

THE PROCESSES AND CHALLENGES OF CONCEPTUAL CHANGE

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Abstract. Students engaged in learning a large body of related knowledge often possess some incorrect naïve knowledge about the domain. These “misconceptions” must be removed and/or the correct conception must be built in order for students to achieve a deep understanding. This repair process is generally referred to as “conceptual change.” However, although conceptual change has been discussed for several decades within different research contexts, the literature nevertheless presents a somewhat blurry picture of what exactly misconceptions are, what constitutes conceptual change, and why conceptual change is difficult. In this chapter, we suggest that one should think of misconceptions as *ontological miscategorizations* of concepts. From this perspective, conceptual change can be viewed as a simple shift of a concept across lateral (as opposed to hierarchical) categories. We argue that this process is difficult if students lack awareness of when a shift is necessary and/or lack an alternative category to shift into. These ideas are explored using a detailed example (i.e. diffusion) from a broad class of science concepts (i.e. emergent processes) that are often robustly misunderstood by students.

1. INTRODUCTION

When students engage in the task of learning some large body of related knowledge, such as a specific topic within a science domain (e.g. electricity or the human circulatory system), they are faced with two main obstacles. First, a great deal of information is simply missing from their initial understanding, and this new information must be acquired. However, it is not the case that students enter a learning situation with a blank slate. Instead, students often have some naïve knowledge or prior conceptions about the domain.

Naïve knowledge has two properties: it is often incorrect (when compared to formal knowledge) and it often (but not always) impedes the learning of formal knowledge with deep understanding. However, some type of naïve knowledge can be readily revised or removed through instruction (for simplicity, instruction in this chapter refers to the presentation of knowledge through written text). We will refer to this type of naïve knowledge simply as “preconceptions”. On the other hand, some other type of naïve knowledge seems highly resistant to change. These misunderstandings persist strongly even when they are confronted by ingenious forms of instruction. We refer to these *robust* ones as “misconceptions.” In the following list of prior conceptions, the final four items are thought to be examples of misconceptions:

- 1) Insects are not a type of animal (Osborne & Wittrock, 1983)

- 2) The heart is responsible for reoxygenating the blood (Chi, de Leeuw, Chiu, & LaVancher, 1994)
- 3) The earth is spherical, and people stand on top or inside of it (Vosniadou & Brewer, 1992)
- 4) Whales are a type of fish
- 5) A thrown object acquires or contains some internal force
- 6) An object and the shadow it casts are made of the same kind of substance
- 7) Electrical current is stored inside the battery
- 8) Coldness from the ice flows into the water, making the water colder

All naive knowledge needs to be repaired in order to promote deep understanding. The challenge is to understand why misconceptions in particular are resistant to change. Thus, although all processes of revising or removing prior conceptions can be generically construed as “conceptual change”, the terms “conceptual change” are often reserved for referring to the processes of repairing misconceptions (Hewson, 1981; Posner, Strike, Hewson, & Gertzog, 1982). For emphasis, sometimes the specific processes of repairing misconceptions have been referred to as “radical” conceptual change (Keil, 1979), “genuine” conceptual change (Gunstone, Champagne & Klopfer, 1981), conceptual change “of the extreme sort” (Carey, 1991, p. 259), or nonconservative conceptual change (Thagard, 1996); whereas the processes of repairing non-robust preconceptions have been described as belief revision (Carey, 1991), mundane (Thagard, 1990), and ordinary (de Leeuw & Chi, in preparation). We will refer to the processes of repairing misconceptions as “conceptual change” and the processes of repairing preconceptions as “conceptual reorganization”.

Although conceptual change has been discussed for several decades in the context of developmental research, science education research, and in the philosophy of science, the literature nevertheless presents a somewhat blurry picture of *what exactly misconceptions are, what constitutes conceptual change, and why it is difficult*. The goal of this chapter is to address these three related questions of process and difficulty in conceptual change. Because we define conceptual change as the processes of removing misconceptions, this definition is circular unless we can first establish what constitutes a misconception. To preview, we base our definition of misconceptions on the assumption that misconceptions are, in fact, miscategorizations of concepts. Thus, our first claim is that misconceptions are concepts categorized into an (“ontologically”) inappropriate category.

From such a definition of misconceptions, our second claim follows, that conceptual change is merely the process of reassigning or “shifting” a miscategorized concept from one “ontological” category to another “ontological” category. “Ontological” categories have a lateral relationship to each other. In contrast, reconceptualizations that occur within the same ontology or hierarchy are better referred to as “conceptual reorganization” (Chi, 1992). Our third claim then is that this conceptual shift process itself is not inherently difficult, but is instead challenging mainly when students lack *awareness* of their misconceptions (i.e., they lack the knowledge that they need to shift) and/or lack the alternative (“ontologically” distinct) categories (*missing categories*) to which they should reassign their misconceptions. We are not denying that conceptual change can also

be difficult because the concepts involved are complex or “incommensurate” (Carey, 1991); instead, we propose that these issues of *awareness* and *missing categories* are an important, new perspective that has not been considered. Thus, these three claims purport to answer the three questions posed above about the nature of misconceptions, the processes of conceptual change, and why it is difficult. These claims are detailed in the remaining part of this paper. Moreover, we will discuss how an ontological category view provides clear and testable definitions of misconceptions and informs unresolved issues in other perspectives. As part of our overall argument, we will provide a detailed analysis of misconceptions of a special class of scientific concepts (e.g. diffusion).

2. PRECONCEPTIONS AT THE “PROPOSITION” AND THE “MENTAL MODEL” LEVELS

2.1. *The Proposition Level and Removing Incorrect Beliefs*

A system of knowledge can be evaluated at the level of single ideas that can be stated as a sentence, or “propositions”. These mentally-represented propositions are beliefs that students assume to be true, such as “Air is not made of matter” (Carey, 1991). If one assumes that beliefs are composed of concepts, then can mistaken beliefs be considered “misconceptions?”

When one examines a student’s initial beliefs, and compares this set of propositions to a student’s final beliefs (after reading a text), two classes of beliefs seem to emerge. In one case, beliefs that are incorrect at the outset are replaced by the correct knowledge after instruction. However, in a second case, a student’s initial, inaccurate beliefs remain even after instruction. We might label beliefs of the first sort as “incorrect beliefs,” and those of the second sort as “alternative beliefs.”

Are alternative beliefs misconceptions, since they were not removed? It turns out that if we examine the text sentences in detail, and assess whether each individual initial belief was refuted or not by the text sentences, then it became clear that incorrect beliefs were the ones that the text sentences directly or indirectly refuted; whereas alternative beliefs were the ones that the text never addressed. For example, a student may initially believe that *all blood vessels have valves*.

However, after reading the text, which never mentions valves in the context of the arteries but only in the context of veins, then such indirect refutation can revise a student’s initial belief to the correct proposition that *veins are the only blood vessels with valves*. It is tempting to say that alternative beliefs, since they seem to resist instruction, must be examples of misconceptions. However, our analysis has shown that the difference between incorrect and alternative beliefs relies not on qualitatively different knowledge, but on how they are addressed by the text. Specifically, incorrect beliefs are readily revised because the text tends to contradict them either directly or indirectly, at the individual proposition level. On the other hand, “alternative beliefs”) are not addressed by the text at all, such as *the liver restores blood* or that *veins are like nerves that transmits signals from the brain*

(these alternative beliefs are taken from the protocols of Chi, Siler, Jeong, Yamauchi, & Hausmann, in press). Such results were shown in our study on learning about the human circulatory system (de Leeuw, 1993). In that study, middle school children (8th graders) were asked to define 23 terms, diagram the path of blood through the circulatory system, and answer 42 questions, prior to instruction. In such pre-tests, students typically expressed about 15.8 propositions of preconceptions. From these 15.8 cases, only “stable” propositions (those that were repeated at least once, and that were not generated online in response to the content of the 42 questions) were considered. This filtering method reduced the number of preconceptions to 2.8 per student, giving a total of 31 across 12 subjects. In the post-tests, 77% of the 31 propositions were correctly revised if the text addressed them (these can be considered the incorrect beliefs). Five of the preconceptions remained. However, these five were not revised because *the text never addressed them*. We can consider these to be alternative beliefs.

The results above lead to a conclusion and a query. Clearly, both “incorrect beliefs” and “alternative beliefs” in this domain are preconceptions in that they can be removed with instruction, and not removed if instruction does not address them. This ease of removal for preconceptions is qualitatively different from misconceptions, which are retained even after much instructional confrontation. For example, if students believed that *Electrical current is stored in the battery*, then correct understanding cannot be easily achieved by merely confronting students at the proposition level with direct refutation, such as telling them that *electrical current is not stored anywhere*. It suggests that conceptual change of “false beliefs” require changes at a larger grain size. The query from the results above is why were all the preconceptions removable, once a text refutes them? That is, why were misconceptions not manifested in this domain? The answer alluded to in the preview, will be more obvious and revisited once we detail more clearly what misconceptions are.

2.2. *The Mental Model Level and Repairing Flawed Models*

Instead of representing knowledge at a piecemeal level, one can represent knowledge as a set of interrelated propositions, or a “mental model”. What this adds to a discussion of proposition level beliefs is a structure in which the propositions are embedded. Examples of research that represent students’ initial knowledge in terms of mental models are Vosniadou and Brewer’s (1992) studies of young children’s concepts of the shape of the earth, and Chi’s (2000b) work with middle school students’ understanding of the human circulatory system.

Like propositions, distinctions can be made about the nature of naïve mental models. One such distinction is made on the basis of coherence. An incoherent, or “fragmented,” mental model can be conceived of as one in which propositions are not interconnected in some systematic way. Such a model cannot be used to give consistent and predictable explanations. Furthermore, because many parts may be unconnected, students are often aware that they lack a complete understanding. Alternatively, mental models can be coherent, meaning that the constituent

propositions are related in an organized manner. Unlike fragmented models, such representations can be used to generate explanations, make predictions, and answer questions in a consistent and systematic fashion.

A coherent model can be correct or flawed. By “flawed” we mean a mental model whose coherent structure is organized around a set of beliefs or a principle that is incorrect. Note that this level of “correctness” is distinct from the correctness of individual propositions. A flawed mental model may share a number of propositions with a correct mental model, but they are interconnected according to an incorrect organizing principle. In addition, though students with fragmented mental models are often aware of their lack of understanding, this is not true for students with flawed, but coherent models. Because these students are able to answer questions adequately and consistently, they may be blind to their lack of deep understanding. Two studies clearly illustrate what we mean by a flawed mental model.

Vosniadou and Brewer (1992) have explored young children’s naïve conceptions of the earth and its shape. One common misconception they’ve identified is the belief that the earth is shaped like a round, flat pancake. However, children can make sense of their world using this flawed, disk-earth model. For example, the flatness of the earth is compatible with their everyday perceptions, in the sense that the ground appears level. They can use this simplistic model to answer questions and generate explanations that are meaningful to them.

Another example is provided by research on middle school students’ naïve conceptions of the circulatory system (Chi, 2000b; Chi et al., 1994). On average, about half of the students think of the human circulatory system as a “single-loop,” in which the blood leaves the heart, travels to all parts of the body, and then returns to the heart (see upper left diagram of Figure 1). This is in contrast to the correct pathway, a “double-loop,” that involves both systemic (heart-to-body) and pulmonary (heart-to-lungs) circulation (see upper right diagram of Figure 1). However, the single-loop model is coherent. We can demonstrate this because it differs from the correct, double-loop model in systematic ways: the source of oxygen, the purpose of blood flow to the lungs, and the number of loops. Specifically, a single loop model is organized by a principle, consisting of the beliefs that the heart (rather than the lungs) is the source of oxygen, that blood goes to the lungs to deliver oxygen (rather than to exchange carbon dioxide and oxygen), and that there is just one loop. Thus, a flawed mental model is one that is organized around an alternative principle, consisting of a set of beliefs shown in the left column of Figure 1, whereas the correct double loop model is organized around another set of beliefs, shown in the right column of Figure 1. With a flawed single loop model, students will give systematic and predictable answers to questions like the following examples (student replies are in parentheses; Chi et al., 1994):

1. Why does blood have to go to the heart? (“to get oxygenated”)
2. Why does blood go to the lungs? (“to deliver oxygen to the lungs”)

In data collected, but not reported, by Chi et al. (1994), over half of the students (8 out of 14 students in the prompted group) had easily and consistently identifiable mental models that were coherent, but flawed.

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