwell developed concepts of electromagnetism using mechanical analogies (Nersessian, 1992), and Kepler extensively used analogies to develop new concepts concerning light and motion (Gentner *et al*., 1997).

Once a new conceptual system has been constructed by mechanisms such as combination and analogy, it becomes a contender to replace an existing conceptual system. The major cognitive mechanism for such large-scale conceptual change is explanatory coherence: scientists adopt a new theory along with its conceptual system because it provides a better explanation of the evidence and is more coherent with other beliefs (Thagard, 1992). Of course, most conceptual change in science does not involve such large-scale shifts in which conceptual systems are substantially altered, but rather the introduction of new concepts that fit in with existing conceptual schemes and theories.

CONCEPTUAL CHANGE IN YOUNG CHILDREN

Young children acquire a wealth of new concepts as their knowledge of language and the world increases. The average high-school graduate in the USA knows around 60 000 root words, which must have been acquired at a rate better than 10 per day. Presumably, children have concepts that are mental representations corresponding to all these words, so how can we account for their acquisition in such large numbers? Much conceptual change is straightforwardly cumulative, as children simply add new concepts such as 'dog' and 'ice cream' to their mental systems. However, some developmental psychologists have argued that conceptual development in children is like conceptual change in science, in that it sometimes requires substantial revisions of existing conceptual schemes.

Susan Carey argued that children's acquisition of biological knowledge between the ages of 4–10 years involves considerable conceptual reorganization (Carey, 1985). In particular, the concepts 'alive' and 'animal' undergo substantial change during those years. Many 4-year-olds have difficulty naming any objects that are not alive, and take objects such as tables and clocks as being alive because they have activities or motions associated with them. By the age of 10 years, however, most children have acquired the adult concept of 'living thing'. Similarly, children under 7 years old often do not count people and insects as animals. According to Carey, children undergo a complete reorganization of knowledge of functions such as eating and sleeping and of organs such as the stomach and heart as the domain of biological knowledge becomes differentiated from the domain of knowledge of human activities. It is not just that the concepts of a 10-year-old have different relations among them than those of a 4-year-old, but more that the concepts themselves have changed as the result of additional biological knowledge. The concepts 'animal' and 'plant' coalesce into the concept 'living thing' by virtue of recognition that they are fundamentally alike. At the same time, children learn to differentiate 'dead' from 'inanimate' as two different senses of 'not alive'. Just as scientists had to learn to differentiate between heat and temperature, so children have to learn to differentiate weight from size and density. Like scientists, children have theory-like conceptual structures, and learning consists in radical alteration of such structures, not just additions to them.

Frank Keil reached similar conclusions from his studies of the development of children's concepts of biological kinds (Keil, 1989). As children gain an increasing appreciation of the biological principles that organize adults' intuitive theories of biology, they increasingly appeal to origins and internal parts in their biological classifications, reducing the impact of visible features. For example, older children are more likely to judge that a pear covered with apple skin is still a pear. In contrast, there was no similar shift for artefacts such as cup and nail, indicating that conceptual change was specific to biological kinds. Keil argues that concepts are part of coherent belief systems, so that conceptual change is closely tied in with theory change in children.

Gopnik and Meltzoff (1997) are even more emphatic in tying conceptual change to theory change. They advocate the 'theory theory', according to which the process of cognitive development in children is similar to and perhaps even identical to the process of theory development in scientists. They describe changes in understanding of objects in infants, who are born assuming a world of three-dimensional objects that have visual, auditory, and tactile features. By 6 months, infants have gained systematic, coherent knowledge about the movements of objects, but they still lack understanding of hidden objects, which develops around 9 months. Later, at around 18 months, infants acquire the ability to represent invisible movements. Gopnik and Meltzoff contend that these shifts are like theory change in science, and that there is a certain incommensurability between the concepts of the old and new theories held by the infants.

These and other studies of learning in children strongly suggest that conceptual development is not simply a matter of accumulating new concepts but also involves important changes in concepts and conceptual systems. However, the evidence is still limited for claims that children's conceptual systems are like those of scientists and that the cognitive mechanisms of change in children are like those that take place in the minds of scientists. It is possible that children's knowledge is much more fragmented than the conceptual systems that make up scientific theories such as relativity and evolution by natural selection. Scientific theories consist of hypotheses that provide unifying explanations of diverse empirical phenomena, but no one knows whether children's beliefs involve the same kind of explanatory hypotheses. Moreover, the process by which scientists come to realize that one theory is better than and should replace a previous one involves a systematic comparison of the explanatory coherence of the two theories. Belief change in children may be much more piecemeal, as isolated fragments of a new theory of objects and kinds are acquired from experience and teaching. It is possible that new ways of looking at things supplant previous ones by a process of gradual build-up of new concepts and progressive disuse of old ones, rather than by a dramatic replacement of the old theories by new ones. The view that conceptual change in children is similar to theory change in scientists has been heuristically useful in stimulating research on children's learning, but much more empirical research is needed before the analogy between children and scientists can be accepted as showing a common set of cognitive processes.

CONCEPTUAL CHANGE IN STUDENTS

Suppose it is true that learning in children and scientists involves radical conceptual change rather than mere accumulation of new concepts and beliefs; then teaching students cannot be understood as merely providing new material to mesh with what students already know. Rather, education in science and other subjects may require a much more challenging process of dealing with the prior concepts and hypotheses that guide students' thinking. If teachers are not aware that students come to science classes with misconceptions about living things and physical processes, the teachers will not understand many of the difficulties that the students have in learning. From the perspective of conceptual change, teaching requires an active approach in which children must be engaged in building explanations that challenge concepts and beliefs that they previously held. Effective teaching may require the use of the kinds of analogical models and thought experiments that have often facilitated conceptual change in the history of science.

Chi (1992) argues that physics education is often difficult because it requires conceptual change across fundamental ontological categories such as matter, events, and abstractions. For example, naive students start with concepts of force, light, heat and current that class them as kinds of material substances, but physics students must learn to reconceptualize them as fields, which are a complex kind of event. Vosniadou and Brewer (1992) studied the development of children's knowledge of astronomy and found that children have difficulty reconciling the teaching that the earth is round with their other beliefs and observations. Children develop models that reconcile their observation-based belief that the earth is flat with what they are taught about the earth being round. For example, first-graders often believe that there are two earths – a flat one on which we live and a round one up in the sky. Other children think that the earth is a sphere, but we live inside it rather than on top of it. Thus, teaching children that the earth is round is not just a matter of telling them an additional fact, but requires them to revise their basic beliefs about the nature of the earth and other planets.

Science education is thus in part a cognitive process involving conceptual change, but it is also being increasingly recognized as a social, contextual, and emotional process (Guzzetti and Hynd, 1998). Conceptual change is a kind of mental change, but this may come about because of social interactions that students have with teachers and each other, as well as with the physical world. Motivation and emotion can greatly influence conceptual change when students acquire the intention and enthusiasm to adopt new concepts and hypotheses rather than to remain entrenched in their previous frames of mind. Future research on conceptual change will have to find ways to integrate cognitive processes with social and emotional processes that interact with them continuously.

The last section raised the question of whether conceptual change in children is like that found in scientists undergoing major theoretical changes. It is also an open question whether students need to undergo conceptual revolutions, or whether instead they can learn by a more gentle process in which new conceptual systems come to predominate over previous ones without the explanatory conflicts that occur in science. More research is needed to determine whether the cognitive mechanisms of conceptual change and theory evaluation that operate in scientists are also responsible for educational progress in science students.

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Conceptual Representations in Psychology

Introductory article

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CONTENTS

Introduction
Within-category representation
Between-category structure
Conclusion

Conceptual representation refers to the way that information about categories is stored and organized.

INTRODUCTION

Concepts are mental representations that are used to divide the world into groups that will be treated as equivalent for some purpose. Concepts may refer to objects, events, or ideas. Concepts may be used for reasoning, prediction, and communication. Some researchers have distinguished between concepts, which are the mental representations of information, and categories, which are sets of objects in the world that are grouped together. Often, however, these terms are used interchangeably.

Psychologists have explored concept representations in detail. This work has examined both within-category representation and between-category structure. Within-category representation refers to the information that describes a particular category such as ‘dog’. Between-category structure refers to the relationships among different categories such as that between the categories ‘dog’, ‘cat’, and ‘animal’.

WITHIN-CATEGORY REPRESENTATION

The central question about within-category representation involves the way people store information about particular concepts that enables them to classify new items (exemplars) as members of a