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The role of domain-general cognitive resources in children's construction of a vitalist theory of biology

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ABSTRACT

Some episodes of learning are easier than others. Preschoolers can learn certain facts, such as "my grandmother gave me this purse," only after one or two exposures (easy to learn; fast mapping), but they require several years to learn that plants are alive or that the sun is not alive (hard to learn). One difference between the two kinds of knowledge acquisition is that hard cases often require conceptual construction, such as the construction of the biological concept *alive*, whereas easy cases merely involve forming new beliefs formulated over concepts the child already has (belief revision, a form of knowledge enrichment). We asked whether different domain-general cognitive resources support these two types of knowledge acquisition (conceptual construction and knowledge enrichment that supports fast mapping) by testing 82 6-year-olds in a pre-training/training/post-training study. We measured children's improvement in an episode involving theory construction (the beginning steps of acquisition of the framework theory of vitalist biology, which requires conceptual change) and in an episode involving knowledge enrichment alone (acquisition of little known facts about animals, such as the location of crickets' ears and the color of octopus blood). In addition, we measured children's executive functions and receptive vocabulary to directly compare the resources drawn upon in the two episodes of learning. We replicated and extended previous findings highlighting the differences between conceptual construction and knowledge enrichment, and we found that Executive Functions predict improvement on the Vitalism battery but not on the Fun Facts battery and that Receptive Vocabulary predicts improvement the Fun Facts battery but not on the Vitalism battery. This double dissociation provides new evidence for the distinction between the two types of knowledge acquisition, and bears on the nature of the learning mechanisms involved in each.

1. Introduction

Some episodes of knowledge acquisition are extraordinarily easy and some are extraordinarily hard. For example, adding new facts to our database on first encountering evidence for them, through testimony or observation, and retaining those facts for weeks or more is easy (Markson & Bloom, 1997). Conversely, adding new facts that express propositions central to a framework theory (Wellman & Gelman, 1992) that is not yet constructed by the child is very hard (Carey, 1985b, 2009). Many factors differentiate the

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easy cases of knowledge acquisition from the hard ones. One is that the hard cases often involve conceptual construction and conceptual change.

1.1. Knowledge enrichment vs. conceptual construction

Concepts are the atoms of beliefs, the units from which representations of propositions are formed. Most knowledge acquisition consists of acquiring new beliefs (adding new propositions to one's stored knowledge) stated over concepts one already has, or concepts one can construct upon first encountering an exemplar of them. Carey (2009) calls this process "knowledge enrichment." A preschooler's forming a concept of lady bugs, or learning what they are called, or learning what they eat, requires only that they encounter a lady bug, hear it labeled, or be told this fact, because they already have the concepts of animals, animal kinds, and their characteristic diets (see Carey, 2015). Of course, not all cases of knowledge enrichment are easy. Memorizing the names of state capitals or the names for every bone in the body, where the items interfere with each other, is one type of knowledge enrichment that is not easy. So too is straightforward hypothesis testing that is not highly constrained. Finally, so too might be cases of learning procedural knowledge – like the count routine formulated over a long numeral list. Nevertheless, although not all cases of knowledge enrichment are easy, the easy cases of concept learning and knowledge acquisition are *always* knowledge enrichment.

In contrast, sometimes new information presented to children is stated in terms of language that expresses concepts that are incommensurable with those in terms of which the child thinks about the entities referred to. That is, not only do children lack the concepts, they do not yet have the conceptual resources even to express them. For example, telling a 6-year-old child "Gold is an element with atomic number 79," cannot lead to new knowledge shared with a chemist, for the child does not have the concepts *element* or *atomic number* that were first constructed in the 19th century. To understand this sentence, conceptual change is required. Such conceptual changes often unfold over centuries of cultural evolution, always unfold in ontogenetic development only upon months or years of exposure, and often are not achieved by many humans despite years of explicit tutorial in school (c.f. Carey, 2009). Episodes of conceptual change are *never* easy.

Both fast-mapped knowledge enrichment and conceptual change have been extensively explored, but rarely side by side in the same study. Furthermore, very little is known about the domain-general cognitive resources that support these two types of learning. The present study addresses these gaps. We begin by characterizing the two types of learning in general terms and summarize some of what is known about the learning mechanisms that support each. Next, we describe a specific case of conceptual construction, children's acquisition of vitalist biology, which is the target of the present study. We contrast the process of constructing a new framework theory requiring conceptual changes within individual concepts (one kind of conceptual construction, but not the only kind; see Carey, 2009, 2015) with the process of knowledge enrichment where the knowledge is fast mapped. Finally, the present study begins to explore the role of domain-general cognitive resources, focusing here on executive functions and receptive vocabulary, in the two types of learning (conceptual construction and knowledge enrichment).

An episode of conceptual change is characterized by two successive systems of concepts for a common domain of phenomena, Conceptual System 1 and Conceptual System 2 (CS1-CS2). Conceptual systems are characterized through content analyses of the concepts that underlie inferences, patterns of judgments, and explicit explanations and justifications for these inferences and judgments. Establishing conceptual construction requires specifying the ways in which CS2 is qualitatively different from CS1. Conceptual change, one kind of conceptual construction, is change at the level of individual concepts, and consists of differentiations, such that the concept that is undifferentiated in CS1 is incoherent in the light of CS2; coalescences, such that the coalesced concept in CS2 unites entities that cross ontological boundaries in the light of CS1. From the point of view of essentialist analyses of conceptual structure (Ahn & Kim, 2000; Gelman, 2005; Strevens, 2000), conceptual changes also sometimes involve changes in representations of the causally deepest properties of the entities that fall under the concept (Carey, 1985a, 1985b, 2009). Episodes of conceptual change always result in new conceptual primitives, new atoms of beliefs (Carey, 2015).

Carey (2009) characterizes a bootstrapping process ("Quinian bootstrapping"), implicated in at least some episodes of conceptual construction. The essence of Quinian bootstrapping is that the core concepts of CS2 are co-constructed, with their meanings initially almost fully determined by their place in a placeholder structure that represents directly some of their relations with each other, *before* these are deployed in explanation of real world phenomena. In this initial stage of acquisition, the concepts that articulate a placeholder are uninterpreted, or only partially interpreted, with respect to the concepts that articulate CS2. For example, beginning physics students represent the propositions, stated in English and in mathematical equations, "force equals mass times acceleration," or "kinetic energy equals one-half mass times velocity squared" before they have any of the Newtonian concepts *mass, instantaneous velocity, or kinetic energy* (Block, 1986). Filling in the placeholder structures involves extended conceptual modeling (Carey, 2009; Gentner, 2002; Nersessian, 1992), deploying structure mapping, limiting case analyses, thought experimentation, and inductive inference. Consequently, the construction of the concepts of CS2 requires years of instruction, and in the case of these Newtonian concepts, many students never succeed despite such instruction (e.g., Clement, 1982; McCloskey, 1983; McCloskey, Caramazza, & Green, 1980).

Knowledge enrichment, in contrast, is subserved by learning mechanisms that involve hypothesis testing, or statistical learning, over concepts already represented. Examples include associative learning (Rescorla & Wagner, 1972) and some kinds of Bayesian learning, those that involve computations involving hypotheses and priors already represented, as a function of data that is already encoded in terms of the relevant concepts. Sometimes much data is required, so the learning process may be protracted. In other cases, when the learning is very highly constrained, the associative learning or Bayesian hypothesis testing is essentially 1-trial