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Two Tales of Conceptual Change: What Changes and What Remains the Same

Frank C. Keil and George E. Newman
Yale University

Conceptual change is not always synonymous with cognitive development. For example, children can undergo changes in their thought process that would not normally be considered instances of conceptual change. Moreover, these changes may influence concept use in a dramatic manner. In many cases, that dramatic influence can easily appear to be true conceptual change, when in fact it is not. Although it can be relatively easy to delineate in principle a large number of different forms of conceptual change, in practice, it often can be difficult to know which form is actually occurring. Scholars can disagree quite dramatically on whether they are witnessing a true conceptual revolution or a more pedestrian case of conceptual elaboration, or no real conceptual change at all. Thus, it is important to be clear about patterns of cognitive development so as to better distinguish real instances of conceptual change from developmental changes that merely appear to be conceptual.

Here, we suggest that true conceptual change occurs under one of two conditions: either a concept's internal structure changes, or its relations to other concepts changes in ways that are central to its meaning. However, the coherence of such accounts obviously depends on the models one proposes for how concepts are represented. For example, if one favors a minimalist view of concept structure in which concepts such as "dog," "car," and "tiger" are represented in essentially the same way as "red," conceptual change may indeed be a rare event only found in relatively exotic compound concepts (Fodor, 1998). In this essay we'll assume that everyday concepts like "dog" or "car" do have more structure than such minimalist views, either by having an internal structure consisting of sets of features, properties and their interrelations (e.g., Smith & Medin, 1981) or by having an "external" structure consisting of their relation to other concepts that give them their meaning (e.g., Quine & Ullian, 1978). We will not dwell here on these alternatives or on possible hybrid combinations (e.g., Murphy, 2002; Keil, 1989; Keil, Smith, Simons, & Levin, 1998). Our approach is to assume that some kind of structural characterization is needed to explain how concepts are represented, used and acquired and that conceptual change consists of cases where that structure changes.

There are, however, some modest additional assumptions about concept structure that are relevant to almost all commonly described cases of conceptual change. One such assumption is the idea that the structural configuration associated with a concept is domain-specific. Thus, when a child's concept of living things undergoes some type of change, we assume that the change is bounded to the domain of biology. The effect of that change can be quite dramatic for many related concepts within that domain, but relatively minor or non-existent for concepts that are outside of the domain. This assumption might seem to clash with meaning holism, the idea that concepts are inferentially linked together to almost all other concepts in the web of belief. It need not be incompatible, however, as the density of linkages might be quite variable: changes within a domain, where links are dense, may cause far more changes than for concepts in other domains, where the links are sparse.

There is also an assumption that concepts are, to some degree, parts of theory-like structures that provide explanatory insight into why their features co-occur. Thus, the concept of bird includes not only the fact that wings and flight are correlated, but also some causal story of how wings enable flight. Such stories can be incomplete, or even outright wrong, but it is commonly assumed that some set of explanatory beliefs is essential to understanding how we acquire and use concepts and, moreover, how they change. For example, if a series of explanatory gaps grows, it may precipitate a conceptual change to structures and relations that have fewer gaps or inconsistencies (Kuhn, 1962; Carey, 1985). The concepts-in-theories idea does encounter challenges, as people's lay theories are often highly fragmentary (diSessa & Sherin, 1998), or surprisingly incomplete (Rozenblit & Keil, 2002). For our purposes, however, we will assume that some notion of explanatory insight is part of most accounts of what concepts are and how they change, while acknowledging that the explanatory component may not be in the form of detailed, well-developed theories or mechanistic mental models (Keil, 2003, 2006).

There have been several discussions attempting to delineate various kinds of conceptual change (Carey, 1985, 1991, 1999; Chi, 1992; Inagaki & Hatano, 2002; Keil, 1999; Nersessian, 1989; Thagard, 1992; Vosniadou & Brewer, 1987). There may be cases of gradual elaboration of a structure by adding new more fine-grained information that doesn't change the kind of structure involved. There may be dramatic restructuring of a concept similar to historical "revolutions" in thought (Kuhn, 1962). These revolutions could consist either of cases of new concepts "differentiating" out of old ones (Carey, 1999); or a restructuring of how features and properties define concepts (Keil, 1989). Conceptual changes can also sometimes result in a reassignment of ontological categories (Chi, 1992), such as thinking of flames as a process instead of as "stuff."

In addition, we will argue that some kinds of conceptual change may be missed altogether if considered at the wrong level of analysis. For example, one level of analysis may reveal the same judgments at different ages, while another may reveal that the same judgments are in reality occurring for dramatically different reasons. In this chapter, we considers two extremes to illustrate how easy it is to be misled about what is changing and why. We consider first a pattern of judgments over the course of development that seems to be essentially the same. When looked at through the lens of one method and set of stimuli, no significant conceptual change appears to be occurring. We will show, however, that when considered in more detail with other stimuli and questions, a dramatic change may be occurring — one that is masked by certain anchoring phenomena in the real world. In other words, sometimes a causal pattern in the world may be so salient and reliable that children in all ages (even infants) will be able to predict it in the same way, but the basis for the predictions may undergo dramatic conceptual change.

Our second example considers a case of apparently dramatic conceptual change that seems to reflect a genuine revolution in conceptual structure and shifts of ontological categories. We will illustrate, however, that the same patterns of change in judgments could occur without any true conceptual change occurring in the traditional sense. We will consider two alternatives to conceptual change that are often overlooked but which can mimic dramatic changes in conceptual structure. We will then examine how one might tease these cases apart.

CONCEPTUAL REVOLUTIONS UNDERNEATH A SEA OF CALM

The world around us consists of two fundamentally forms of patterns: those that appear random and those that appear to radically depart from randomness by having some sort of order. Order may be perceived in any number of modalities and in many different forms, whether it be via axes of symmetry, spatial or temporal sorting, or complex structural arrangements. Moreover, the way in which we differentiate the causal origins of these patterns (randomness vs. order) may be as distinct as the structural arrangements themselves: whereas any number of underlying causal processes may give rise to apparent randomness, departures from randomness tend only to result from the intentional actions of goal-directed actors (or agents) — e.g., a parent cleans up a child's room by stacking items of like kind in different piles, or a diamond miner sorts rough diamonds by size, color, and quality. As adults, we clearly recognize that agents have the capacity to manipulate, organize, and structure the world around them such that they create patterns that deviate from random or chance occurrences.

We do not, however, see simple bounded objects as capable of having such effects. Throw a stone, roll a ball, or slide a block at a disordered system and it is highly unlikely that any of those events will make a more orderly arrangement. We would be surprised to see such an effect because we normally assume that order arises from the intentional actions of agents, not inanimate objects. Thus, one major division in the world of causal entities is between those that are capable of creating order and those that are not.

Previous work suggests that even infants appear sensitive to this fundamental distinction. By 12 months of age, infants appear to understand that whereas agents are capable of creating order (or reversing entropy on a local scale), inanimate objects are not (Newman, Keil, Kuhlmeier, & Wynn, 2005; under review). Using a standard violation-of-expectation procedure, Newman et al. (2005) presented infants with two types of short, computer-animated movies. In one type of movie (the "Ordering" movie), infants first saw a disordered array of blocks. An opaque screen appeared and moved in front of the blocks, hiding them from view. Then an "entity" moved behind the screen. For half the infants the entity was an inanimate object, a polka-dotted ball that rolled behind the screen. For the other half of the infants, the entity was an animate agent (a ball-like character with a face). In test trials, the screen dropped to reveal the blocks in an ordered arrangement. Thus, it appeared as if the entity (ball or agent) changed the disordered pile of blocks into an ordered pile.

In the other type movie (the "Disordering" movie), infants saw an identical sequence of events, however, the beginning and end-states of the block-arrays were reversed: infants first saw an ordered array of blocks, the entity moved behind the screen, then the screen dropped to reveal the blocks in disarray. Now it appeared as if the entity changed the ordered arrangement of blocks into a disordered pile. The Ordering and Disordering movies were identical, except for the sequence in which the ordered and disordered arrays appeared.

Whereas it is perfectly consistent for a ball to disorganize a group of blocks (e.g., by colliding with them), it is impossible for a ball to organize a group of blocks. Therefore, we predicted that infants in the "Ball" condition should look longer at the movie of a ball creating order than at the movie of a ball creating disorder. In contrast, infants in the "Agent" condition should look equally long at the movies of an agent creating order and an agent creating disorder, because both outcomes are consistent with actions that agents are capable of completing. Consistent with these predictions, infants looked reliably longer when the ball apparently caused a disordered array to become ordered, than when it caused an ordered array to become disordered. In contrast, when infants saw identical events involving an agent, they did not differentiate between ordered and disordered outcomes, suggesting that infants did not apply the same sorts of expectations to the agent as they did the ball.

It was unclear, however, from this initial study exactly why infants in the Agent condition failed to distinguish between the Ordering and Disordering events. It may be that infants, like adults, appreciate that agents can cause either order or disorder; thus, they found neither event unexpected. Alternatively, it may be that infants were simply unable to generate predictions about the agent's actions. Perhaps infants selectively apply the principle of entropy to inanimate objects without making firm predictions about the capacities of agents.

To distinguish between these two possibilities, a second study explored whether infants can in fact form positive expectations about an agent's ability to create order. Borrowing from a series of studies in which infants attribute consistent, object-specific goals to human hands but not to inanimate sticks (Leslie, 1984; Woodward, 1998), we asked whether infants appreciate that an agent may have the "goal" to cause order, and whether they recognize that goal as different from a goal to cause disorder.

Infants were familiarized to short movie sequences involving real objects (instead of computer-animated cartoons), in which a hand or a claw appeared to create order. Infants in the Hand condition first saw a disordered pile of blocks, and an opaque barrier was raised to cover the blocks. Then, an experimenter's hand traveled behind the barrier, appeared to manipulate the objects and then exited the display. The barrier was dropped to reveal the blocks in an ordered arrangement. After infants saw this event three times, they were shown two different types of test events involving new blocks (i.e., different shapes and colors). In the Ordering event, the hand continued to create order by changing a disordered pile of blocks into an ordered array (similar to the familiarization trials). In the Disordering event, the sequence of events was reversed: the hand appeared to cause disorder, changing an ordered arrangement of blocks into a disordered array.

A second group of infants in a Claw condition saw exactly the same series of events, however, instead of a hand, infants saw events in which a claw-like stick appeared to either organize or disorganize arrays of objects: Infants were first familiarized to the claw creating order and then saw the claw either continuing to create order, or creating disorder.

When infants were familiarized to the hand creating order, they expected the hand to continue to create order: thus, they looked reliably longer when the hand changed its goal and appeared to cause disorder than when it continued to create order. Thus, infants appeared to recognize that the goal to create order was distinct from the goal to create disorder, and they expected such a goal to remain consistent across subsequent test events involving novel arrays of objects. In contrast, when infants saw the identical sequence of events involving the claw, they did not look longer when the claw changed to cause disorder. In fact, infants in the Claw condition continued to look longer at the claw creating order, presumably because they continued to find that sequence of events unexpected.

Together, these studies suggest that by 12 months of age, infants appreciate that intentional agents are capable of creating order in ways that inanimate objects are not. Moreover, on the surface it would seem as though infants have, roughly, the same appreciation as adults: infants expect that causal interactions involving only inanimate objects should result in more disorderly arrangements. They know, for instance, that an inanimate ball can cause an ordered array to become disordered, but not a disordered array to become ordered (also see Friedman, 2002). Infants, however, also appear capable of making predictions about the actions of agents. They expect an agent who creates order to remain an "orderer" and thus find it "unexpected" when the agent changes its goal to become a "disorderer." Without previous exposure to the agent's goals, however, infants do not appear to distinguish between an agent creating order and an agent creating disorder. Thus, infants appear sensitive whether or not an agent has the apparent goal to create order.

For adults, it is this second understanding of order as the product of intentional goal-directed action that seems particularly important to how we interpret and explain the existence of order in the world. The capacity to create more ordered structures from less ordered ones represents one of the most salient aspects of human agency. Evidence that humans are capable of creating order is present in virtually every aspect of our daily lives, from buildings, to artifacts, to visual art. In fact, we often associate ordered arrangements with the mental plans that produce them, rather than the physical or mechanical causes that may have brought them into existence. For example, even in situations where order is physically caused by inanimate objects, such as robots on an assembly line, we often associate the change from relative disorder to order with the *mental* plan to create order (e.g., a blueprint, or the robot's designer), rather than the mechanical causes that may have produced such a change (e.g., the robot itself).

Although the work discussed above suggests that, at some level, infants like adults may think of order in terms of intentional goal-directed action rather than pure mechanical causes, the nature of looking-time measures prevents drawing any strong conclusions about how infants may be representing such events. The present case is one where robust patterns in the world may support an early-emerging conceptual distinction that is relatively continuous across development. However, it may also be that infants and adults represent such a distinction in fundamentally different ways, while producing a pattern of responses that only *appears* to be the same.

A potential method for exploring this issue is to investigate how young children may represent similar conceptual distinctions. For example, do we see evidence of similar patterns of reasoning in young children (e.g., preschoolers), who might be better able to articulate a basis for their response? In contrast to the infant studies, previous work indicates that in certain circumstances, children may actually have a great deal of difficulty reasoning about the effects of random forces (e.g., Piaget & Inhelder, 1975; Shultz & Cottington, 1981). However, more recent studies that reduce task demands have found that children as young as four-years-old appreciate that random forces are only likely to produce disordered arrangements (Friedman, 2001). Thus, it is unclear from previous work whether an understanding of causality and order undergoes any sort of conceptual change between infancy and adulthood.

THE CAUSE REMAINS THE SAME

Here, we briefly describe two experiments that attempted to address this issue directly. In our first study we simply wanted to replicate the pattern of responses observed with infants. Using a paradigm similar to the first infant study, we contrasted agents versus inanimate causes. We tested whether preschoolers (3- to 6-year-olds) appreciate that inanimate forces (e.g., the wind blowing) are only capable of producing disorder, while agents (e.g., a person) can produce either order or disorder.

Children were first presented with a cartoon drawing of a room. The drawing depicted six different piles of blocks distributed around the room. For each child, the experimenter said, "This is a picture of Billy's room, and these are some of the things that are in his room. One day, Billy went outside to play, and this is how things looked before he went outside." Children in the Person condition were then presented with a cartoon drawing of a teenage girl. The experimenter said, "This is a picture of Billy's older sister, Julie. While Billy was outside playing, Julie went into his room and changed some of his things." The experimenter then presented two different test cards. One test card depicted an ordered array of blocks. The other test card depicted a disordered array of blocks. The ordered and disordered arrays were both different than the arrays presented in the initial drawing, but were composed of the same blocks. Children were then asked, "Which one of these piles looks most like if Julie changed it?" Children were presented with six different pairs of ordered and disordered arrangements. Each ordered arrangement was organized along a different perceptual dimension, such as color, shape, or spatial arrangement.

The other half of the children were assigned to the Wind condition. Children in this condition were presented with exactly the same series of pictures. However, instead of a drawing of teenage girl, children were shown a cartoon drawing of an open window. The experimenter said, "This is a picture of the window in Billy's room. The window was open, and the wind was blowing really strong. While Billy was outside playing, the wind blew in his room and changed some of his things." Analogous to the Person condition, the experimenter then presented two different test cards. One card depicted an ordered array of blocks, while the other card depicted a disordered array of blocks. Children were then asked, "Which one of these piles looks most like if the wind changed it?"

We predicted that children in the Person condition should be likely to say that the person could make either the ordered or disordered arrangements, because both outcomes are consistent with actions that agents are capable of completing. Thus, children's pattern of response should mirror the looking time pattern of infants. In contrast, whereas a strong gust of wind can disorganize a group of blocks, it is highly unlikely that the wind blowing could organize a group of blocks. Therefore, we predicted that children in the Wind condition should be significantly more likely to say that the wind made the disordered arrangement than to say that the wind made the ordered arrangement.

The results from this study were consistent with these predictions. Children in the Person condition reported that the person could make either the ordered or disordered arrangement. In contrast, children in the Wind condition were significantly more likely to say that the wind blowing could only create the disordered arrangement. Splitting the sample into two age groups (5- to 6-year-olds and 3- to 4-year-olds) revealed no differences in the pattern of responding across the two age ranges.

For each item in this study, children were also asked to explain *why* they thought the particular causal agent (person or wind) would produce the arrangement they selected. Interestingly, children were often unable to articulate the basis for their response. In fact, children's most common justification was simply to describe the visual array, such as merely redescribing that the wind had knocked over the blocks. Thus, children rarely described the nature of the causal agent when describing the ordered and disordered arrays.

Results from this study suggested that children as young as three- to four-years-old appreciate that, whereas agents can cause either order or disorder, inanimate forces such as the wind are only likely to cause disorder. This pattern of judgments is consistent with infants' looking time preferences: 12-month-olds look longer when an inanimate ball creates order than when it creates disorder, yet, they look equally long at an agent creating either order or disorder. Furthermore, we did not observe any differences in judgments between three-year-olds and six-year-olds. Thus, beliefs about the unique connection between order and agency appear to be relatively unchanging throughout early development. However, though preschoolers clearly appreciate that agents are unique in their ability to create order, it is still uncertain from their justifications (or lack thereof) how they might be representing such an understanding. Although the overall pattern of judgments may be the same, perhaps young children and adults represent an identical causal pattern in fundamentally different ways. Here we briefly consider three possibilities for how children may initially be representing such an understanding.

EARLY CONCEPTUAL MODELS FOR AN ABILITY TO CREATE ORDER

One possibility may be that children's expectations about the ability to create order emerge from the psychological domain. Perhaps children start with the appreciation that only agents are responsible for order. Such an expectation would be plausible given early exposure to many instances in which people create ordered arrangements. From an association between agents and order, children may then come to expect that inanimate causes rarely bring about order. In contrast, expectations about the causes of *disorder* may receive little systematic feedback. Hence, children may accept that either agents or inanimate causes are capable of causing disorder. This view predicts that, initially, children may be likely to describe both animate and inanimate causes in terms of psychological characteristics. For instance, "people create order because they want to, while the wind doesn't know how."

A second possibility is that children's expectations about order emerge from an understanding of physical causality. Children may first appreciate that inanimate causes lack the capacity to physically bring about ordered arrangements, whereas agents (e.g., human hands) are capable of causing many different types of change. Such an appreciation may not include a detailed understanding of mechanism, but rather may consist of only a very general notion that agents are not necessarily subject to the same physical laws that govern simple inanimate objects. In other words, young children and infants may have a relatively abstract, intuitive appreciation that agents and inanimate objects differ in their capacities to bring about certain types of physical change. This view predicts that young children may represent the difference between inanimate causes and agents in terms of physical characteristics. For instance, "the wind can't create order because it can't pick stuff up, while people can move things around in many ways."

A third possibility is that young children represent the connection between causality and order as two distinct understandings: a) that animate entities tend to produce order, and b) that inanimate forces are only capable of bringing about disorder. This view predicts that whereas children may be likely to discuss inanimate causes in terms of mechanical characteristics, they may be more likely to describe agents and order in terms of psychological characteristics. For instance, "a ball causes disorder because it can only knock things over, while an agent causes order because they want to." Intuitively, this third possibility seems the most similar to the adult appreciation.

ANTHROPOMORPHIZING ORDER

One way to experimentally distinguish between the interpretations outlined above may be to explore what types of entities young children view as capable of creating order. Given that preschoolers are often likely to anthropomorphize and over-attribute human-like mental states to many different types of entities (e.g., Lutz, 2003), the first and third views predict that younger children may be more liberal than older children in the types of entities that they view as capable of creating order. In other words, if children do explain agents and order via psychological characteristics then beliefs about the ability to create order may follow beliefs about an organism's mental capacities. Thus, younger children may say that a wider-range of entities can create order than older children, because they believe a wider-range of entities to have more human-like mental capacities.

Our second study specifically probed children's judgments about the kinds of agents capable of creating ordered arrangements. We wanted to explore how narrowly or broadly children might construe an "ability to create order". Using a similar design as the first study we presented children with changes from disorder to order and asked about different entities that may be capable of causing such a change. We also explored whether children make any conceptual distinctions between different *types* of order and the type of entity involved.

Young elementary school children (ranging from Kindergarteners to second graders) were presented with photographs of real objects. Children were first shown a photograph of a disordered arrangement (e.g., a scrambled pile of red and black beans). Then, they were shown a photograph of the same objects in an ordered array (e.g., two neat piles of beans, organized by color). The experimenter said, "Here are some objects. The objects used to look like this (disordered photo), but a little while later they looked like this (ordered photo)." The experimenter would ask, "What do you notice about these pictures? What has changed?" For children who were unable to articulate the difference between the two pictures, the experimenter helped explain the differences. For instance, he said, "Look, in this picture they are all messed up. But, in this picture they are put into neat piles. All of the black ones are over here while all of the red ones are over there."

After the child acknowledged the difference between the disordered and ordered photographs, the experimenter asked (pointing to the ordered photo), "How do you think it got to be this way?" The experimenter then presented four cartoon drawings of different "agents." The four agents were drawings of a teenage girl, a baby, a cat, and an open window. The experimenter then pointed to each the agents saying, "Which one of these do you think changed the objects? Was it the big girl, the baby, the kitty cat, or the wind blowing really strong?" After the child selected a particular agent the experimenter asked (pointing to the remaining agents), "Do you think that any of the other ones could have changed the objects?" This process was repeated until either the child said that none of the other agents were capable of causing the ordered array, or the child said that all of the agents were capable of causing the ordered array. This same procedure was repeated for ten different sets of items. The ten items were designed to represent five different types of order, with two exemplars of each, i.e., grouping by color, grouping by shape, grouping by spatial arrangement, grouping by category, and grouping by "complimentarity" (e.g., small objects that were always placed *inside* of rings, though the exact spatial arrangement was not ordered). Additionally, children were asked to justify the basis for their response for three of the items. For instance, the experiment asked, "Why do you think that the girl made the objects look like that?" or "Why couldn't the baby make the blocks look like that?"

For each child, we tallied the total number of times that they chose a particular agent (e.g., person, baby, cat, or wind). Unsurprisingly, both Kindergartners and second graders were significantly more likely to say a person could make order than any of the other agents; and overall, children did not distinguish between different kinds of order and the type of agent responsible — suggesting that their appreciation of an ability to create order might be fairly abstract. However, there was a rather curious result: second graders were significantly more likely to say that the baby could create different types of order than were kindergarteners (no other differences between the age groups were observed). This finding that *older* children were more likely to say that the baby could create order than were younger children was quite surprising. In fact, this result was directly opposite the prediction that younger children should judge a wider-range of entities to be capable of creating order than older children. Instead, we found that *younger* children appeared more restrictive in their judgments than older children. To explore what might be responsible for this counterintuitive pattern, we more closely examined children's justifications.

Children's justifications were coded into one of three categories. For this analysis we combined across "positive" justifications (e.g., explanations for why a particular entity could cause order) and "negative" justifications (e.g., explanations for why a particular entity could not cause order). The justifications were coded as either "Physical" (e.g., "the (agent) couldn't do it because it doesn't have hands", "it can't pick it up", "it is too little", "the blocks are too heavy", or "the (agent) has hands", "the (agent) is big"), "Mental" (e.g., "doesn't know how", "not smart enough", "can't do it on purpose", or "because they want to"), or "Other" (e.g., "b/c only the person could do it", "can only make it messy", "can only mess around with it"). Using this coding scheme, we found a significant difference between younger and older children's justifications: Younger children were reliably more likely to provide "Physical" justifications, while older children were reliably more likely to provide "Mental" justifications. Thus, despite a similar response pattern, Kindergarteners and second-graders seem to causally account for order in very different ways.

Such a pattern potentially explains the counterintuitive finding that older children are *more* likely report that a baby can create order than are younger children. Perhaps because older children are coding order more in terms of psychological characteristics, they are more likely to think that a baby can create order than are younger children (note that this explanation assumes that children are over-attributing adult-like mental capacities to infants). In contrast, younger children may be coding the identical pattern in terms of physical characteristics. As such, they may correctly recognize that an infant lacks the physical dexterity to create ordered structures; thus they are less likely to report that an infant can create order.

A SHIFT IN STRUCTURE?

The studies discussed here with children suggest that despite an apparently consistent pattern of responding across multiple age ranges, there may actually be quite a dramatic shift in how children account for ordered arrangements: Five- to six-year-olds appear to represent the capacity to create order more in terms of the physical characteristics that may produce ordered structures (e.g., hands, adult dexterity). In contrast, seven- and eight-year-olds seem to account for the identical causal patterns more in terms of psychological characteristics (e.g., the plan to create order). Such a shift is potentially indicative of a conceptual reassignment in ontological categories, of the sort discussed above. Initially, young children and perhaps infants may situate the capacity to create order more in the physical domain (along with other types of physical changes, such as causal contact). Under this view, early appreciations of order may consist of only of the very general notion that agents are not subject to the same physical laws that govern simple inanimate objects. This understanding, however, may still include notions of intentionality despite emerging from the physical domain: the intentional actions of agents (and their causal powers) might be viewed as a sort of break from the deterministic affects of physical causes.

Seven- and eight-year-olds, on the other hand, appear to appreciate that the mental plan to produce order is a necessary prerequisite for bringing about ordered arrangements. In this sense, their understanding of an ability to create order may be more heavily tied to the psychological domain. Again, such a reassignment does not preclude an understanding of physical process; rather, it merely suggests that an understanding of the capacity to create order in older children may have stronger ties to other types of psychological concepts (mental representations, design, etc.) than in younger children. Thus, in terms of the potential representations outlined earlier, children seem to be shifting from a predominately physical account of order to a more nuanced view that incorporates an understanding of the mental capacities necessary to bring about ordered structures.

It could be argued that in fact there is less conceptual change going on here than meets the eye. Perhaps the younger children are interpreting the "why" question as one about how the action was actually performed while older children are interpreting the same question as about underlying causes. If this alternative were correct, then different kinds of questions might prompt more similar responses across ages. We don't, however, think that this alternative can fully explain these results as the younger children did sometimes refer to underlying causes (e.g., that the infant was physically too weak to cause order) — but only an extensive series of studies can determine for sure whether this rather dramatic change in justifications is more than simply a shift in the understanding of a question, rather than a deeper sort of conceptual change. Our point here is only to note that a pattern of judgments, which at one level might suggest no conceptual change at all, might reveal dramatic change when examined at a different level of analysis.

If this difference in understanding is borne out, then we have a case where developmental constancy in judgments about which agent is responsible for creating order masks an underlying conceptual change concerning the kinds of causal reasons behind that change. One empirical prediction here is that if children really are shifting from physical to psychological understandings of order, then at some point in development we should observe a fairly dramatic shift in children's understanding of the requisite mental capacities necessary to produce order. For example, younger children may be more likely to endorse the plausibility of ordering devices that lack true mental underpinnings (such as purely mechanical robots). Similarly, as children shift from physical to psychological explanations they may begin to more accurately match varying complexities of order with appropriately complex mental capacities. For example, younger children may simply think that any human is capable of causing any type of order, while older children may more accurately report that more complicated structures require sufficiently greater mental abilities. If, however, task demands are part of the story and younger children are simply interpreting "why" questions in a different manner, follow-up studies should reveal that when the question is clarified, they can fully grasp the relatively intricate ways in which mental states are related to order. We think that this is unlikely, but recognize the need for further studies in this area.

In short, even infants understand quite well that agents are the likely causes of ordered events, and judgments linking order to agents remain highly consistent from infancy on into adulthood. The correlation is simply too strong and salient in the world to ignore. As a result, there is great deal of developmental continuity in judgments concerning what cause (agent vs. inanimate cause) goes with what outcome. Yet, the basis for such judgments (when viewed from a different level of analysis) may change dramatically as children come to understand a different causal basis for ordering events.

False Revolutions — Surface Change without Deep Conceptual Change

In marked contrast to cases of consistent judgment patterns over time, there are many examples in cognitive development where children's judgments seem to change dramatically. In some instances, such changes may appear to be direct reflections of changes in conceptual structure, when in fact other kinds of developmental change may be at work. One classic case along these lines concerns the development of transitive reasoning. It was long believed, following Piaget, that younger children simply didn't have the ability to engage in transitive reasoning because they were missing some kind of logical operator that enabled them to know that inequalities such as $A > B$ and $B > C$, logically entailed $A > C$. Yet, in a now classic study, Bryant and Trabasso (1971) illustrated how the main developmental change might be caused by general memory limitations instead of profound conceptual change. When young children were extensively trained on sets of inequalities and could easily remember each of them, the transitive inferences seemed to naturally fall out. Thus, there may not be any change in the concept of transitivity, but rather, merely a change in the ability to hold enough inequalities in mind so as to use them as the foundation for transitive inferences. This kind of change is therefore a domain-general one of changing abilities to memorize arbitrary relations, not a result of a specific problem with a transitive operator. Developmental changes in domain-general capacities may have effects on performance in specific tasks, but should not be confused with conceptual changes of mental representations or operations that are much more focused, such as transitive reasoning.

More broadly, developmental psychology over the past few decades has witnessed several cases where changes in memory capacity or attention, rather than changes in knowledge structures or conceptual systems, seem to be the basis for developmental change. In cases of conservation (Gelman, 1969; McGarrigle & Donaldson, 1974), egocentrism (Shatz & Gelman, 1973), or classification (Mandler, 2004), memory and attention limitations have often provided compelling alternative explanations. In most cases, however, the arguments have been against domain-general conceptual changes of the sort proposed by global stage theorists such as Piaget. Changes in memory and attention capacity can also be domain-general, but they are not normally considered instances of conceptual change (given the characterization that we developed at the beginning of the chapter). We don't, for example, normally think of changes in memory and attention as involving changes in causal beliefs in an explanatory structure. Nor do we think of memory and attention capacity changes as causing changes in ontological status, such as shifting from seeing a flame as a substance to seeing it as an event, or from seeing ordered arrangements as a predominately physical, rather than a mental creation.

Presently, we consider conceptual change in folk-biological thought, a case where qualitative conceptual change seems to be quite compelling, namely that a child may shift from thinking of living things as members of one domain with one kind of relations to being members of a different domain with very different kinds of relations. Biological thought has often been considered a paradigmatic instance of conceptual change. We consider the case of biology here because the kind of conceptual change that has been proposed (a revolutionary restructuring of an entire domain) is among the most dramatic and interesting forms in that literature. Thus, if we can show that a case of an apparent shift in ontological types and networks of causal relations is in fact something far less dramatic, we have illustrated the challenges of inferring conceptual change from only one level of evidence.

Conceptual Change in Folk-Biology

One of the most fascinating and influential claims of conceptual change is the idea that young children (e.g., preschoolers) have no real sense of the biological world per se, but instead understand the living world in terms of two earlier emerging systems: a naïve physics and a naïve psychology (Carey, 1985). There is now abundant evidence that even infants can have dramatically different expectations about agents who they consider psychological, as opposed objects that they view as merely mechanical (Carey & Spelke, 1994; Leslie, 1994). For example, there is ample evidence that infants see goal-directed actors as different from inanimate objects (Kuhlmeier, Bloom, & Wynn 2004; Meltzoff, 1995; Poulin-Dubois, Lepage, & Ferland, 1996; Woodward, 1998), and they expect these two kinds of objects to interact differently with the environment (Gergely, Nadasdy, Csibra, & Biro, 1995; Rakison & Poulin-Dubois, 2001; Saxe, Tenenbaum, & Carey, 2005; Spelke, Phillips, & Woodward, 1995). Indeed, the case of order and agents, just considered, relies on the ability of infants to distinguish intentional psychological agents from unintentional mechanical causes. Infants may not yet be able to figure out how intentional agents create order (in terms of specific mental capacities), but they may well code that the category of things that comprises intentional agents has particular causal powers that the other category (inanimate objects) does not.

It has been argued that unlike the early-emerging systems of psychology and physics, the grand revolution for biology is one where living kinds are first interpreted in a Procrustean manner as being part of either psychology or mechanics (Carey, 1985). In essence, psychology and mechanics are alleged to be the only early explanatory frameworks of any generality. Thus, by necessity, other causal patterns must be absorbed into one of these two domains until a new theory can emerge that is more specific to biology. A young child might view a plant as fundamentally the same sort of thing as a rock or an icicle, and see a dog as fundamentally the same sort of thing as an intentional human agent. However, somewhere around seven or eight years of age, a new domain of biological thought emerges along with the dramatic insight that dogs, plants, people, and bugs are all in the same domain of living things. Thus, the child no longer needs the crutches of psychology and physics to interpret biological properties and processes. A newly emergent understanding of reproduction, nutrition, and basic physiology makes it possible to see the ontological commonality to all living things (Carey, 1985).

Evidence of this dramatic shift in conceptual structure is argued to be apparent in patterns of reasoning, such as property induction. For example, a child might be taught that a particular biological entity has a novel property, such as "an omentum." The child is then asked what other types of entities might also have that property (Carey, 1985). In other cases a more familiar property known to be true of humans, such as having babies, might be asked of other living and nonliving things (Carey, 1985). These induction tasks often reveal dramatic developmental changes in judgments. Younger children's inductions appear to be based on the extent to which an entity is psychologically similar to humans. Thus, dogs can have babies because the predicate "have babies" is understood in terms of its associated *psychological* roles such as being nurturing, protective and caring. By contrast, a supposed ignorance of the biological aspects of having babies, such as the need for a species to reproduce, causes young children to argue that other animals, such as worms, cannot have babies.

Older children, however, show a dramatic shift in their induction patterns, judging that appropriate biological properties apply to all living things. For example, older children will appropriately attribute biological properties, such as reproduction to all animals and often plants, but not to nonliving kinds. Such patterns are thought to reflect the emergence of theories unique to biological process. Later studies with different groups of children do not always find such developmental shifts (e.g., Ross, Medin, Coley, & Atran, 2003). For example, young children in rural Native American (Menominee) culture show adult-like patterns of induction (Ross et al., 2003), and in a somewhat different version of the task, Japanese children are also considerably more precocious (Hatano & Inagaki, 1994). In both cases, however, it could be argued that children in other cultures simply undergo the revolution to developing true biological thought much earlier. In other words, deep and profound conceptual change is occurring on a culture-wide basis. But, the special practices of a particular culture may alter the timetable for which such change happens.

There are, however, alternative accounts of how children's inductions might be changing; accounts in which changes in the pattern of judgment may occur without the mechanism of underlying conceptual change. In the following sections we more deeply consider two such alternatives. Our purpose is not to unilaterally decide whether or not profound conceptual change is *really* occurring. Instead, it is to more simply consider how other forms of change, besides conceptual change, might be responsible for dramatic shifts in judgment.

SHIFTING RELEVANCE: ONE FORM OF NON-CONCEPTUAL CHANGE

How might a child's patterns of judgment dramatically shift without underlying conceptual change? One way is through the notion of shifting relevance. Shifting relevance is a different mechanism for producing dramatic changes in judgments without necessarily implying underlying conceptual change. With respect to biology, there is strong evidence that developmental changes in patterns of induction may be explained by shifting relevance (Gurthiel, Vera, & Keil, 1998; Keil, 2003, 2006). A key feature of the notion of shifting relevance is that one often has to decide which conceptual domain is relevant before engaging in reasoning about an entity. For example, when predicting the motion path of a person we normally draw upon inferences from the psychological domain. We assume that a person's goals, beliefs and desires may best predict their movements. But, we could also treat the person as a brute physical object and reason about their motion path accordingly. We might very well do so, for example, if we knew that the person was in a coma, or in free-fall. Thus, our domain of mechanical physics is completely developed; it just doesn't spring to mind first when evaluating the motions of humans.

For induction tasks, similar influences may be at work. There are indeed multiple ways of construing predicates like "sleeps" and "has babies." Although it may be true that younger children interpret such phrases in psychological terms, they may do so not because they lack a conceptual domain of biology, but rather because they don't understand that biology is the preferred domain for the task at hand. In other words, younger children's confusion might occur in deciphering which conceptual domain (psychology, biology, or physics) is the most relevant way to construe a given property. For example, consider the question, "Does a worm think?" One might respond yes if "thinks" is understood in the biological sense as the raw, neural computation to process information so as to guide behavior. But, more likely, one will respond "no" because one interprets "thinks" in terms of mental states. Thus, the way in which "thinks" is understood may dramatically shift the types of entities to which "thinks" is thought to apply.

Many tasks contain terms that could be understood in one conceptual domain or another, an ambiguity that often is clarified by context, but which may be clarified in different ways at different ages. If both domains can be readily used once their relevance is made clear, then a shifting relevance account of developmental change in induction is supported. To test the shifting relevance possibility, Gutheil, Vera, and Keil (1998, p. 37) provided contextual cues to young children. The first kind of cue elaborated on the meaning of a term in a biological or psychological manner, such as:

> This person eats because he needs food to eat and grow. The food gives him energy to move. If he doesn't eat he will die (biological context for 'eat').

and,

> This person eats because he loves to be at meals with his family and friends. Meals bring the family together to eat and have fun. If he didn't eat, he would never see his family all together (psychological context for "eat").

This cue was provided only in talking about humans. Children were then presented with the standard induction task used by Carey (1985). As seen in Figure 4.1 (from Gutheil et al., 1998), the two contexts either made four-year-olds look just like Carey's four-year-olds, with a gradual drop off in induction suggestive of judgments relying upon a psychological system of interpretation or, with the biological context, made the four-year-olds look just like the seven-year-olds in the Carey studies who had presumably undergone a major conceptual revolution and understood the domain of biology proper. The four-year-olds in this study were not taught anything about the applicability of these terms to entities other than people, but once the biological sense of the terms was made clear, they immediately saw the relevance of biological similarities and judged accordingly. The presence of such induction patterns in four-year-olds suggests that the seven-year-olds might not differ because they have a new domain of biological thought, but more because they realize the greater relevance of a long existing conceptual realm of biology to the task at hand.

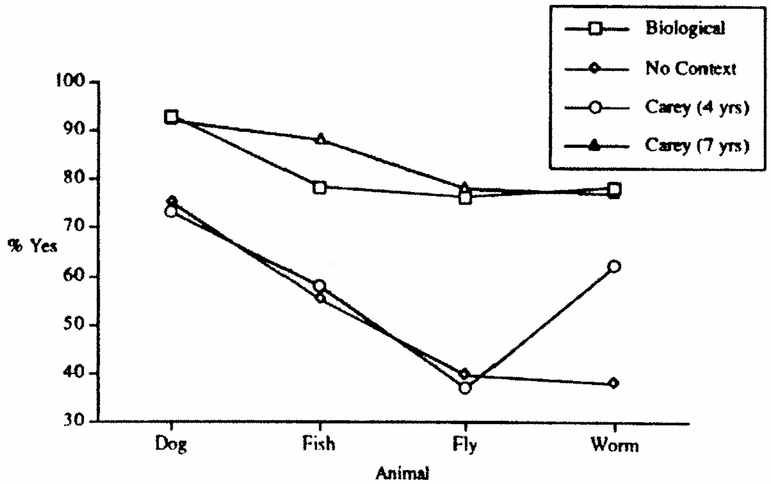

FIGURE 4.1 Children's patterns of induction can be shifted radically depending on whether they think that the biological or psychological sense of terms are implied (from Gutheil et al., 1998).

However, it might be argued that elaborating on the terms in ways done in the first study somehow allowed children to see the specific relevance of those terms without really engaging the broader domain of biological thought. To explore this issue, Gutheil et al. (1998) conducted a second study in which they didn't elaborate at all about the terms and instead merely provided a very general context for thinking in biological terms, a kind of conceptual system "priming." To cause such priming, they used the following passage:

> Let's talk about people, okay? You know how machines have inside parts that let them do things, like motors that make trucks move or batteries that make flashlights light up? Well, people have inside parts that let them do things in all sorts of interesting ways as well. We all can breathe by ourselves and we can all move around by ourselves and we all have the same kinds of stuff inside that lets us do this. People aren't the only things in the world that can do things like move around and breathe, right? We're going to look at the pictures of people and other things and talk about them. While we look at the pictures, try to think about all the different kinds of things in the world that can do things like move around by themselves, and breathe by themselves, and have the same kinds of stuff inside. Okay, here we go. (Gutheil et al., 1998, p. 43)

This simple thirty-second passage caused the same sort of shift as the more specific elaborations used in the first study. Simply putting four-year-old children into a biological frame of mind was enough to induce a pattern of judgments much like seven-year-olds. No specific biological terms were ever discussed, just the general idea of people functioning like complex machines.

It is clear how such patterns could, at least in principle, explain how shifts in judgments could occur without appealing to conceptual change: The four-year-olds could have exactly the same sense of biology as seven-year-olds, but just not appreciate all of the contexts to which biology (vs. psychology) applies. In practice, the story is probably not that simple. Indeed, increasing elaboration of knowledge, one of the most conservative forms of conceptual change may indeed be the mechanism that shifts relevance (Gutheil et al., 1998). Thus, as conceptual knowledge in an area becomes more articulated and richer, the child starts to appreciate more and more of its explanatory power for a wider range of phenomena. This same effect can be found in adults as they immerse themselves in a particular discipline. For example, consider undergraduates who become entranced with Marxist theory and use it to explain an enormous range of social, economic, and political phenomena. Similarly, those who become immersed in Freudian theory may start to see its relevance everywhere, such as in literary and artistic analysis. In such cases, it would probably be appropriate to describe these changes as conceptual change.

Moreover, shifting relevance may also engender conceptual change through different means. We have argued that changes in judgment patterns can occur simply as a reordering of default biases — i.e., which domain (or, mode of construal) first comes to mind in a task. But it may also be that other mental processes, such as analogies, similarly attract a certain mode of construal as relevant, while reflecting conceptual change at a deeper level. For example, a person might realize that some techniques in computer programming, such as recursion, can be used in writing down cooking recipes. This is an example of realizing the relevance of one domain to another. That realization, however, may additionally require conceptual elaborations of the understandings of recipes, which suddenly makes the computer programming routines more relevant. Thus, certain shifts in relevance via analogical insight may have relations to deeper sorts of conceptual change and elaboration.

We don't, however, think that the biological induction case described above can be explained in this way because the shift is so easily malleable. Even briefly priming the domain of biology can cause a dramatic flip in judgment patterns. In other words, this type of shift doesn't seem to require the corresponding shifts in conceptual elaboration. Indeed, one way to delineate these two notions of shifting relevance is by the nature of their affects: Shifts in relevance that occur in brief contexts (perhaps with specific types of conceptual primes) and with minimal elaboration may reflect minimal conceptual change, while those that occur more spontaneously and with greater elaboration (often through analogical insight) may have more complex change occurring.

In short, patterns of judgments that suggest dramatic conceptual change may actually reflect developmental changes that are not conceptual, such as shifting relevance. On the other hand, conceptual change may also, in turn, drive changes in children's ability to determine relevance via elaboration. Again, such analyses are not intended to unilaterally decide whether or not profound conceptual change is *really* occurring. Instead, we briefly considered how other forms of change, besides conceptual change, might be responsible for dramatic shifts in judgments. It is critical for researchers to be aware of this interplay between factors such as shifting relevance, depth of elaboration, etc. when making claims about conceptual change, and to consider that in some cases, the appearance of conceptual change may actually mask developmental changes of a different sort.

Increasing Access: A Second Form of Non-conceptual Change

A more general sort of change thought to underlie many types of developmental change, and possibly forms of conceptual change, is the notion of increasing access. The idea of increasing access has been in the literature for many years. Some of the most eloquent and compelling proposals for its role in cognitive development are present in seminal papers by Rozin (1976) and Fodor (1972). In both cases, the authors argued against global stages of cognitive development, such as those proposed by Vygotksy, Bruner, and Piaget, and instead suggested that a child may possess necessary logical operators or representational capacities but may have a much more limited use of them. The possible reasons for the limitations are many, but often revolve around memory and attention limitations, and the automaticity of related skills. Thus, a child might fail to recognize that liquid quantities are conserved (as in Piaget's classic task) because the end states are so compelling that they interfere with reflection about the earlier states and processes that produced them. Piaget certainly thought that the end states contributed to the failure to conserve. However, he linked a focus on end states to missing quasi-logical operators. Instead, the "increasing access" alternative posits fully intact operators that simply can't be accessed due to a sort of attentional override.

For Rozin, the "access" concerned access of the conscious mind to prior unconscious cognitive abilities, such as phonological principles used in speech that needed to be accessed for reading. Some tasks require an ability to retrieve information that one is already using very fluently and use it in new ways. But not all patterns of increasing access need to bring implicit knowledge into the explicit arena. Increasing access to a cognitive capacity may also occur because other cognitive structures and processes now enable a child to use an already present capacity in new tasks. For example, we can think of increasing memory skills as allowing a child to access transitive reasoning skills in a wider and wider range of situations that require more memory. Or increasing executive skills at shifting and controlling focus might allow conservation based reasoning to apply to a wider range of tasks. In all these cases, underlying conceptual change does not have to be occurring.

Can such an increasing access story also work for induction about biological properties? There have not been systematic studies exploring this option, but it is one way of explaining the cross-cultural differences in biological knowledge that have been found. For example, differences in when biological thought comes online in varying cultures (e.g., Ross et al., 2003) have been explained via the influence and practices of a particular culture. But, at the cognitive level, the influence of culture (in this context) may be to rehearse and emphasize necessary premises for reasoning about the biological domain. Just as in Bryant and Trabasso (1971), a particular culture may extensively train a certain set of inferences about biological process, such that an already existing domain of biological thought can be accessed more readily. Thus, without true conceptual change, judgments may shift depending on how access to certain biological concepts is reinforced, or perhaps inhibited in a given culture.

Briefly consider a culture that emphasizes the continuous reproductive cycle present in all living things versus a culture that emphasizes the animistic, anthropomorphic aspects of living kinds. Clearly, these two different sorts of influences may have profound consequences in establishing access to biological versus psychological concepts. Thus, a child raised in the biologically-heavy conceptual environment may more easily access concepts such as heredity and reproduction, than the child raised in the psychologically-heavy environment. As we saw in the previous section, such types of reinforcement may have dramatic influence for shifting relevance, and in turn, the resulting patterns of judgment.

Indeed, there is some empirical support for this idea. For example, Waxman, Medin, and Ross (in press) gave children from several different cultures versions of the adoption paradigm: children were told about a baby pig that was adopted and raised solely by other cows. They were then asked about many of the pig's properties, for example, what things would be pig-like and what would be cow-like. Across all cultures, they found evidence for a strong biological component to children's understanding of property inheritance. However, Native American children seemed to have more firm commitments about the biological mechanism underlying the transmission of properties from parent to offspring. Under the "increasing access" view, such patterns may result not from the presence or absence of theories about biological mechanism, but rather, the ease with which children are capable of retrieving them (as determined by their prevalence in a particular culture). Indeed, this interpretation does not seem to be all that different from the one made by Waxman et al. (in press): "In sum, the results (of Experiments 1 and 2) suggest that children may be more likely to consider biological (blood) than non-biological (nurturance) processes as candidate essences, and that in identifying candidate biological processes, they are sensitive to community-wide discourse."

Of course, conceptual change proper may also play an important role in either culture-wide or culture-specific change. The purpose of this section is simply to illustrate how increasing access might work (perhaps in tandem with shifting relevance) to give the illusion of deep conceptual change, when in fact, there is none. When considering whether or not one is witnessing true conceptual change, it is important to consider the many ways that task-specific or culture-specific factors may shape a pattern of judgments, perhaps in even dramatic ways.

CONCLUSIONS

Our general purpose in this chapter has been to argue that the study of conceptual change encompasses a rich and diverse set of mental phenomena: sometimes dramatic conceptual change may underlie a sea of apparent conceptual calm while, at other times, a surface of marked conceptual change may derive from other sorts changes in processing. It is important whenever examining patterns of development to realize the many distinct ways in which underlying cognitive processes could cause changes in judgments. All too often, researchers come to a task with a particular theoretical model that can indeed explain the developmental pattern but that causes them to neglect several other models that can also explain the same pattern. This is not to say that there is no way to tell theories apart; rather, when one explicitly considers the full range of possible accounts, it is then possible to design follow-up studies that can distinguish between different theoretical interpretations. However, the pluralism of patterns of change, both conceptual and not, does need to be acknowledged to motivate the right sorts of experimental designs.

Similarly, there are cases where a powerful pattern in the real world, such as that holding between agents and order, may result in common judgments across a wide range of ages (as discussed in the first section). A closer look, however, can reveal how at a different level of analysis dramatic conceptual change may still be occurring. In such cases as well, one needs to consider the full range of alternative models and what sorts of experimental results might distinguish among them. The only way to know what is really going on is to consider the many additional factors that may influence judgments (some of which we outlined here) and engage in close analyses of task performance — often from several different perspectives to see how they converge on the phenomena of interest. Thus, one key component of conceptual change (as a psychological construct) may be to engage lively and challenging theoretical discussion about what is *really* changing and why.

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REFERENCES

Bryant, P. E., & Trabasso, T. (1971). Transitive inferences and memory in young children. *Nature, 232*, 456–458.

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

Carey, S. (1991). Knowledge acquisition: Enrichment or conceptual change? In S. Carey & R. Gelman (Eds.), *The epigenesis of mind: Essays on biology and cognition* (pp. 257–291). Hillsdale, NJ: Erlbaum.

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

Carey, S., & Spelke, E. S. (1994). Domain specific knowledge and conceptual change. In L. Hirschfeld, & S. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 169–200). Cambridge: Cambridge University Press.

Chi, M. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. *Minnesota Studies in the Philosophy of Science, 15*, 129–186.

diSessa, A. A., & Sherin, B. L. (1998). What Changes in Conceptual Change? *International Journal of Science Education, 20*, 1155.

Fodor, J. A. (1972). Some reflections on L.S. Vygotsky's Thought And Language, *Cognition, 1*, 83–95.

Fodor, J. A. (1998). *Concepts: Where cognitive science went wrong*. New York: Oxford University Press.

Friedman, W., (2001). The development of an intuitive understanding of entropy. *Child Development, 72*, 460–473.

Friedman, W., (2002). Arrows of time in infancy: The representation of temporal-causal invariances. *Cognitive Psychology, 44*, 252–296.

Gelman, R. (1969). Conservation acquisition: A problem of learning to attend to relevant attributes. *Journal of Experimental Child Psychology, 7*, 167–187.

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

Gutheil, G., Vera, A., & Keil, F. C. (1998). Do houseflies think?: Patterns of induction and biological beliefs in development, *Cognition, 66*, 33–49.

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

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

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

Keil, F. C. (1999) Cognition, content and development. In M. Bennett (Ed.), *Developmental psychology: Prospects & achievements* (pp. 165–184). London: Psychology Press.

Keil, F. C. (2003). That's life: Coming to understand biology. *Human Development, 46*, 369–377.

Keil, F. C. (2006). Cognitive science and cognitive development. In W. Damon & R. Lerner (Series Eds.) & D. Kuhn & R. S. Siegler (Vol. Eds.), *Handbook of child psychology: Vol 2: Cognition, perception, and language* (6th ed., pp. 609-635). New York: Wiley.

Keil, F. C., Smith, C. S., Simons, D., & Levin, D. (1998). Two dogmas of conceptual empiricism, *Cognition, 65*, 103–135.

Kuhlmeier, V., Bloom, P., & Wynn, K., (2004). Do 5-month-old infants see humans as material objects? *Cognition, 94*, 95.

Kuhn, T. (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Leslie, A. (1984). Infant perception of a manual pick-up event. *British Journal of Developmental Psychology, 2*, 19–32.

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). New York: Cambridge University Press.

Lutz, D. J. (2003). Young children's understanding of the biological and behavioral processes underlying life and death. Unpublished Doctoral Dissertation

Mandler, J. M. (2004). *The foundations of mind: The origins of the conceptual system*. New York: Oxford University Press.

McGarrigle, J., & Donaldson, M. (1974). Conservation accidents. *Cognition, 3*, 341–350.

Meltzoff, A. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children, *Developmental Psychology, 31*, 838–850.

Murphy, G. L. (2002). *The big book of concepts*. Cambridge, MA: MIT Press.

Nersessian, N. (1989). Conceptual change in science and in science education. *Synthese*, 163–183.

Newman, G. E., Keil, F. C., Kuhlmeier, V., & Wynn, K. (2005, April). 12 Month-olds Know That Agents Defy Entropy: Exploring the Relationship Between Order and Intentionality. Society for Research in Child Development, Atlanta, GA.

Newman, G. E., Keil, F. C., Kuhlmeier, V., & Wynn, K. (under review). One-year-olds appreciate that only intentional agents can create order.

Piaget, J., & Inhelder, B. (1975). *The origin of the idea of chance in children*. New York: Norton.

Poulin-Dubois, D., Lepage, A., & Ferland, D. (1996). Infants'concept of animacy. *Cognitive Development, 11*, 19.

Quine, W. V., & Ullian, J.S. (1978). *The web of belief*. New York: Random House.

Rakison, D., & Poulin-Dubois, D. (2001). Developmental origin of the animate–inanimate distinction. *Psychological Bulletin, 127*, 209.

Ross, N., Medin, D. L., Coley, J. D., & Atran, S. (2003). Cultural and Experiential Differences in the Development of Folkbiological Induction. *Cognitive Development, 18*, 25–47.

Rozin, P. (1976). The evolution of intelligence and access to the cognitive unconscious. In J. M. Sprague & A. N. Epstein (Eds.), *Progress in psychobiology and physiological psychology, Vol. 6* (pp. 245–280). New York: Academic Press.

Saxe, R., Tenenbaum, J. B., & Carey, S. (2005). Secret agents: Inferences about hidden causes by 10- and 12-month-old infants. *Psychological Science, 16*, 995–1001.

Shatz, M., & Gelman, R. (1973). The development of communication skills: Modifications in the speech of young children as a function of listener. *Monographs of the Society for Research in Child Development, 38*, 1–38.

Shultz, T. R., & Cottington, M. (1981). Development of the concept of energy conservation and entropy. *Journal of Experimental Child Psychology, 31*, 131–152.

Smith, E. E., & Medin, D. L. (1981). *Categories and concepts*. Cambridge, MA: Harvard University Press.

Spelke, E., Phillips, A., & Woodward, A. (1995). Infants' knowledge of object motion and human action. In D. Sperber, D. Premack, & A. J. Premack (Ed.), *Causal cognition: A multidisciplinary debate* (chapter 3). Oxford: Oxford University Press.

Thagard, P. (1992). *Conceptual revolutions*. Princeton, NJ: Princeton University Press.

Vosniadou, S., & Brewer, W. F. (1987). Theories of knowledge restructuring in development. *Review of Educational Research, 57*, 51–67.

Waxman, S. R., Medin, D. L., & Ross, N. (in press). Folkbiological reasoning from a cross-cultural developmental perspective: Early essentialist notions are shaped by cultural beliefs. *Developmental Psychology*.

Woodward, A. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition, 69*, 1–34.