
What changes in conceptual change?

Andrea A. diSessa, Graduate School of Education, University of California-Berkeley and Bruce L. Sherin, School of Education and Social Policy, Northwestern University, Evanston, Illinois, USA

This paper has two aims. First, it reviews literature about conceptual change and about the study of concepts more broadly. The principal claim is that much prior work has suffered from inexplicitness and imprecision in terms of what constitutes a concept. Second, we introduce a theory of one particular type of concept. A *coordination class* is a systematic collection of strategies for reading a certain type of information out from the world. We identify both structural components and performance properties of coordination classes. Using this theory, we analyse protocol data from a student with respect to the difficult concept of force in Newtonian mechanics.

Introduction

The intent of this paper is to add to theory about the fundamentals of conceptual change. We want to show where imprecision in prior descriptions has marred progress and we want to take some steps towards a more sound account of the nature of conceptual change. Our basic contention is that it is essential for researchers to answer the question 'What changes in conceptual change?' with substantially greater precision than has heretofore been attempted. We will, of course, argue for this contention as the paper proceeds, but the central observation is that how one understands and describes the *processes* of conceptual change must flow from an account of the entities that are changing. For example, suppose we begin with the image of a network of nodes, each of which corresponds to a concept, with the nodes connected by links of multiple types. This is called a semantic net and its purpose is to model meaning by situating a concept in a larger field. What are the relevant types of change? Some possibilities are:

- We can add or delete nodes (concepts).
- We can add or delete links between nodes, or change the type of an existing link.
- If the network has a characteristic global organization (perhaps a hierarchical structure), we can perform more dramatic alterations to this structure.

These are just a few of the possibilities. Thagard (1992), for example, begins with a network of this type and lists nine degrees of change.

Alternatively, suppose we start with the image of a concept as a set consisting of elements which are instances of the concept. Given such a model, changes to the concept correspond to changes in the constituting elements, which means adding or deleting instances. We might also identify some special types of changes to these

sets. For example, the set could be broken into two parts (differentiation), or we could form the union of two sets (coalescence). The point, once again, is that the possible types of change are largely dictated by the nature of what is changing.

As this paper proceeds, we will be working towards our own answers to the 'what changes' question. We are, of course, not the first people to propose to answer this question. However, we will argue that many proposed answers only end up begging the question. Furthermore, we believe that, even where answers are given, greater precision is needed.

In what follows, we begin by presenting what we call the 'standard model' of conceptual change. This model is, we will argue, typical of the way that conceptual change is understood in educational research. Within this model, the answer that is typically given to the 'what changes' question is 'concepts'. This observation motivates us to turn our attention to the notion of concept. We will examine how this notion has been treated in the literature dealing with conceptual change, and we will try to pinpoint some difficulties. Ultimately, we will argue that it is necessary to replace the notion of concept with a variety of more carefully defined theoretical constructs.

In the second major portion of this paper we will present our own candidate for one of these new theoretical constructs, what we call a *coordination class*. After presenting a general introduction to coordination classes, we will focus our attention on physical or mathematical quantities as examples of coordination classes. We will then illustrate these ideas with excerpts from some clinical interviews, providing an analysis focused around the concept of force.

The standard model of conceptual change

The purpose of introducing the notion of conceptual change, especially in educationally-oriented work, is to separate learning into at least two types: we want to have a vocabulary that distinguishes deep varieties of change from more routine sorts of learning, such as fact memorization and the gradual accretion of beliefs. Any account of conceptual change should draw a line between these two types of learning. The standard model does this; it is an image that is invoked by a wide array of researchers, both implicitly and explicitly, to describe what counts as 'conceptual change', which represents deep, more difficult to accomplish learning, in opposition to more mundane sorts of learning. For us, the standard model serves as a jumping-off point, but we will ultimately react against it.

We begin with a version of the standard model that appears in the work of Susan Carey (1988). In order to distinguish more and less fundamental varieties of change, Carey contrasts the accounts that appear in two bodies of literature. First, she begins with a discussion of literature concerning the novice/expert shift, especially as it appears in accounts of physics learning. She describes how some novice misconceptions may be replaced by more expert beliefs. For example, the misconception 'there is no motion without a force' should be replaced with the expert belief 'there is no acceleration without a force'.

What sort of change is this? According to Carey, one possibility is that we should understand this as a change in the *relations* among the concepts that appear in these beliefs. The point is that concepts such as force, motion, and acceleration may remain unchanged in the move from novice to expert; they are simply related

in new ways. Students develop new beliefs, and follow those which are a type of relation. But they may be beliefs about the same concepts.

For contrast, Carey describes another body of literature that emphasizes the possible existence of more dramatic varieties of change. Here, Carey turns to the history of science, and especially to the work of Thomas Kuhn. Carey states that, although there has been much argument and counter-argument, 'a strong view of restructuring has survived, one that allows for true conceptual change among core concepts of successive theories'. In discussing the historical development of theories, historians have argued that there may be changes 'even in the individual concepts in the center of each system' and 'because of these differences, some terms in one theory may not even be translatable into the terms of the other' (Carey 1988: 6).

Carey thus provides a contrast between more and less dramatic varieties of change. If the less dramatic variety is accurate for describing what happens when a student learns physics, then it may be good enough to understand students as simply acquiring new beliefs about (that is, new relations among) concepts, such as force and mass, that they already possess. However, if the stronger version is correct, it may not be accurate to think of students as even talking about the same things when they say 'force' or 'mass'; the very concepts may differ in some fundamental manner. The concepts may be incommensurable, to use the term that is used by historians of science.

Carey calls these two varieties of change 'weak' and 'strong' knowledge restructuring. In weak restructuring 'new relations among concepts are represented, and new schemata come into being which allow the solution of new problems and which change the solutions to old problems'. In contrast, strong restructuring involves 'change at the level of individual concepts at the core of the successive systems' (p. 7). The latter, stronger variety of restructuring we call conceptual change.

This is the standard model of conceptual change. We can see that it attempts to do the job of distinguishing between conceptual change and more mundane varieties of learning. Other researchers use different language than Carey, but present very similar images. For example, Gentner *et al.* (1997: 31–2), writing in a recent special issue on conceptual change, distinguish three grades of change: belief revision, theory change, and conceptual change.

Belief revision is a change in facts. Theory change is a change in the global knowledge structure. Conceptual change, in some sense the most drastic, is a change in the fundamental concepts that compose the belief structure. Conceptual change thus requires at least locally nonalignable or incommensurable beliefs.

Although Gentner *et al.* (1997) distinguish two degrees of change in the relations among concepts, it is clear that their notion of what counts as conceptual change is very similar to that of Carey.

It is worth emphasizing that the standard model originated in literature from the history of science. We saw that Carey drew on this literature to develop her own distinction. And, although not all researchers subscribe to many of the specifics – such as whether it is ever accurate to speak of concepts as being 'incommensurable' – terminology from the history of science has been central to discussions of conceptual change. For example, in an influential article that has been described as 'seminal' (Magnusson *et al.* 1997), Posner *et al.* (1982: 212)

develop their version of the standard model precisely by making analogies to the history of science. In particular, they make analogy to the Kuhnian notions of 'normal science' and 'scientific revolution':

There are two distinguishing phases of conceptual change in science. Usually scientific work is done against the background of central commitments which organize research... The second phase of conceptual change occurs when these central commitments require modification. Here the scientist is faced with a challenge to his basic assumptions. If inquiry is to proceed, the scientist must acquire new concepts and a new way of seeing the world. Kuhn terms this kind of conceptual change a 'scientific revolution'

With Kuhn's version laid out, Posner and colleagues (1982: 212) make their analogy to individual learning:

We believe there are analogous patterns of conceptual change in learning. Sometimes students use existing concepts to deal with new phenomena... Often, however, the student's current concepts are inadequate to allow him to grasp some new phenomenon successfully. Then the student must replace or reorganize his central concepts.

Not only are ideas borrowed from the history of science, much of the conceptual change literature uses historical examples for illustration. For example, the article by Gentner *et al.* (1997) cited above, looks in detail at the work of Kepler. Similarly, Wisner (1988) discusses the historical development of the concepts of heat and temperature. Thagard (1992) uses a number of historical examples, including the replacement of the phlogiston theory by the oxygen theory.

Not all conceptual change researchers would subscribe to the standard model, at least not in the particular way that we have presented it. Furthermore, even those that do subscribe to a version of this model might reasonably complain that what we have presented is overly simplified. There are complications and theoretical positions that relate to the standard model in ways that are not trivial to work out. In addition, most writers who describe conceptual change in this manner also count other types of change as conceptual change. To cite what is perhaps an extreme example, Thagard (1992) counts six of his nine degrees of change, mentioned above, as conceptual change.

Nonetheless, the above exposition of the standard model is sufficient to establish the jumping-off point that we need for the remainder of this paper. What we have tried to do, thus far, is document that conceptual change is very often understood as involving changes in 'the very concepts' at the 'core' of a conceptual system, the very 'terms' in which the world is understood. When this foundation of terms changes, everyone seems to agree that this is difficult, and we call it conceptual change.

Thus, we must turn our attention more seriously to *concepts* and how they change. In asking what changes in conceptual change, we will now answer 'concepts'. But, since we have yet to say much about what a concept is, this only goes so far towards answering our question. Indeed, one of the most important difficulties of the standard model, in most of the relevant presentations in the literature, is its failure to unpack what 'the very concepts' are in sufficiently rigorous terms. Without a clear notion of what a concept is, the standard model really only begs the question of what counts as conceptual change.

