New Approaches to the Problem of Conceptual Change in the Learning of Science and Math

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Introduction

Concepts are not static. They change in many ways from the most simple – as in cases where a new instance is added on to an existing concept – to the most radical – as in cases that involve belief revision, ontological category shifts and changes in causality. The purpose of the present symposium is to present some of the most recent attempts to describe and explain the more radical kinds of conceptual changes that take place when students are exposed to counter-intuitive concepts in science and mathematics.

One important issue in conceptual change research has focused on whether conceptual change requires the revision of concepts embedded in relatively coherent 'framework theories' (e.g.,Vosniadou, Vamvakoussi & Skopeliti, 2008) or the integration of fragmented pieces (diSessa, 2008). According to the 'framework theory' approach, students use enrichment mechanisms to incorporate scientific information to an incompatible naive theory. Because of the incompatibility between existing knowledge structures and the new, to-be-acquired, information, such learning processes may lead either to internal consistency (and, thus, to fragmentation) or to the formation of misconceptions. In recent work, Brown and Hammer (2008) propose that the knowledge system should be seen as consisting of dynamic cognitive structures which arise from the interactions of smaller conceptual elements. They claim that such a complex systems perspective can integrate the differences between the fragmentation vs. coherence accounts.

Another recent debate in this area concerns Chi's (2008) categorical shift hypothesis vs. Ohlsson's (2011) resubsumption hypothesis to explain the processes thereby which learners abandon their prior beliefs because they are inconsistent with currently accepted scientific explanations. As noticed by Ohlsson (2009) such non-monotonic changes are difficult to promote with instruction and have a low probability of occurring spontaneously. According to the resubsumption hypothesis, when a learner comes to realize that an alternative theory, developed to make sense in one domain, may be preferable in order to explain a phenomenon which applies to some other domain, s/he will subsume the phenomenon under the alternative theory. This process depends on the recognition of similarities rather than on being confronted with anomalies. In contrast, according to the category shift hypothesis, a concept is categorized under the wrong category in the first place and conceptual change is brought about by noticing the anomalies caused by this mis-categorization.

Even though these arguments are important for understanding conceptual change processes they have had little presence in the meetings of the Cognitive Science Society so far. The aim of this symposium is to bring some of the current discussions and different perspectives on conceptual change to the attention of the cognitive science audience. All the speakers are key developers of the different approaches and have led their development.

The Symposium

Misconceived Causal Explanations for 'Emergent' Science Processes: *Michelene T.H. Chi.* Examples of the visible or imagined patterns of science processes such as *natural selection* and *diffusion* might be giraffes' necks getting longer over generations and ink "flowing" in water after several drops have been added. Instead of explaining the patterns of these processes as emerging from the collective interactions of all the agents (e.g., both the water and ink molecules), students often explain the pattern as being caused by controlling agents (e.g., the ink only) with intentional goals. Radical conceptual change refers to learning that changes such robust and incorrect prior explanations to the correct explanations, and this kind of conceptual change has been impossible to achieve.

Our hypothesis for why students generate misconceived explanations is that students have formed familiar scripts and narratives from their daily exposures to everyday events and stories, and they rely on a generalized version of their narrative scripts to interpret and explain science processes. This generalized script, (or a "direct causal schema"), is perfectly adequate and accurate for explaining sequential and stage-like science processes such as cycles of moon, circulation of blood, stages of mitosis, and photosynthesis, as well as the conditions and constraints of the patterns themselves. However, such a “direct causal schema” is inappropriate for explaining non-sequential (or emergent) kind of sciences processes, such as diffusion, natural selection, osmosis, and heat flow, resulting in robust misconceived explanations. In order to achieve conceptual change, students need an alternative general schema that is suitable for explaining and interpreting emergent processes. We describe one attempt at designing and teaching a generalized “emergent causal schema.”

Explicit and Implicit Processing in a Laboratory Model of Conceptual Change: *Stellan Ohlsson and David Cosejo*. We hypothesize that conceptual change requires both deliberate hypothesis testing and implicit learning of co-occurrence information in the environment. However, well-defined computational process models of conceptual change are yet to appear. Conceptual change is a temporally extended process with infrequent and course-grained expression in observable behavior. Developmental psychologists, educational researchers and historians of science work with temporally scarce data that provide scant information about the processes involved. To study these processes under controlled conditions, we have developed a laboratory model of conceptual change that we call re-categorization. In a re-categorization paradigm, participants learn an unfamiliar category, to criterion, at which point the target category is re-defined. The participants are not informed of this but continue the standard categorization cycles of stimulus presentation, categorizations, and feedback until the revised category has been learned to criterion. The question is how, by what processes, the initially acquired category – the “misconception” – is unlearned, and the revised, target category is acquired. We present some preliminary data obtained with this paradigm that supports the view that conceptual change (in this paradigm) is an interaction between explicit and implicit processing. The relation of the model to naturalistic conceptual change is raised, and the question of how the model can be improved to capture more of naturalistic processes is discussed.

Conceptual change processes in mathematics: The case of fractions: *Stella Vosniadou.*The results of a series of experiments will be presented and used to argue that students’ difficulties with fractions go beyond the mere lack of adequate practice and unfamiliarity Rather, the evidence points to the conclusion that we are dealing with a conceptual change problem, where the new, to-be-acquired information conflicts with students’ concept of number as natural number and where the whole number concept inhibits the acquisition of fraction information and constrains operations with fractions even in adults. According to the framework theory (Vosniadou et al., 2008), students’ initial concept of number constrains their interpretation of new information regarding rational number causing persistent misconceptions. Misconceptions such as ‘multiplication always makes bigger’ and ‘the bigger the terms the bigger the fraction’ reveal the interference of rational number reasoning on rational number tasks. The framework theory suggests that misconceptions are often caused as students use enrichment mechanisms to add the new, incompatible information to their initial number concept. Understanding fractions requires the construction of an integrated representation of number which may critically depend on the development of executive function skills such as the capacity to inhibit habitual responses.

A Complex Dynamic Systems Perspective on Conceptual Change: *David E. Brown.* When a student's conception is considered as a Complex Dynamic System -CDS (i.e., as like a dynamic ecosystem rather than as like a "regular thing," such as a rock), aspects of students' conceptions and conceptual change, which are surprising if these conceptions are considered as regular entities, become expected. First, with CDS's, at times strong influences can lead to little change (strong stabilities or "attractors" develop that are affected little by external influences), which predicts the kind of robustness often seen with students' conceptions. Second, CDS's are emergent and evolving rather than static. Any identifiable systematicities in student thought would then be the result of dynamic emergence from the complex system of knowledge elements. Such emergent structures can be fleeting or highly stable, accounting for both strong coherence and significant contextuality in students' conceptions, both of which have been seen in numerous studies. Finally, CDS's are embedded in and embed other CDS's. We would therefore expect interactions among various levels of complexity that impinge on students' conceptions: subconceptual, conceptual, metaconceptual, discursive, sociocultural, etc. A CDS view encourages consideration of such interactions, without a reification of one level to the exclusion of others. Such a multidimensional perspective, a natural outgrowth of a CDS view, is increasingly seen as important in considerations of student conceptual change.

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