Developmental Review 38 (2015) 36–54

Contents lists available at ScienceDirect

Developmental Review

journal homepage: www.elsevier.com/locate/dr

Theories of development: In dialog with Jean Piaget

Susan Carey *, Deborah Zaitchik, Igor Bascandziev

Department of Psychology, Harvard University, 33 Kirkland Street, Cambridge, MA 02138, USA

ARTICLE INFO

Article history:
Received 2 July 2015
Available online 1 September 2015

Keywords:
Jean Piaget
Constructivism
Stage theory
Conceptual change
Executive function

ABSTRACT

Piaget's body of work had two major theoretical thrusts: constructivism and stage theory. Both constructivism and stage theories articulate modern work on conceptual development, albeit transformed by developments in cognitive science and cognitive neuroscience. A case study of conceptual change in childhood within a framework theory of intuitive biology illustrates these points.

Introduction

Jean Piaget was the towering figure in the science of cognitive development throughout much of the 20th century. His work had two complementary thrusts: constructivism and stage theory. The concerns that drove Piaget's work with respect to each of these thrusts, the conclusions he came to, and the evidence he brought to bear on those conclusions are still very relevant in today's discourse. Nevertheless, the conversation has changed in many ways, sometimes fundamentally, thanks to advances in the cognitive sciences and in cognitive neuroscience.

Throughout his illustrious career, Piaget grappled with two different challenges for a theory of cognitive development. The first challenge is explaining the human conceptual repertoire. We are the only animal that can ponder the existence and causes of global warming, the causes and cures for cancer, whether the square root of 2 is irrational, and any of billions of propositions formulated over hundreds of thousands of concepts no other animal represents. Understanding the acquisition of any specific concept (and Piaget studied dozens of specific concepts*: object, cause, number, weight, density, life*, and many others) requires specifying the innate primitives (which Piaget believed to be sensorimotor in nature), and the processes through which they are transformed, through learning, into the adult state.

---

* Corresponding author. Department of Psychology, Harvard University, 33 Kirkland Street, Cambridge, MA 02138, USA. Fax: 617-384-7944.

E-mail address: scarey@wjh.harvard.edu (S. Carey).

http://dx.doi.org/10.1016/j.dr.2015.07.003
0273-2297/

Piaget's constructivism concerns the emergence of new conceptual content. The fundamental theoretical commitment of constructivism is that there are qualitative changes within representational systems throughout the course of development. As Piaget repeatedly said, constructivism about any particular conceptual content is in contrast with nativism with respect to the origins of that content and also with empiricism, the view that the relevant content can be acquired by associational processes carried out over already available representations, ultimately grounding out in sensorimotor primitives. Although today's cognitive science no longer endorses the view that innate representational primitives are limited to sensorimotor content (see, Carey, 2009, for a review), here we nonetheless endorse constructivism. Conceptual development includes episodes of change in which new representational resources are constructed, which in turn permit thoughts previously unthinkable.

The second challenge faced by a theory of cognitive development is characterizing the domain-general cognitive resources that make learning, including conceptual construction, possible, and characterizing and explaining developmental changes in this fundamental aspect of cognitive architecture. It was here that Piaget's stage theory came into play. Piaget held that developmental changes in domain general cognitive architecture constrained the conceptual content that could be mastered by children of different ages. His description of those changes changed throughout his long career. For example, he characterized the transition between preoperational and concrete operational thought as a change from egocentric to non-egocentric perspective taking, as an increase in information processing capacity, such as a change from not being able to coordinate two variables in a compensatory fashion to being able to do so, and finally, in his mature theory, as a change in the logical operations available for thought and reasoning. With respect to the 5- to 7-year-old stage change, for example, he held that preoperational children could not represent linear ordering or class inclusion relations, capacities that became available in the transition to concrete operational thought. Below we also endorse the claim that changes in domain-general cognitive resources are important to learning and conceptual change.

Keeping Piaget's two thrusts distinct

Explaining the human conceptual repertoire requires a theory of conceptual content (what makes a given representation have the meaning it has?), a theory of the innate representational primitives, and a theory of the learning mechanisms that transform the initial state into the adult state. A commitment to constructivism requires, in addition, a detailed description of qualitative changes in conceptual content (what kinds of conceptual transitions count as qualitative changes; what makes an acquired representational resource genuinely *new?).* A commitment to constructivism also requires an account of the learning mechanisms that underlie these qualitative changes. Because within-content development sometimes involves qualitative changes, constructivists often refer to "stages" in the acquisition of specific content, for example, stages in the acquisition of the concept *number*, or *matter*. There is nothing wrong with this usage, but it is confusing with respect to Piaget's stage theory, which sought to characterize developmental changes at a very abstract, content neutral, level of description.

Piaget himself did not confuse his two enterprises. For example, in Piaget's and Inhelder's classic study of the conservations, *The Child's Construction of Quantities* (Piaget & Inhelder, 1974), each chapter was devoted to a description of age related changes in children's appreciation of conservation of amount, weight, and volume, as well as the construction of an extensive concept of weight, differentiating it from the intensive concept of density. At the end of each chapter there were *two distinct* theoretical interpretations of the basic descriptive data. First, the content specific changes were characterized in terms of theory changes within children's intuitive theory of matter (see Carey, 2009; Smith, 2007, and Smith, Carey, & Wiser, 1985, for further elaboration). Second, differences in the theories held by 4-year-olds, 8-year-olds, and 15-year-olds were explained in terms of transitions from preoperational to concrete operational to formal operational thought. Piaget kept the two explanatory enterprises conceptually distinct, but he believed that the stage changes at a domain-general level had immediate consequences for constraints on conceptual content. This final hypothesis is not well supported by subsequent work (see Carey, 1985a; Gelman & Baillargeon, 1983), but Piaget's and Inhelder's analyses of conceptual changes within the concepts *weight, density, volume,* and *matter* in the course of constructing theories of the physical world have stood the test of time (Carey, 2009).

Constructivism, the theory–theory, and conceptual change

The thesis of constructivism demands evidence for qualitative changes within conceptual content over the course of development. This, in turn, requires a theoretical analysis of what counts as a *qualitative change*, so that evidence can be brought to bear on whether constructivism is true. Evidence for constructivism requires descriptions of successive conceptual systems that specify the representations involved in terms of their format, content and computational roles. These descriptions must specify precisely how the second conceptual system (CS2) is qualitatively different from the first (CS1). In Piaget's debates with Chomsky and Fodor (in Piatelli-Palmarini, 1980), his example of qualitative change was an increase in expressive power of the conceptual system, as exemplified in the history of mathematics and in mathematical development within the child. Expressive power is a function of conceptual primitives and the combinatorial machinery through which complex concepts are built. Constructivism requires the acquisition of new conceptual primitives, or of new combinatorial machinery, resulting in the capacity to think thoughts previously *unthinkable* (not merely previously *unthought*). We agree that conceptual development sometimes results in increases in expressive power, and that these constitute examples of the qualitative changes required by constructivism (Carey, 2009, 2015). They are attested in the acquisition of both mathematical and nonmathematical content, both over historical time and in ontogenesis.

Our focus here is on a different type of qualitative change from those seen within mathematical development, namely, those at stake in the theory change described in *The Child's Construction of Quantities.* This thread of Piaget's work was the forerunner to the "theory–theory" of conceptual development (Carey, 1985b, 2009; Gopnik & Meltzoff, 1997; Keil, 1989; Wellman & Gelman, 1992) as an elaboration of constructivism. Much disparate work takes place under the rubric of the "theory–theory," but theory–theorists, for the most part, share several fundamental assumptions: the first is that one important target of conceptual development is a small set of framework theories, including theories of mind, of matter, of causal interactions among objects, and of biology. Framework theories, such as commonsense want/belief folk psychology, embody our deepest ontological commitments and explanatory principles. Second, some of these framework theories are manifest early in infant development, and are manifest cross-culturally, but others are culturally constructed in historical time, and must be constructed by each child over ontogenesis. In these latter cases, successive representational systems with overlapping content are sometimes qualitatively different from each other, in ways that may be precisely stated. Sometimes conceptual development involves conceptual incommensurabilities. The concepts that articulate a later theory (CS2) cannot even be expressed, using the combinatorial machinery of logic, mathematics, or natural language, in terms of the concepts that articulate CS1, the early theory (Carey, 1985b, 2009; Kuhn, 1982). The consequence of this second assumption is that those of us studying conceptual development must distinguish episodes of theory development that involve belief revision (no change in the framework theory) from those that involve conceptual change (changes in the conceptual repertoire that articulate the beliefs expressed by the theory). Conceptual changes are changes at the level of individual concepts. Belief revisions, in contrast, are changes in what is taken to be true about the world, when different propositions are formulated over a constant set of concepts.

Conceptual changes come in several varieties: conceptual differentiations, conceptual coalescences, and changes in conceptual cores. In each type, the ancestor concepts in the earlier conceptual system are incoherent from the point of view of the descendent concepts in the later conceptual system (and vice versa). In episodes of conceptual change, one always sees changes of all three types, occurring in parallel across a suite of interrelated concepts. Carey (2009) shows how this analysis applies to the conceptual changes within a framework theory of matter over the elementary school years (updating Piaget and Inhelder's case study), as well as to several cases of conceptual change in the history of science. Here we focus on a different case study, conceptual change within children's framework theories of the biological world, the theory change relevant to Piaget's classic work on childhood animism.

Vitalist *biology*

Vitalist biology is a cross-culturally widespread theory that underlies thinking about life, death, and health (Carey, 1985b, 1999; Contento, 1981; Hatano & Inagaki, 1994; Inagaki & Hatano, 1993, 2002; Slaughter, Jaakkola, & Carey, 1999; Slaughter & Lyons, 2003). According to this theory, air, food, and water are sources of *vital energy* or *vital substance* that must get from the outside world to all parts of the body in order to maintain bodily function. Vitalism provides a functionalist understanding of bodily processes: the functions of bodily organs and bodily processes are to sustain life, health and growth. Body parts are specialized and work together. Some body parts serve as containers – lungs hold air; the stomach holds food and water – and each also has specific causally relevant processes to carry out (e.g., food is broken into tiny pieces in the stomach; the heart pumps blood through the body and blood carries food, air and water to all parts of the body. Death, on this view, is due to the breakdown of bodily function. The process of constructing a vitalist biology begins as young as age 4 or 5 for some children, with an average age of first emergence of some of its core principles around age 6 or 7 (Carey, 1999; Hatano & Inagaki, 1994; Inagaki & Hatano, 1993, 2002; Slaughter et al., 1999).

Before the acquisition of vitalist biology: preschoolers' understanding of animals

Research on preschool children's biological knowledge began with Piaget's (1929) classic studies of childhood animism, the tendency to attribute life – clearly a key concept in any theory of biology – to inanimate objects (see also Carey, 1985b; Laurendeau & Pinard, 1962; Richards & Siegler, 1984). When asked what it means to be alive, preschoolers often respond that it means to move or to be active. They often attribute life to the sun and the wind, as well as animals and people, but deny life to plants. Moreover, young children fail to differentiate *alive* from *real*, *visible, present*, or even just *existing* (Carey, 1985b; Piaget, 1929). Similarly, they fail to differentiate the contrast between *alive* and *dead* from the contrast between *animate* and *inanimate* (Carey, 1985b; Piaget, 1929). In line with the claim that young children have not worked out the biological meaning of *alive,* they show similar conflations when asked what it means to *die*. Common responses are that it means to stop *doing* things or to become *invisible* or simply to *go away, to live on in vastly altered circumstance, such as under the ground* (Carey, 1985b). Later work showed that, when asked about the function of the body organs, they tend to report a single independent function for each body part (e.g., the heart is *for beating*), showing no understanding of the body as a biological *system* whose parts work together to sustain life (Slaughter et al., 1999). Moreover, though they understand that bodily processes are not under *intentional* control (Hatano & Inagaki, 1994; Hickling & Wellman, 2001), preschool children appear to have no alternative conception – no system of *biological functions* – with which to understand them. Similarly, young preschool children have been shown to have a concept of death as the cessation of existence, a concept they draw on when thinking about relations between predators and prey (Barrett, 2005). This, however, is a far cry from the concept of death that is part of a *vitalist biology,* in which death is seen not only as the end of existence, but as the end of life (Carey, 1985b; Slaughter et al., 1999).

Underlying the preschool child's conceptions of what adults construe as living things, we believe, is a system of concepts that identifies life with animals – and animals, in this system, are conceptualized as fundamentally causal and intentional *agents.* This explains why the sun and the wind (as well as people and animals) are considered *alive* while plants, which certainly don't *do* much or *go* anywhere, often are not. It is only when children undergo the conceptual change from this agent-centered theory of animals to the more mature vitalist biology that they can differentiate *alive* from *existent, real,* or *active* and *dead* from *inanimate.* Because of these conceptual differentiations, along with the coalescence of *animal* and *plant* into the single ontological kind *living thing,* a vitalist biology is locally incommensurable with preschoolers' concepts of animals and plants. In constructing a vitalist biology, children create an interrelated system of knowledge couched in a whole set of concepts not available to young preschoolers.

Accretion of facts and conceptual change

Clearly, it is only with age that children acquire the culturally widespread vitalist theory, but what is it about age that leads to this acquisition? Is it merely that older children, having lived longer, have acquired more facts about animals? The accretion of facts certainly plays an important role in learning any science. Nevertheless, accretion of facts is different from conceptual change in several critical ways. First, in learning new facts, children simply alter beliefs stated in the very same conceptual vocabulary they already have. On the above analysis, however, preschool children do not have the concepts to represent the proposition adults express with the sentence "animals and plants are alive." Second, in cases of conceptual change, a system of concepts is mastered all together, as a coherent, interdefined whole, and the new concepts are partly defined by their place in that new coherent whole.

The claim that the acquisition of vitalist biology is an instance of such conceptual change is based on evidence for the incommensurability of concepts of biological phenomena in preschoolers and young elementary school children (Carey, 1985b, 1999). Piaget's clinical interview method is the richest source of such evidence. Piaget's body of work gave the field dozens of robust phenomena that suggest incommensurabilities, phenomena that captured the field's attention because children are locked into patterns of judgment that lead them to internal contradictions and are incoherent from the point of view of the later (adult) conceptual system. The non-conservations are one such set of phenomena; childhood animism another. Preschool children, with their explanation seeking "why" questions, provide such evidence spontaneously – they exhibit "Huh?!!!" phenomena. For example, Carey (1985b) reports the following exchange with her 3-year-old daughter, Eliza. E: "That's funny, statues are not alive, but you can still see them." Me: "What?" (Huh?) "What's funny about that?" E. "Well, Grampa's dead, and that's sad, because we will never see him again." Eliza had noticed a contradiction in her concepts that follows from the lack of differentiation between *dead* and *inanimate*, itself resulting from her undifferentiated concept *animal/real/existent/active.* Of course, my attempt to clear up this conceptual matter fell on deaf ears. Me: "Oh, I see. Some things, like animals and plants, are alive, so they can die, and that's sad because then they don't exist anymore. Other things, like statues and also tables and chairs, are never alive, so they can't die." E. (after some thought to process what I had just said.) "Yah, isn't that funny. Tables and chairs are not alive and we can still see them." Just as in the history of science, reverse engineering such patterns of judgments to diagnose the underlying set of concepts that give rise to them is the primary method for characterizing successive conceptual systems.

The existence of conceptual changes in the context of theory construction has the empirical consequence that suites of concepts should show interrelated change, a consequence Piaget confirmed throughout his career. In the Piagetian literature, responses on animism clinical interviews predict responses on clinical interviews concerning death (Carey, 1985b). More recently Virginia Slaughter and colleagues (Slaughter et al., 1999; Slaughter & Lyons, 2003) found strong coherence of biological concepts. First, performance on an interview tapping the understanding of body parts and their functions was shown to predict performance on an interview about death. Second, a curricular intervention aimed at teaching the biological functions of internal organs increased performance on the death interview as much as the body parts interview, despite the fact that the concept of death was not the focus of instruction.

The above analyses predict that the learning mechanisms that underlie conceptual change are likely to differ from those that underlie belief revisions and merely acquiring new factual knowledge. A study of adults with Williams Syndrome (WS) confirmed this prediction (Johnson & Carey, 1998). Williams Syndrome is a genetically determined developmental disability that leads to severe mental retardation, yet spares the capacity to acquire both language and factual knowledge. Strikingly, though our WS participants' factual knowledge was relatively intact, equivalent to the factual knowledge of normally developing 12-year-olds, not a single WS adult demonstrated the biological understanding achieved by normally developing 6-year-olds. Lacking the framework of a vitalist biology, they failed to understand life in terms of bodily function and death as the breakdown of the bodily machine; similarly, lacking understanding of any biological mechanisms involved in reproduction or biological inheritance, they failed to distinguish between biological and social conceptions of family. These data provide powerful evidence that a huge database of factual knowledge does not, in and of itself, lead to conceptual change. They also raise the question of what domain-general cognitive abilities are impaired in individuals with Williams Syndrome such that even adults never undergo the conceptual change achieved by normally developing 6- to 10-year-olds. We turn to that question below.

So where are we with respect to Piaget's constructivism? Work within the theory–theory of cognitive development confirms the existence of developmental transitions yielding new representational systems that are qualitatively different from those with overlapping content that existed before. This work motivates the question of what kinds of learning mechanisms can possibly underlie conceptual changes and increases in expressive power. Carey (2009) characterized one bootstrapping mechanism (Quinian bootstrapping) implicated in every case study of conceptual construction examined in that book. Quinian bootstrapping was first characterized in the history and philosophy of science literature (e.g., Nersessian, 1992), and involves several steps, including building uninterpreted placeholder structures using the representational resources available at the outset of the episode, various modeling techniques, and various inductive mechanisms. While in no way contradicting the insights Piaget offered, insights from cognitive science, including history and philosophy of science, have allowed us to go well beyond "equilibration of assimilation and accommodation" as what we can say about the learning mechanisms underlying the construction of the adult conceptual repertoire.

Stage theory: domain-general cognitive development

As noted above, Piaget's stage theory proposed periods of major change in the availability of domain-general cognitive resources in childhood. The stages, which were characterized in abstract and content-free terms, were thought to place limits on the child's ability to undergo construction in *any* and *all* conceptual domains. What happened to this thrust of Piaget's legacy?

During the late 1960s and 1970s, the cognitive revolution in psychology, with its commitment to a computational model of mind, led to detailed models of the representations and computations that underlie human behavior, cognition and language. Piaget's characterization of stage theories in terms of the successive logics available to articulate thought has not stood the test of time (Crain & Khlentzos, 2010; Osherson, 1974–1976). It is now clear, for example, that the full resources of propositional logic are deployed in the semantics of natural language and are mastered by age 3. But one of the early, and enduring, topics in the cognitive revolution was the characterization of systems of working memory (Baddeley, 1981; Baddeley & Hitch, 1974; Sperling, 1960). Developmental psychologists who designated themselves "neo-Piagetians" quickly began to integrate this new approach with Piaget's stage theory (Case, 1985, 1992a, 1992b; Fischer, 1980; Halford, 1993; Pascual-Leone, 1970). Much of the neo-Piagetian research focused on how developments in working memory capacity with age lessen constraints on cognitive achievements. For example, these researchers hypothesize that the complexity of structures that can be held in working memory increases with age, thus increasing the complexity of possible computations that underlie inference and learning (see Demetriou, 2006, for review). The ability to represent more complex conceptual structure constitutes the child's entry into a new stage of development.

Executive functions

The search for domain-general mechanisms underlying conceptual change has broadened over the last decade, partly due to advances in cognitive neuroscience. In particular, researchers have expanded their exploration of information processing beyond *working memory* alone. The focus now is on a suite of cognitive mechanisms together called *executive function* (hereafter EF). Diamond (2013) characterizes executive function as top-down processes involved in any cognitive work that demands novel thinking, thinking 'out of the box', operating in a non-automatic way. They underlie planning, cognitive control, self-control, and sustained attention. Confirmatory factor-analysis (Miyake et al., 2000) has identified three basic EF mechanisms that contribute both shared and unique variance in tasks designed to diagnose EF. These include: *working memory* (for storing and updating information deployed in on-line processing), *inhibition* (for damping down the activation of competing responses or conflicting representations), and *setshifting* (the capacity to flexibly select among potentially relevant sources of information). Other higher-order processes, such as conscious and deliberate *planning, problem-solving, and reasoning* appear to involve combinations of the three core processes (Collins & Koechlin, 2012; Diamond, 2013).

Executive function develops dramatically in infancy and the preschool years, and continues to grow through the school years (Cepeda, Kramer, & Gonzalez de Sather, 2001; Davidson, Amso, Anderson, & Diamond, 2006; Luciana & Nelson, 1998). In classic work that initiated the application of the cognitive neuroscience of EF to understanding Piagetian stage theory, Adele Diamond teamed up with

Patricia Goldman-Rakic, a neuroscientist with expertise in frontal lobe function and maturation, especially in rhesus macaques. Together they demonstrated that the developmental changes in the Piagetian phenomena of object permanence reflected maturational changes in prefrontal cortex, a brain region that underlies the development of working memory and inhibition. These two executive functions are implicated in success on many tasks from many different conceptual domains – and certainly on tasks that demand *reaching for hidden objects,* as Piagetian object permanence tasks do (Diamond, 1991; Diamond & Goldman-Rakic, 1989). This raises the possibility that a different type of task, one that does not require reaching for hidden objects, could provide positive evidence of object permanence in younger babies. Indeed, findings from infant labs that used *violation-of-expectancy looking-time* rather than *reaching for hidden objects* have demonstrated that babies as young as 2.5 months old already have rich object representations that observe spatiotemporal constraints; that is, they already have the concept of object permanence (Aguiar & Baillargeon, 1999, 2002; Baillargeon, Spelke, & Wasserman, 1985; Spelke, Kestenbaum, & Simons, 1995; Wynn, 1992). It seems, then, that the changes in reaching for hidden objects did not reflect changes in domain-specific object representations; they did not reflect a conceptual construction (see Carey, 2009, for a review).

There is now strong consensus that executive function is largely subserved by prefrontal cortex (PFC) (Grafman, 1994; Miller, 1999; Passingham, 1993; for review, see Miller & Cohen, 2001). PFC offers feedback signals to widespread targets throughout the brain, so it is anatomically well situated to orchestrate complex behavior (Miller & Cohen, 2001). Most important for the current discussion, the types of representations actively maintained by PFC are the *goals* of a current task and the *rules* constraining current behavior (Miller & Cohen, 2001). These types of representations play a major role in developmental theories of executive function, to which we turn now.

Developmental psychologists have proposed several theoretical accounts of the consequences of EF development for cognitive development. Very much on the same page as the earlier neo-Piagetians, Zelazo and his colleagues proposed the Cognitive Complexity and Control Theory (CCC) (Zelazo & Frye, 1997). This theory emphasizes that the function of EF is deliberate problem solving. Critically, it proposes that the plans children generate in the process of problem solving are formulated, quite literally, as rules. Development, on this view, consists (in part) in increased ability to formulate and use rules. Increases in EF allow more than one rule to be held at a time in working memory, and more importantly, for hierarchical structures of rules to be built (e.g., in the Dimensional Change Card Sort task, "if the shape game, put the squares on the left, the circles on the right; if the color game, put the red on the left and the blue on the right.") The ability to represent increasingly complex rule structures develops with age, as children are increasingly able to step back and reflect on their own mental contents. A later elaboration and revision of the theory (CCC-r) provides more detail on the determination of rule complexity, the role of experience in rule activation and inhibition, the circumstances in which children will have difficulty in using rules at various levels of complexity, and the importance of *intentionality* in the study of executive function (Zelazo et al., 2003). Engagement in self-reflection plays a key role in the theory, and ties the development of theory of mind to the development of cognitive control (Lyons & Zelazo, 2011; Zelazo, 2004).

A subtly different theoretical account focuses on the demand for active maintenance of *goal representations* in working memory (Munakata et al., 2011; Munakata, Snyder, & Chatham, 2012; Snyder & Munakata, 2010). On this view, maturation of EF leads to a shift from exogenous flexibility (where reminders of the goal are provided by others) to endogenous or self-directed flexibility, leading to a developmental shift from "reactive" to "proactive" cognitive control (Chatham, Frank, & Munakata, 2009). The idea here is that flexible behavior, in contrast to habitual behavior, demands a process of *response selection* – and the larger the set of candidate responses, the harder it is to choose. The problem is that while memory search and response selection take place, the goal representation itself may decay. Evidence that *response selection* demands affect flexibility is especially clear in the Verbal Fluency task, where children are given 60 seconds to name as many members as they can of a particular semantic category (e.g., *foods*). In one study, target children heard the experimenter mention a few subcategories of foods (e.g., *fruits, desserts*) before the task began (while control children heard a few exemplars, e.g., *carrots, cookies).* Since each of the subcategories includes fewer items than the superordinate category *foods*, using them to organize and guide memory search when asked to name *foods* should reduce selection demands and, by hypothesis, improve task performance. Indeed, it does. Not only did children in the *subcategory* group name more foods than did control children, they also flexibly switched to other subcategories of foods – including subcategories never mentioned by the experimenter (Munakata et al., 2012; Snyder & Munakata, 2010).

The above (highly selective and incomplete) review makes clear that the relation between the basic components of EF (working memory, inhibition, set shifting) and higher order cognitive processes is an active, important, topic of research. However this work progresses, the importance of EF in academic success is well established. EF is more strongly associated with school readiness than is IQ, entry-level reading skills, or entry-level math skills (Blair & Razza, 2007; Diamond, Barnett, Thomas, & Munro, 2007; Morrison, Ponitz, & McClelland, 2010). Moreover, EF maintains its importance throughout the school years; indeed, working memory and inhibition independently predict math and reading scores in every grade from preschool through high school (e.g., Blair & Razza, 2007; Gathercole, Pickering, Knight, & Stegmann, 2004; Gathercole, Tiffany, Briscoe, Thorn & ALSPAC Team, 2005). Clearly, then, EF broadly predicts the child's performance in school, a finding of great importance to educators. Of course, there are many, not mutually exclusive, reasons this might be so. Children more capable of inhibiting impulsive action and maintaining sustained attention would be expected to do better in school than those less so. This would be so even if all school learning were mere factual learning. But a further question, the question we address in the remainder of this brief review, is this: What is the relation between EF development and conceptual change? If EF development, by hypothesis, is a locus of the domain general cognitive changes Piaget sought to characterize in his stage theory, and conceptual change, by hypothesis, is a proper locus of Piaget's constructivism with respect to conceptual content, just how are they related? Are the EFs implicated in the process of conceptual changes associated with theory development? To explore this possibility, researchers have investigated the relation between EF scores and performance on tasks that appear to tap conceptual milestones in different domains.

EF and domain-specific conceptual change

EF and theory of mind

The first locus of such work concerned conceptual construction within theory of mind (Carlson & Moses, 2001; Frye, 1999; Frye, Zelazo, & Palfai, 1995; Sabbagh, Xu, Carlson, Moses, & Lee, 2006). Studies focused primarily on the relation between EF and the false belief task. There are several different versions of the task, but all demand the understanding that a belief is a *representation* of reality and as such, it can *misrepresent;* that is, it can be false. In the classic version of the task (Wimmer & Perner, 1983), a character puts an object into one container (say a box) and then leaves the scene. In her absence, another character removes the object from the box and puts it into another container (say a closed basket). The study participant is then asked where the first character, who is still absent, *thinks* the object is, or, alternatively, where the character will *look* for the toy when she returns. These studies have found that success in attributing a false belief, the milestone in theory of mind development in the preschool years, is highly correlated with executive function skills, even controlling for age and verbal IQ (e.g., Carlson & Moses, 2001; Sabbagh et al., 2006). A recent meta-analysis included one hundred studies of the relation of EF and the false belief task. These studies were collected over the last 20 years in 15 different countries and included almost 10,000 3–6 year old subjects (Devine & Hughes, 2014). Results of the meta-analysis showed that EF and FB are moderately but significantly associated, with approximately 15% shared variance. Indeed, even after controlling for age and verbal ability, EF and FB shared a significant 8% of the variance.

These data were initially taken to reflect a correlation between EF and a conceptual construction – the construction of a representational theory of mind. This may be so, but subsequent studies have found success on *implicit* false belief tasks by infants and toddlers (Buttelmann, Carpenter, & Tomasello, 2009; Onishi & Baillargeon, 2005; Southgate, Senju, & Csibra, 2007; Surian, Caldi, & Sperber, 2007). These studies, as well as those providing evidence for infant representations of perception, attentional focus, and communicative intent, reveal rich representations with content at least overlapping that of explicit theory of mind (Baillargeon, Scott, & He, 2010; Baldwin, 1991, 1993; Baldwin & Moses, 1994; Carlson & Moses, 2001; Gergely & Csibra, 2003; Gergely, Nadasdy, Csibra, & Biro, 1995; Johnson, 2003;

Leslie, 1994, 2000; Luo & Baillargeon, 2007; Luo & Johnson, 2009; Onishi & Baillargeon, 2005; Perner & Ruffman, 2005; Premack & Premack, 1995; Ruffman & Perner, 2005; Sirois & Jackson, 2007; Tomasello & Haberl, 2003; Wellman, Cross, & Watson, 2001). Because of this rich body of work on infants, some doubt that the preschool milestones reflect conceptual change at all, that is, reflect a Piagetian construction. We do not take a stand on this matter, although we lean toward the existence of genuine discontinuity during the preschool years, in spite of rich innate content in this domain (see below). We will consider possible explanations of the correlations between measures of EF and success on the false belief task below. For now, we turn to our studies on the relation between EF and the construction of a vitalist biology. In contrast to theory of mind, vitalist biology is nowhere manifest in infancy. Its construction is indubitably an episode of theory development that involves conceptual change.

EF and vitalist biology

Recall that vitalist biology, in contrast to the preschooler's agency theory, represents animals as *living things*, where *life* is construed in terms of biological functions of bodily organs. Various organs take in and distribute energy throughout the body, energy needed for life, activity, growth, and health. When body parts do not function, you lose the vital energy needed to sustain life, so death occurs. Death, then, is the cessation of all body function, the end of life.

Zaitchik, Iqbal, and Carey (2013) tested the hypothesis that children's EF would predict their performance in vitalist reasoning. Seventy-nine children, aged 5–7 years, were presented with a battery of 3 Vitalist Biology tasks. The first task, the classic Animism Interview (Carey, 1985b; Laurendeau & Pinard, 1962; Piaget, 1929), probes the meaning of *alive* and the range of entities included in the category *living things.* Specifically, the child is asked: *'What does it mean to be alive?' 'Can you name some things that are alive?'; 'Can you name some things that are not alive?'* Following these initial open-ended questions, the child is asked to judge, for each of a series of individually named entities, *'Is it alive? Is it a living thing?'* The series includes people and animals, and a wide range of inanimate objects, ranging from moving, causally potent or functional objects (such as the sun, fire, and clocks), to inert objects (such as rocks, mountains, and tables).

The second task, the Death Interview (Carey, 1985b; Slaughter et al., 1999; Slaughter & Lyons, 2003; Zaitchik et al., 2013) probes the distinction between *alive* and *dead.* Here children are asked, 'What does it mean to *die?* What happens to a person when he dies? What happens to a person's *body* when he dies? These questions are followed by a series of yes–no questions tapping the understanding that dead people no longer have *any* bodily or mental functions (e.g., *Does a dead person: eat? pee? feel bad that he's dead?).* Finally, children are asked what causes someone to die, whether everyone has to die, and whether someone who is dead can come back to life.

In the third and final task, the Body Parts interview (Carey, 1985b; Slaughter et al., 1999; Slaughter & Lyons, 2003), children are asked about the location and function of each of a series of body parts (e.g., brain, heart, lungs, stomach, blood). They are also asked, for each body part, what would happen if a person didn't have it. Children were then asked why we eat, why we breathe, and what happens to the food and air after they are taken into the body.

As expected, scores on all three biology tests were significantly correlated [animism_body parts, $r(79) = .64$; animism_death, $r(79) = .54$; and body parts_death, $r(79) = .58$, in all cases $p < .001$ two-tailed], justifying aggregation into a single composite measure of vitalist biology.

The EF battery

The same children were then presented with an age-appropriate Executive Function Battery that included two tests: Hearts & Flowers (H&F) and Flanker Fish (FF), each of which taps all three of the basic executive functions (Davidson et al., 2006; Diamond et al., 2007). H&F and FF are structurally similar computerized tests involving three blocks of trials. We illustrate using Hearts & Flowers. In the Congruent condition, a series of hearts appear, one at a time, on either the left or the right side of the screen. The child must press the button on the *same* side of the screen that the heart appears on. In the Incongruent condition, a series of flowers appear, one at a time, on either side of the screen. The child is instructed to press the button on the *opposite* side of the screen from the flower. In the

Mixed condition (the test condition), the child is presented with a randomly ordered series of Congruent and Incongruent trials. Scores on the Mixed condition of both Hearts & Flowers and Flanker Fish were significantly correlated [r (79) = .25, p = .026, two-tailed], justifying aggregation into a composite Executive Function score for each subject.

The correlation between the composite EF and composite Vitalist Biology scores was significant, r (79) = .52, p < .001. To control for effects of age and verbal IQ, a multiple regression analysis was run that included age, verbal IQ (using standard scores on the Peabody Picture Vocabulary Test, a test of receptive vocabulary), and composite EF score as predictor variables; the composite Vitalist Biology score was the dependent variable. Even after controlling for both age and verbal IQ, children's Executive Function scores significantly predicted their performance on the Vitalist Biology tasks [t (75) = 2.279, p = .026, two-tailed].

Thus, not only do measures of EF predict performance on theory of mind tasks, they also predict performance on Vitalist biology tasks – and they do so at the very age when Vitalist biology is in the very early stages of construction. Although this study was explicitly modeled on the previous developmental work on EF and theory of mind, it presents a substantially different case. As noted above, the infant literature has ignited a great deal of controversy surrounding the issue of innate support for theory of mind, with recent findings supporting previous arguments that development in this domain does not demand conceptual change at all (Fodor, 1992; Scholl & Leslie, 1999). The domain of Vitalist biology, on the other hand, has no innate biological representations to support its development; it is a wholly constructed theory. We now turn to the question of *why* EF might be correlated with performance on tasks that appear to tap into conceptual knowledge.

Like all correlational findings, those showing a stable relationship between Executive Function scores and performance on conceptual tasks (whether within ToM, or Vitalist biology), are open to several quite different interpretations. These have been extensively investigated in the ToM literature. Before turning to the nature of the relations between EF and the framework theory of vitalist biology, we briefly review the progress that has been made toward interpreting the relations between EF and the preschool child's theory of mind.

EF and preschool theory of mind

As reviewed above, individual differences in EF (especially differences in *cognitive conflict inhibition* and *response selection)* predict preschoolers' performance on false belief tasks. The literature provides three broad accounts for how this could happen. On one account, the role of EF is restricted to the *deployment* of conceptual knowledge; that is, the maturation of EF leads to success on the false belief task solely by increasing children's capacity to *express* the underlying conceptual understanding they already have (Baillargeon et al., 2010; Leslie, Friedman, & German, 2004). Another possibility is that EFs play a role in the very *construction* of the theory of mind. On this view, the development of EF allows the child to *build* a representational ToM, a theory that newly enables false belief understanding (Benson, Sabbagh, Carlson, & Zelazo, 2013; Sabbagh et al., 2006). A third possibility is that the causal relationship between the two constructs is exactly the reverse: ToM development plays a role in the development of EFs (Perner & Lang, 1999). We now consider these in turn.

Is ToM influencing the development of EFs?

One broad hypothesis about the correlation between ToM and EFs is that the development of ToM leads to stronger EF, rather than the reverse. Of course, both directions of influence are possible; they are not mutually exclusive. For example, gaining better theoretical understanding of their own thought processes might help children strengthen their cognitive control over their thoughts (Perner & Lang, 1999). To test this hypothesis, Hughes (1998) followed 50 children over a period of one year and asked if earlier performance on EF tasks would predict later performance on ToM or vice versa. The relationship was asymmetric: EF variability at age 4 predicted ToM variability at age 5, but ToM variability at age 4 did not predict EF variability at age 5. Several more recent studies have confirmed this finding, using both a longitudinal design (Carlson, Mandell, & Williams, 2004; Hughes & Ensor, 2007) and a microgenetic design (Flynn, 2007; Flynn, O'Malley, & Wood, 2004). These studies confirmed the asymmetry between EF and ToM in younger children (2-, 3-, and 4-year-olds), who were tested over various spans (several months, one year, and two years), who were recruited from typical middle-class and disadvantaged families, and who received a wide range of EF and ToM tasks. Of all four studies, only one study (Hughes & Ensor, 2007) found that early variability in ToM predicted to variability later EF (in 2 out of 6 analyses), whereas the same study also found that early EF predicted later ToM in 5 of 6 analyses. These results undermine the hypothesis that ToM development importantly drives EF development. Rather, increases in EFs appear to influence the development or expression of ToM. We are left, then, with two viable broad hypotheses concerning the correlations between EFs and ToM: the *learning/construction* hypothesis and the *expression alone* hypothesis.

Expression alone hypothesis

There are two components of the *expression alone* hypothesis: 1) EFs are necessary for the expression of already present ToM knowledge and 2) changes in the preschool years on explicit ToM tasks are due to maturational changes in EF alone. We will return to the second part of this hypothesis below. Here, we consider the first part. It is plausible that EF leads to success on the false belief task by allowing children to express the knowledge they already have. On their face, the preschool explicit false belief tasks place high demands on EF. Consider the situation, for example, in the Sally/Ann false belief location task. Children know the toy's actual location – and they know that Sally wants the toy. They must therefore inhibit the prepotent response that she will look for it where it is (given that if she wants it, that's where she would have to look). Consistent with this view, ToM tasks with reduced EF demands lead to improved performance. In a meta-analysis, Wellman et al. (2001) examined 178 ToM studies and found that manipulations that are likely to reduce EF demands (by removing the target object in false belief tasks, or by emphasizing the protagonist's mental state) indeed improve children's performance: older children went from at-chance to above-chance performance, while younger children went from below-chance to at-chance performance. Conversely, manipulations likely to increase EF demands of the task should lead older preschoolers to fail. Changing the task so that children had to predict what location a protagonist would avoid, based on a false belief (adding an extra step to the on-line calculation), led even 4.5-year-olds to fail a first order false belief task (Leslie & Polizzi, 1998). While consistent with the inference that EF resources are drawn upon in first order false belief tasks, the empirical support from such studies is indirect. These studies manipulate the task difficulty rather than the subjects' EF resources. Task difficulty level is not completely determined by EF demands. Other factors may render a task more or less difficult. In other words, these studies presuppose, but offer no evidence, that it is the manipulation of EF demands that make the difference.

For unequivocal evidence that ToM draws on EF resources, one must manipulate those resources and study the effects of that manipulation on performance on the false belief task. Powell and Carey (2015) did just that, building on Baumeister, Bratslavsky, Muraven, and Tice's (1998) "ego-depletion" paradigm. Baumeister's original intuition was that will-power ("ego-strength") might be a depletable resource. In a series of widely replicated studies, adults were given a preliminary task that taxed their will-power (e.g., inhibiting the desire to eat fresh-baked cookies in favor of nibbling on radishes). The result was decreased performance on subsequent EF demanding tasks (e.g., maintaining attention and motivation to solve difficult anagram problems (see Hagger, Wood, Stiff, & Chatzisarantis, 2010 for a meta-analysis of 83 studies). It is now recognized that ego-depletion and EF-depletion are likely to be one and the same thing.

Powell and Carey (2015) provided the first evidence that EF can be depleted in 4- and 5-year-olds. In two separate studies, children were given a Child Stroop pretest and posttest. The Child Stroop demands conflict inhibition (e.g., saying "square" when presented with a circle, and "circle" when presented with a square, or saying "up" when presented with an arrow pointing down and "down" when presented with an arrow pointing up). Children were randomly assigned to depletion or control conditions. Between the pretest and posttests, children in the depletion condition participated in an EF demanding task, whereas those in the control condition participated in a well-matched control task that did not tax inhibitory control or cognitive conflict resolution. In one study children were presented with a large wrapped box said to contain "lots of wonderful toys", one of which the child could choose to keep. In the depletion condition, children were asked to wait until the experimenter returned from making a phone call (a period of 5 minutes) before opening the box, while children in the control condition were allowed to open the box immediately and play with their chosen toy for 5 minutes. In the other study, the depletion task was a “go/no go” task, difficult for children this age, while the control task was closely matched but made no demands on response inhibition. In both studies, the depleted children performed worse on the post-test Child Stroop task than on pretest, whereas control children, showing practice effects, performed better on posttest than pretest. In both experiments the interaction between condition and pretest/posttest performance was significant. Thus EF can be temporarily depleted in children of this age.

With these results in hand, we used these depletion methods to assess whether EF is drawn upon in the child’s expression of ToM. Four and a half and 5-year-olds, at the age where children robustly pass the standard first order false belief tasks, were assigned to depletion or control conditions. Again, two studies were carried out, one using each depletion/control comparison as in the two studies reported above. In each study children were assigned to the depletion or control condition and first participated in the depletion or control task, respectively. They then were given standard first order false belief tasks. If EF is needed for success on these tasks, children in the depletion conditions should perform worse than children in the control conditions. As predicted, given their age, children in the control conditions were at ceiling on the false belief tasks. Children in the depletion conditions, in contrast, performed significantly worse than those in the control condition. One study included a control question, matched in every respect to the false belief question except not involving a false belief. Importantly, depletion had no effect on this control question. Depletion did not affect children’s overall motivation or engagement in the task; rather, its effect was specific to inferences involving false belief. These results provide the first unequivocal evidence that EFs play a role in the expression of a theory of mind that is already present in the preschool years. This, in turn, could explain the correlations between measures of EF and success on tasks that diagnose a representational ToM. However, evidence that EFs are implicated in the on-line computations underlying success on ToM tasks does not preclude the possibility that EFs might *also* play a role in the acquisition of an explicit, verbally encoded, ToM in the preschool years. We now consider this possibility.

Learning/construction hypothesis

This hypothesis proposes that the learning processes through which children acquire a representational ToM draw on EF. If we restrict the term “construction” to its Piagetian use, where it applies to learning episodes that involve conceptual change or increases in expressive power, the construction hypothesis would have three parts: 1) changes in the preschool years on explicit ToM tasks reflect a developmental discontinuity; 2) EFs are drawn upon by the learning mechanisms that underlie that discontinuity; and 3) the development of EF makes available the resources needed by these learning mechanisms. Of course, even if ToM development in the preschool years does not reflect a Piagetian construction, it is still possible that EF is needed for the learning processes reflected in the developmental milestones in preschool ToM (Wellman & Liu, 2004), which is why we designate this hypothesis the “learning/construction” hypothesis.

Adjudicating between the learning/construction and the expression alone hypotheses

Recall that, according to the *expression alone* hypothesis, changes in the preschool years on explicit ToM tasks are due to maturational changes in EF alone. In other words, young children fail ToM tasks not because they lack a theory of mind, but because this knowledge is masked by their poor EF abilities. Sabbagh et al. (2006) tested this hypothesis by comparing the EF and ToM performance of 107 Chinese 3.5- to 4.5-year-olds with that of 109 U.S. 3.5-to 4.5-year-olds. Although the Chinese 3.5-year-olds scored as high as U.S. 4-year-olds on EF measures, they performed identically to the U.S. 3.5-year-olds on ToM tasks. Thus, stronger EF abilities did not lead to better performance on ToM tasks. This result, which confirms that learning is also required, is inconsistent with the *expression alone* hypothesis. Of course, *it does not establish that EFs are drawn upon in that learning*.

The *learning/construction* hypothesis under consideration here is that EFs are crucially involved in the construction of ToM during the preschool years. It follows from that hypothesis that EFs would be correlated even with those ToM tasks that do not draw on EFs in on-line processing. One piece of evidence taken to support this prediction is the finding that children's ToM *explanations* are correlated with EFs (Perner, Lang, & Kloo, 2002). According to Perner et al., the standard false belief task, in which the child must predict where Sally will look for her toy, requires inhibition of a prepotent response. In contrast, an explanation task, where children are shown Sally looking in the place where the toy is not, and are then asked to *explain* this finding, the inhibitory demand is removed. Children under 4 fail the explanation task as abjectly as they fail the prediction task, which, Perner argued, militates against the *expression alone* hypothesis. Perner et al.'s argument presupposes that the explanation task actually makes fewer EF demands than does the prediction task, but that is an empirical question, a question explored in the Powell and Carey EF depletion study reviewed above. In that study we found that EF depletion in 4 1/2- to 5-year-olds impaired both prediction and explanation in false belief tasks equally. Apparently EF is required for children to realize the relevance of a false belief in the explanation task, and not just to inhibit a prepotent response in a prediction task. Thus, given the evidence reviewed so far, both hypotheses concerning the interpretation of the correlation between EFs and ToM in the preschool years are still very much open.

Training studies may offer a useful method for adjudicating between the *learning/construction* and the *expression alone* hypotheses. That's because the *learning/construction* hypothesis makes a straightforward prediction regarding exposure to new information: insofar as theory construction demands EF, children with stronger EFs should be better able to take advantage of exposure to theory relevant information than children with weaker EFs. Training studies can thus be used to test the *learning/construction* hypothesis. There are indeed several training studies that have shown success in fostering better performance on ToM tasks by 3-year-olds (Hale & Tager-Flusberg, 2003; Slaughter, 1998; Slaughter & Gopnik, 1996). Benson et al. (2013) screened 3.5 year olds with a pretest consisting of a battery of false-belief tasks (Contents change, Location change, appearance-reality, and deceptive pointing). In addition, children were screened on a pre-false-belief ToM measure (Wellman & Liu, 2004). Twenty-four children who failed the false belief battery then received two false-belief training sessions. Each session consisted of four location change scenarios where the experimenter asked children to predict where a protagonist with a false belief would search for an object. After answering the question, the child was provided corrective or confirmatory feedback. Training was followed by a posttest on the false-belief battery of tasks. Children's response-conflict EF was also assessed, through the Dimensional Change Card Sort, the Bear/Dragon, and the Grass/Snow tasks, as was the child's receptive vocabulary (Peabody Picture Vocabulary Test, III). Benson et al. found that children who scored higher on an aggregate of the response-conflict EF tasks benefitted more from false-belief training, (partialing out age, receptive vocabulary, and pre-false-belief ToM knowledge). They concluded that EFs do indeed play a role in the learning/construction of a representational theory of mind.

We applaud the logic of this elegant study, but its conclusion must be tempered by several caveats. This study provides little evidence for a Piagetian construction. All of the change achieved by high EF children occurred on the first (of 8) training vignettes. Furthermore, the improvements on the posttest were restricted to false belief tasks alone; there were no effects on other tasks reflecting a representational ToM. Thus, this training intervention did not occasion, by itself, a theory change within ToM. Indeed, Bartsch and Wellman's (1995) study of spontaneous speech locates 3:0 as the age at which children construct a representational ToM. An expression account of these results is thus equally likely. Given Powell & Carey's results that EF is drawn upon even in explanation tasks, that is even in the process of attributing a false belief to another person, it is likely that the 3.5-year-olds in this study with higher EFs were better able to draw upon their underlying ToM knowledge to attribute a false belief to the protagonist and to understand the feedback provided in the training vignettes.

As described above, Onishi and Baillargeon (2005) provided evidence that toddlers under age 2 not only represent other agents' knowledge, they also correctly predict other agents' behavior, taking into account the agents' relevant false beliefs. There are now several additional studies that call into question whether there is actually any conceptual discontinuity to be explained in the development of a theory of mind (Buttelmann et al., 2009; Scott & Baillargeon, 2009; Song & Baillargeon, 2008; Southgate et al., 2007; Surian et al., 2007). Developmental psychologists have so far failed to reach a consensus on how to resolve the apparent conflicts between the infant studies, which appear to reveal rich conceptual competence, with the equally robust developmental changes observed on explicit false belief tasks in the preschool years. Therefore, ToM might not be the best case study with which to explore the relations between Piagetian constructivism (theory changes involving conceptual change) and domain general changes in cognitive resources (EFs in this case). We turn now to a review of recent work exploring the same issues, but this time in an episode of theory development that indubitably involves conceptual change – and hence instantiates a Piagetian construction. This is the case of the acquisition of a vitalist biology around age 6.

Explaining the correlation between EFs and vitalist biology

Normally developing English-, French-, and Japanese-speaking children undergo a conceptual change within their intuitive biology between ages 5 and 12 (Carey, 1985b; Inagaki & Hatano, 2002; Laurendeau & Pinard, 1962; Piaget, 1929; Slaughter et al., 1999). The change in the conceptual repertoire in the course of this theory change has been characterized in great detail. During these years the concepts *alive, real, present,* and *existing* are differentiated; the categories *plants* and *animals* coalesce into a single category *living organisms; dead* is differentiated from *inanimate;* and activity and self-propelled motion are no longer at the very center of the concept *alive* (Carey, 1985b, 2009). Thus, this case study is a classic example of a Piagetian construction. There is no evidence, nor any proposal, that the concepts within vitalist biology are innate.

As reviewed above, measures of EF predict the progress 5- to 7-year-olds have made toward the construction of the vitalist biology. Of course, the correlation between EFs and naïve biology is open to various interpretations. As in the ToM case, EFs may be required for the on-line expression of biological knowledge in any given task, and this fact alone may explain the correlation. Alternatively, EFs may be required for the learning process that underlies the construction of a vitalist biology. Even though a vitalist biology is indubitably learned, it is still possible that the relation between developing EFs and developing biological understanding is one of *expression alone.* If the learning mechanisms involved in constructing the vitalist theory are associative, or otherwise do not draw upon EFs, then the correlations observed in Zaitchik et al. (2013) might reflect the fact that EF is needed for *expression* of the conceptual understanding children have – and *only* for that reason. These correlations, then, do not provide conclusive evidence that EF is required for the process of construction itself.

Do the vitalism tasks make on-line EF demands?

The viability of the *expression alone* hypothesis depends upon showing that deploying one's conceptual knowledge of biology, while being questioned about that very knowledge, does in fact draw on EF resources. If so, typical adults' (perhaps even biology professors') judgments should be impaired under conditions that do not allow them to deploy the effortful and slow EFs. Goldberg and Thompson-Schill (2009) administered the Animism interview to college undergraduates in a speeded presentation. Under these conditions, college students make the same errors that young children make under non-speeded conditions, attributing life to inanimate objects associated with activity and movement, and denying life to plants. Although biology professors make no errors, their response times reflect this same pattern; they are slower to say a tree is alive than to say a dog is alive and they are slower to say the sun is not alive than to say a table is not alive. These data are consistent with the conclusion that the vitalist pattern of judgments requires inhibition of the responses that would be generated by the developmentally prior agency theory (see also Shtulman & Valcarel, 2012).

Another prediction of the hypothesis that EF resources are required for the expression of vitalist biology is that participants with impaired EFs should perform worse on the vitalist battery than do participants with intact EFs. Consistent with this prediction, Zaitchik and Solomon (2008a, 2008b) found that patients in the early stages of Alzheimer's disease, as well as some healthy elderly controls, were more likely to judge that inanimate objects (e.g. the sun) are alive, and were more likely to deny that plants are alive) than were young adults on the animism interview. Aging and Alzheimer's disease both result in decreases in EF. A follow-up study (Tardiff, Bascandziev, Sandor, Carey, & Zaitchik, 2015) replicating these earlier findings also compared the performance of typical young adults with that of healthy elderly subjects on an EF battery as well as a biology battery. The elderly adults performed worse than young adults not only on the EF measures but on the Animism interview too, attributing life to inanimate objects associated with activity and movement. Furthermore, measures of EF predicted which healthy elderly participants provided animist responses. Importantly, the healthy elderly subjects did not differ from young adults on the Body Parts and on the Death interview. These results suggest that the vitalist theory of biology in healthy elderly subjects is intact and they only show decreased performance on questions that elicit prepotent (animist) responses. In sum, there is convincing evidence that EF is required for the on-line expression of a vitalist understanding, especially on the animism interview. Still, this conclusion is consistent with the possibility that EF is also drawn upon in the processes of construction of a vitalist biology.

Is EF needed for the construction of vitalist biology?

The Williams Syndrome study described above (Johnson & Carey, 1998) provides suggestive evidence for the construction hypothesis. Individuals with WS have impaired EFs, and not a single adult had constructed a vitalist biology, Indeed, they performed like 4- and 5-year-olds on a battery of tasks that diagnosed conceptual understanding of biology. Yet their factual knowledge about animals was equivalent to that of 12-year-olds, showing preserved capacity for acquiring new beliefs. However, Johnson and Carey (1998) did not explore the hypothesis that impaired EF was implicated in the failure of individuals with WS to construct a vitalist biology.

A recent study adopted the logic of the Benson et al. (2013) training study described above. Bascandziev, Tardiff, Zaitchik, and Carey (2015) directly tested the prediction that children with higher EFs would acquire a vitalist theory of biology at a faster rate compared to children with lower EFs. Eighty-two 6-year-olds received a pre-training interview on the battery (Animism Interview, the Body Parts interview, the Death interview), as well as on a set of Fun Facts about animals (e.g., where are cricket's ears – answer, on their legs; how do dolphins sleep – answer, one half of their brain at a time). Next, all children participated in two training sessions that taught them about the function of various body organs and how those organs work together as an integrated system to support movement, growth, and health. Importantly, the training did not mention the words *alive* or *dead*. In addition, each training session included the answers to the Fun Facts questions. A posttest identical to the pretest followed the training. Lastly, children received two response conflict EF tasks (Hearts and Flowers and Flanker Fish, tasks that tap inhibitory control, set shifting, and working memory), a test of verbal fluency, and a test of Receptive Vocabulary.

Consistent with previous findings, the three vitalism interviews were positively correlated at the time of the pretest, as should be the case if they reflect an integrated theory. Not surprisingly, given that the training concerned the location and function of internal body parts, children improved on the body parts interview between pretest and posttest. Also, children's answers to the questions about the Fun Facts improved, again, not surprisingly, as they were told the answers during each of the two training sessions. Extending Slaughter and Lyons's (2003) finding, children improved between pretest and posttest on the animism and death interviews as well. An unanticipated finding was that the three vitalism interviews were vastly more intercorrelated on the posttest than on the pretest (*r*s ranging from .22 to .35 at pretest and from .45 to .54 at posttest), in spite of the fact that the training concerned only the functioning of the bodily machine, where maintaining life and avoiding death were not among the targeted functions. We interpret this finding as evidence that the training contributed to the constructive process of creating a vitalist biology. Of course, our main interest in this study was the relation between EFs and improvement on the vitalism battery.

Not all children improved at the same rate. A multilevel modeling analysis showed that children who scored higher on an EF composite measure (including verbal-fluency animals, verbal fluency-food, and flanker fish), benefited more from the training sessions and scored higher on the biology composite measure (aggregated scores of Animism, Death, and Body parts), compared to children who scored lower on the EF composite measure, even after controlling for age and receptive vocabulary. In contrast, both children with high EF and those with low EF learned the Fun Facts at a similar rate. Rather, a multilevel modeling analysis showed that receptive vocabulary scores predicted improvement on the Fun Facts. This pattern of results supports a distinction between processes that underlie gaining factual knowledge and processes that underlie conceptual change – with EF implicated specifically in the latter.

These data provide strong evidence that EF is recruited in the construction of a vitalist biology. There are several reasons this might be so. EF is required for sustained attention, and this fact alone might explain why children with higher EF learned more from the training intervention. However, the finding that there was no effect of EF on learning the Fun Facts militates against this being the sole reason for the advantage of higher EF in gains on the biology battery. Rather, we think it likely that the bootstrapping processes that underlie conceptual change draw heavily on EF. Remember Eliza's questions concerning how statues could be alive, given that one can see them (see above)? Such questions suggest that conceptual change requires comprehension monitoring – including noticing contradictions within one's current conceptual understanding. This in turn makes high working memory demands – holding the contradictory propositions in mind, and comparing them to try to locate the source of the contradiction. Furthermore, the bootstrapping process requires both building partially interpreted placeholder structures and bringing them to bear on explaining known facts, processes that place demands on working memory and conceptual conflict management. As Piaget insisted, construction is an *active* process, and the EFs are a seat of conceptual *activity*.

Conclusions

The case study of developmental change in biological knowledge provides strong evidence for both of Piaget's theoretical thrusts. The process of conceptual construction dissociates from mere accretion of new facts, and draws on domain-general resources that undergo massive developmental change.

The constructivist hypothesis that there is a developmental discontinuity between children's early agent-centered theory of the biological world and their later vitalist theory of biology is well-confirmed by several sources of data. Each of the theories is internally coherent, reliably diagnosable through clinical interviews. The developmental progression from the agency theory to the vitalist biology unfolds over several years, and some populations, such as individuals with Williams syndrome, never achieve it, despite acquiring vast amounts of factual information about the biological world. The identification of constructivism with conceptual change and the theory–theory of development has allowed developmental cognitive science to go beyond Piaget's insights, both through systematic work on how evidence is brought to bear on hypothesis confirmation (e.g., Gopnik & Schulz, 2007) and on the characterization and explanation of conceptual change (e.g., Carey, 2009).

Furthermore, the hypothesis that EF development may be the locus of the domain-general changes Piaget sought in his theorizing about stage changes also derives support from this case study. Even adults draw upon EF in the on-line deployment of vitalist biology. Moreover, the training study just reviewed provides strong evidence that EF is recruited in the processes of construction of a vitalist theory of biology. Although this work is an outgrowth of neo-Piagetianism, it proposes a very different view of the nature of stage changes from those proposed in Piaget's mature accounts. Most importantly, it locates the domain-general changes in aspects of representational structure and computational mechanisms that are divorced from conceptual content.

As is plain from this review, Piaget's constructivism and Piaget's stage theory are still with us today. Adapting in light of the insights provided by modern cognitive science and cognitive neuroscience, they remain current, motivating research on conceptual change and enriching our understanding of its role in cognitive development.

Acknowledgments

We acknowledge with gratitude the support of the Spencer Foundation 2012-00109 and the National Science Foundation BCS 1247396.

References

Aguiar, A., & Baillargeon, R. (1999). 2.5-month-old infants' reasoning about when objects should and should not be occluded. *Cognitive Psychology*, *39*(2), 116–157.

Aguiar, A., & Baillargeon, R. (2002). Development in young infants' reasoning about occluded objects. *Cognitive Psychology*, *45*(2), 267–336.

Baddeley, A. D. (1981). The concept of working memory: A view of its current state and probable future. *Cognition*, *10*, 17–23.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), *Recent advances in learning and motivation* (Vol. VIII). New York: Academic Press.

Baillargeon, R., Scott, R. M., & He, Z. (2010). False-belief understanding in infants. *Trends in Cognitive Sciences*, *14*, 110–118.

Baillargeon, R., Spelke, E. S., & Wasserman, S. (1985). Object permanence in 5-month- old infants. *Cognition*, *20*, 191–208.

Baldwin, D. A. (1991). Infants' contribution to the achievement of joint reference. *Child Development*, *62*(5), 875–890.

Baldwin, D. A. (1993). Early referential understanding: Infants' ability to recognize referential acts for what they are. *Developmental Psychology*, *29*(5), 832–843.

Baldwin, D. A., & Moses, L. J. (1994). Early understanding of referential intent and attentional focus: Evidence from language and emotion. In C. Lewis & P. Mitchell (Eds.), *Children's early understanding of mind: Origins and development* (pp. 133–156). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Barrett, H. C. (2005). Adaptations to predators and prey. In D. M. Buss (Ed.), *The handbook of evolutionary psychology* (pp. 200–223). New York: Wiley.

Bartsch, K., & Wellman, H. (1995). *Children talk about the mind*. New York: Oxford University Press.

Bascandziev, I., Tardiff, N., Zaitchik, D., & Carey, S. (2015). *Exploring the relationship between executive functions and the construction of a vitalist theory of biology in young children* (Manuscript in preparation).

Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource? *Journal of Personality and Social Psychology*, *74*, 1252–1265.

Benson, J. E., Sabbagh, M. A., Carlson, S. M., & Zelazo, P. D. (2013). Individual differences in executive functioning predict preschoolers' improvement from theory-of-mind training. *Developmental Psychology*, *49*, 1615–1627.

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*, 647–663.

Buttelmann, D., Carpenter, M., & Tomasello, M. (2009). Eighteen-month-old infants show false belief understanding in an active helping paradigm. *Cognition*, *112*, 337–342.

Carey, S. (1985a). Are children fundamentally different thinkers and learners from adults? In S. F. Chipman, J. W. Segal, & R. Glaser (Eds.), *Thinking and learning skills* (Vol. 2). Hillsdale, NJ: Erlbaum. Reprinted by Open University Press, Open University Readings in Cognitive Development.

Carey, S. (1985b). *Conceptual change in childhood*. Cambridge MA: MIT Press.

Carey, S. (1999). Sources of conceptual change. In E. K. Scholnick, K. Nelson, S. A. Gelman, & P. Miller (Eds.), *Conceptual development: Piaget's legacy* (pp. 293–326). Hillsdale, NJ: Erlbaum.

Carey, S. (2009). *The origin of concepts*. New York: Oxford University Press.

Carey, S. (2015). Why theories of concepts should not ignore the problem of acquisition. In E. Margolis & S. Laurence (Eds.), *Concepts: New directions* (pp. 415–454). Cambridge: MIT Press.

Carlson, S. M., Mandell, D. J., & Williams, L. (2004). Executive function and theory of mind: Stability and prediction from ages 2 to 3. *Developmental Psychology*, *40*, 1105–1122.

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development*, *72*(4), 1032–1053.

Case, R. (1985). *Intellectual development. Birth to adulthood*. New York: Academic Press.

Case, R. (1992a). Neo-Piagetian theories of child development. In R. J. Sternberg & C. A. Berg (Eds.), *Intellectual development* (pp. 161–197). Hillsdale, NJ: Erlbaum.

Case, R. (1992b). *The mind's staircase: Exploring the conceptual underpinnings of children's thought and knowledge*. Hillsdale, NJ: Erlbaum.

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. C. M. (2001). Changes in executive control across the life span: Examination of task-switching performance. *Developmental Psychology*, *37*, 715–730.

Chatham, C. H., Frank, M. J., & Munakata, Y. (2009). Pupillometric and behavioral markers of a developmental shift in the temporal dynamics of cognitive control. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(14), 5529–5533.

Collins, A., & Koechlin, E. (2012). Reasoning, learning, and creativity: Frontal lobe function and human decision making. *PLoS Biology*, *10*, e1001293.

Contento, I. (1981). Children's thinking about food and eating: A Piagetian-based study. *Journal of Nutrition Education*, *13*, 86–90.

Crain, S., & Khlentzos, D. (2010). The logic instinct. *Mind and Language*, *25*(1), 30–65.

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task-switching. *Neuropsychologia*, *44*, 2037–2078.

Demetriou, A. (2006). Neo-Piagetische Ansatze. In W. Schneider & F. Wilkening (Eds.), *Theorien, modelle, und methoden der Endwicklungpsychologie. Volume of Enzyklopadie der Psychologie* (pp. 191–263). Gotingen: Hogrefe-Verlag.

Devine, R. T., & Hughes, C. (2014). Relations between false belief understanding and executive function in early childhood: A meta-analysis. *Child Development*, *85*(5), 1777–1794.

Diamond, A. (1991). Neuropsychological insights into the meaning of object concept development. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind: Essays on biology and cognition* (pp. 67–110). Hillsdale, NJ: Earlbaum.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*, 1387–1388.

Diamond, A., & Goldman-Rakic, P. S. (1989). Comparison of human infants and rhesus monkeys on Piaget's A-not-B task: Evidence for dependence on dorsolateral prefrontal cortex. *Experimental Brain Research*, *74*, 24–40.

Fischer, K. W. (1980). A theory of cognitive development: The control and construction of hierarchies of skills. *Psychological Review*, *87*, 477–531.

Flynn, E. (2007). The role of inhibitory control in false belief understanding. *Infant and Child Development*, *16*, 53–69.

Flynn, E., O'Malley, C., & Wood, D. (2004). A longitudinal, microgenetic study of the emergence of false belief understanding and inhibition skills. *Developmental Science*, *7*, 103–115.

Fodor, J. A. (1992). A theory of the child's theory of mind. *Cognition*, *44*, 283–296.

Frye, D. (1999). Development of intention: The relation of executive function to theory of mind. In P. D. Zelazo, J. W. Astington,

& D. R. Olson (Eds.), *Developing theories of intention: Social understanding and self control* (pp. 119–132). Mahwah, NJ: Lawrence Erlbaum.

Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development*, *10*, 483–527.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from National Curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology*, *40*, 1–16.

Gathercole, S. E., Tiffany, C., Briscoe, J., Thorn, A. S. C., & ALSPAC Team (2005). Developmental consequences of poor phonological short-term memory function in childhood: A longitudinal study. *Journal of Child Psychology and Psychiatry*, *46*, 598–611.

Gelman, R., & Baillargeon, R. (1983). A review of some Piagetian concepts. In J. H. Flavell & E. M. Markman (Eds.), *Cognitive development: Handbook of child development* (Vol. 3, pp. 167–230). New York: Wiley.

Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: The naive theory of rationale action. *Trends in Cognitive Science*, *7*, 287–292.

Gergely, G., Nadasdy, Z., Csibra, G., & Biro, S. (1995). Taking the intentional stance at 12 months of age. *Cognition*, *56*, 165–193.

Goldberg, R. F., & Thompson-Schill, S. L. (2009). Developmental 'roots' in mature biological knowledge. *Psychological Science*, *20*, 480–487.

Gopnik, A., & Meltzoff, A. (1997). *Words, thoughts, and theories*. Cambridge, MA: MIT Press.

Gopnik, A., & Schulz, L. E. (Eds.), (2007). *Causal learning: Psychology, philosophy, and computation*. Oxford: Oxford University Press.

Grafman, J. (1994). Alternative frameworks for the conceptualization of prefrontal functions. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (p. 187). Amsterdam: Elsevier.

Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. L. D. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin*, *136*, 495–525.

Hale, C. M., & Tager-Flusberg, H. (2003). The influence of language on theory of mind: A training study. *Developmental Science*, *6*, 346–359.

Halford, G. S. (1993). *Children's understanding: The development of mental models*. Hillsdale, NJ: Erlbaum.

Hatano, G., & Inagaki, K. (1994). Young children's naive theory of biology. *Cognition*, *50*, 171–188.

Hickling, A. K., & Wellman, H. M. (2001). The emergence of children's causal explanations and theories: Evidence from everyday conversation. *Developmental Psychology*, *37*, 668–683.

Hughes, C. (1998). Finding your marbles: Does preschoolers' strategic behavior predict later understanding of mind? *Developmental Psychology*, *34*, 1326–1339.

Hughes, C., & Ensor, R. (2007). Executive function and theory of mind: Predictive relations from ages 2 to 4. *Developmental Psychology*, *43*, 1447–1459.

Inagaki, K., & Hatano, G. (1993). Young children's understanding of the mind-body distinction. *Child Development*, *64*, 1534–1549.

Inagaki, K., & Hatano, G. (2002). *Young children's naïve thinking about the biological world*. New York: Psychology Press.

Johnson, S. C. (2003). Detecting agents. *Philosophical Transactions of the Royal Society*, *358*, 549–559.

Johnson, S. C., & Carey, S. (1998). Knowledge enrichment and conceptual change in folk biology: Evidence from people with Williams syndrome. *Cognitive Psychology*, *37*, 156–200.

Keil, F. C. (1989). *Concepts, kinds, and cognitive development*. Cambridge, MA: MIT Press.

Kuhn, T. (1982). *Commensurability, comparability, communicability*. In Proceedings of the biennial meeting of the Philosophy of Science Association, Vol. 2: Symposia and invited papers (pp. 669–688). East Lansing, MI: University of Chicago Press.

Laurendeau, M., & Pinard, A. (1962). *Causal thinking in the child: A genetic and experimental approach*. New York: International Universities Press.

Leslie, A. M. (1994). ToMM, ToBy, and Agency: Core architecture and domain specificity. In L. Hirschfeld & S. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 119–148). Cambridge, UK: Cambridge University Press.

Leslie, A. M. (2000). How to acquire a representational theory of mind. In D. Sperber (Ed.), *Meta-representations: A multidisciplinary perspective* (pp. 197–224).

Leslie, A. M., Friedman, O., & German, T. P. (2004). Core mechanisms in 'theory of mind'. *Trends in Cognitive Sciences*, *8*, 528–533.

Leslie, A. M., & Polizzi, P. (1998). Inhibitory processing in the false-belief task: Two conjectures. *Developmental Science*, *1*, 247–253.

Luciana, M., & Nelson, C. A. (1998). The functional emergence of prefrontally-guided working memory systems in four- to eight-year old children. *Neuropsychologia*, *36*, 273–293.

Luo, Y., & Baillargeon, R. (2007). Do 12.5-month-old infants consider what objects others can see when interpreting their actions? *Cognition*, *105*, 489–512.

Luo, Y., & Johnson, S. (2009). Recognizing the role of perception in action at 6 months. *Developmental Science*, *12*, 142–149.

Lyons, K. E., & Zelazo, P. D. (2011). Monitoring, metacognition, and executive function: Elucidating the role of self-reflection in the development of self-regulation. *Advances in Child Development and Behavior*, *40*, 379–412.

Miller, E. K. (1999). The prefrontal cortex: Complex neural properties for complex behavior. *Neuron*, *22*, 15–17.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*, 167–202.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100.

Morrison, F. J., Ponitz, C. C., & McClelland, M. M. (2010). Self-regulation and academic achievement in the transition to school. In S. D. Calkins & M. Bell (Eds.), *Child development at the intersection of emotion and cognition* (pp. 203–224). Washington, DC: Am. Psychol. Assoc.

Munakata, Y., Herd, S. A., Chatham, C. H., Depue, B. E., Banich, M. T., & O'Reilly, R. C. (2011). A unified framework for inhibitory control. *Trends in Cognitive Sciences*, *15*, 453–459.

Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing cognitive control: Three key transitions. *Current Directions in Psychological Science*, *21*, 71–77.

Nersessian, N. (1992). How do scientists think? Capturing the dynamics of conceptual change in science. In R. Giere (Ed.), *Cognitive models of science* (pp. 3–44). Minneapolis: University of Minnesota Press.

Onishi, K. H., & Baillargeon, R. (2005). Do 15-month-old infants understand false beliefs? *Science*, *308*, 255–258.

Osherson, D. N. (1974–1976). *Logical abilities in children* (Vol. 1–4). Hillsdale, NJ: Erlbaum.

Pascual-Leone, J. (1970). A mathematical model for the transition rule in Piaget's developmental stages. *Acta Psychologica*, *32*, 301–345.

Passingham, R. (1993). *The frontal lobes and voluntary action*. Oxford, UK: Oxford Univ.

Perner, J., & Lang, B. (1999). Development of theory of mind and executive control. *Trends in Cognitive Sciences*, *3*, 337–344.

Perner, J., Lang, B., & Kloo, D. (2002). Theory of mind and self-control: More than a common problem of inhibition. *Child Development*, *73*, 752–767.

Perner, J., & Ruffman, T. (2005). Infants' insight into the mind: How deep? *Science*, *308*(5719), 214–216.

Piaget, J. (1929). *The child's conception of the world*. London: Routledge and Kegan Paul.

Piaget, J., & Inhelder, B. (1974). *The child's construction of quantities: Conservation and atomism*. London: Routledge & Kegan Paul.

Piatelli-Palmarini, M. (1980). *Language learning: The debate between Jean Piaget and Noam Chomsky*. Cambridge, MA: Harvard University Press.

Powell, L. J., & Carey, S. (2015). *Executive function depletion in children and its impact on Theory of Mind* (Manuscript submitted for publication).

Premack, D., & Premack, A. J. (1995). Intention as psychological cause. In *Causal cognition: A multidisciplinary debate* (pp. 185–199).

Richards, D. D., & Siegler, R. S. (1984). The effects of task requirements on children's life judgments. *Child Development*, *55*, 1687–1696.

Ruffman, T., & Perner, J. (2005). Do infants really understand false belief?: Response to Leslie. *Trends in Cognitive Sciences*, *9:*, 462–463.

Sabbagh, M. A., Xu, F., Carlson, S. M., Moses, L. J., & Lee, K. (2006). The development of executive functioning and theory of mind. *Psychological Science*, *17*, 74–81.

Scholl, B. J., & Leslie, A. M. (1999). Modularity, development and 'Theory of Mind'. *Mind and Language*, *14*, 131–153.

Scott, R. M., & Baillargeon, R. (2009). Which penguin is this? Attributing false beliefs about object identity at 18 months. *Child Development*, *80*, 1172–1196.

Shtulman, A., & Valcarel, J. (2012). Scientific knowledge suppresses but does not supplant earlier intuitions. *Cognition*, *124*, 209–215.

Sirois, S., & Jackson, I. (2007). Social cognition in infancy: A critical review of research on higher order abilities. *European Journal of Developmental Psychology*, *4*(1), 46–64.

Slaughter, V. (1998). Children's understanding of pictorial and mental representations. *Child Development*, *69*, 321–332.

Slaughter, V., & Gopnik, A. (1996). Conceptual coherence in the child's theory of mind: Training children to understand belief. *Child Development*, *67*, 2967–2988.

Slaughter, V., Jaakkola, K., & Carey, S. (1999). Constructing a coherent theory: Children's biological understanding of life and death. In M. Siegel & C. C. Peterson (Eds.), *Children's understanding of biology and health* (pp. 71–98). Cambridge, UK: Cambridge University Press.

Slaughter, V., & Lyons, M. (2003). Learning about life and death in early childhood. *Cognitive Psychology*, *46*, 1–30.

Smith, C., Carey, S., & Wiser, M. (1985). On differentiation: A case study of the development of size, weight, and density. *Cognition*, *21*(3), 177–237.

Smith, C. L. (2007). Bootstrapping processes in the development of students' commonsense matter theories: Using analogical mappings, thought experiments, and learning to measure to promote conceptual restructuring. *Cognition and Instruction*, *25*(4), 337–398.

Snyder, H. R., & Munakata, Y. (2010). Becoming self-directed: Abstract representations support endogenous flexibility in children. *Cognition*, *116*, 155–167.

Song, H., & Baillargeon, R. (2008). Infants' reasoning about others' false perceptions. *Developmental Psychology*, *44*, 1789–1795.

Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief by 2-year-olds. *Psychological Science*, *18*, 587–592.

Spelke, E. S., Kestenbaum, R., & Simons, D. J. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology*, *13*(2), 113–142.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs*, *74* (Whole No. 498), 1–29.

Surian, L., Caldi, S., & Sperber, D. (2007). Attribution of beliefs by 13-month-old infants. *Psychological Science*, *18*, 580–586.

Tardiff, N., Bascandziev, I., Sandor, K., Carey, S., & Zaitchik, D. (2015). *Diminished executive function affects biological reasoning in elderly adults* (Manuscript in preparation).

Tomasello, M., & Haberl, K. (2003). Understanding attention: 12- and 18-month-olds know what is new for other persons. *Developmental Psychology*, *39*(5), 906–912.

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development*, *72*, 655–684.

Wellman, H. M., & Gelman, S. (1992). Cognitive development: Foundational theories of core domains. *Annual Review of Psychology*, *43*, 337–375.

Wellman, H. M., & Liu, D. (2004). Scaling of theory-of-mind tasks. *Child Development*, *75*, 523–541.

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition*, *13*(1), 103–128.

Wynn, K. (1992). Addition and subtraction by human infants. *Nature*, *358*, 749–750.

Zaitchik, D., Iqbal, Y., & Carey, S. (2013). The effect of executive function on biological reasoning in young children: An individual differences study. *Child Development*, *85*, 160–175.

Zaitchik, D., & Solomon, G. (2008a). Animist thinking in the elderly and in patients with Alzheimer's disease. *Cognitive Neuropsychology*, *25*, 27–37.

Zaitchik, D., & Solomon, G. (2008b). Inhibitory mechanisms and impairment in domain-specific reasoning: Studies of healthy elderly adults and patients with Alzheimer's disease. *Proceedings of the Cognitive Science Society*, *30*, 141.

Zelazo, P. D. (2004). The development of conscious control in childhood. *Trends in Cognitive Sciences*, *8*, 12–17.

Zelazo, P. D., & Frye, D. (1997). Cognitive complexity and control: A theory of the development of deliberate reasoning and intentional action. In M. Stamenov (Ed.), *Language structure, discourse, and the access to consciousness* (pp. 113–153). Amsterdam: John Benjamins.

Zelazo, P. D., Müller, U., Frye, D., Marcovitch, S., Argitis, G., Boseovski, J., et al. (2003). The development of executive function in early childhood. *Monographs of the Society for Research in Child Development*, *68*(3).