CHILD DEVELOPMENT

Child Development, January/February 2010, Volume 81, Number 1, Pages 390–409

Sensing the Coherence of Biology in Contrast to Psychology: Young Children's Use of Causal Relations to Distinguish Two Foundational Domains

Jane E. Erickson, Frank C. Keil, and Kristi L. Lockhart
Yale University

To what extent do children understand that biological processes fall into 1 coherent domain unified by distinct causal principles? In Experiments 1 and 2 (N = 125) kindergartners are given triads of biological and psychological processes and asked to identify which 2 members of the triad belong together. Results show that 5-year-olds correctly cluster biological processes and separate them from psychological ones. Experiments 3 and 4 (N = 64) examine whether or not children make this distinction because they understand that biological and psychological processes operate according to fundamentally different causal mechanisms. The results suggest that 5-year-olds do possess this understanding, and furthermore, they have intuitions about the nature of these different mechanisms.

Young children seem to have a clear sense that there are fundamentally different kinds of things in the world, or ontological categories, and they distinguish them by using different causal-explanatory frameworks (Carey, 1985; Keil, 1989; Murphy & Medin, 1985; Wellman & Gelman, 1992, 1998). Many questions remain, however, about the nature of these causal frameworks and how they guide acquisition and use of knowledge. Related questions ask how these frameworks develop into more sophisticated domain-specific causal ''theories'' possessed by lay adults. Here we explore aspects of the internal structure of such frameworks and consider the implications for models of conceptual development.

Three sorts of causal-explanatory frameworks have dominated much of the discussion on domain-specific causal principles—those fundamental to the domains of physics, psychology, and biology. The discussion revolves around the process through which children become aware of which entities belong in each of these domains and the extent to which the assignment of entities to domains is based on knowledge of deeper causal relations. Even preverbal infants consistently differentiate between animate and inanimate things and display some understanding of the causal principles driving the actions of entities within each of these domains (Baillargeon, 1994; Bertenthal, 1993; Bullock, 1985; Gelman, Durgin, & Kaufman, 1995; Poulin-Dubois & Shultz, 1990; Rakison & Poulin-Dubois, 2001; Rochat, Morgan, & Carpenter, 1997; Sommerville & Woodward, 2005; Spelke, Phillips, & Woodward, 1995; Surian, Caldi, & Sperber, 2007).

However, it remains less clear how an understanding of the fundamental principles underlying biological processes emerges in development. The animate–inanimate distinction may be a precursor to understanding the domain of living things, but this distinction can be easily approximated perceptually according to which objects move on their own, which objects engage in goal-directed actions, and which objects show other perceivable patterns of biological behavior or motion unique to living kinds. To proceed from an animate–inanimate distinction to an understanding of the living–nonliving distinction, one must group together entities that vary drastically on the perceptual level both statically and dynamically (plants and animals against nonliving natural kinds and artifacts). This requires

This research was supported by the National Institutes of Health Grant R37-HD023922 to Frank C. Keil. We thank the staff, parents, and students at Bell-Graham, Gales Ferry, Guilford Lakes, and Thalberg elementary schools for their support. Special thanks to Yaw Anim, Amy Hart, and Jared Aguirre for their assistance with this research.

Correspondence concerning this article should be addressed to Jane E. Erickson, Department of Psychology, Yale University, 2 Hillhouse Ave., New Haven, CT 06520-8205. Electronic mail may be sent to jane.erickson@yale.edu.

that one look past perceptual features to identify more fundamental characteristics of living things, such as physiological properties and processes they share in common, and the causal structures that explain these characteristics and behaviors (namely, that these entities are living and thus need to perform certain actions to maintain their survival in niches they typically inhabit).

One influential view claims that children do not have an understanding of biology and its underlying causal principles until late in childhood, and argues further that children first conceive of living things in a psychological, not biological, framework (Carey, 1985; Solomon, 2002; Solomon, Johnson, Zaitchik, & Carey, 1996). This view arises from the finding that children fail to group together plants with animals into one category (i.e., *living thing*) that guides their reasoning about biological parts and properties. Second, children reason about biological processes in terms of psychological states such as desires and beliefs. For example, when asked why various living things sleep or reproduce, children younger than 7 years old answer, ''Because they want to dream'' or ''Because they want to have babies,'' thereby making reference to desires and thus construing these processes as psychological, rather than biological, in nature. These sorts of studies seem to suggest that children do not have an understanding of biology—neither of what entities are alive nor an understanding of the causal mechanisms responsible for biological properties and processes. Instead, children's concept of *living thing* is akin to *animate thing* or an entity possessing mental states. All of the properties and behaviors of these entities are therefore supposedly understood to be the result of psychological, as opposed to biological, causal mechanisms.

Some researchers, however, argue that young children do possess a concept of *living thing* that includes both plants and animals while excluding nonliving things (Inagaki & Hatano, 2002; Keil, 1992, 1994; Waxman, Medin, & Ross, 2007). These researchers believe that children do have an understanding of some causal principles fundamental to the domain of biology, and furthermore, children understand that these principles differ from those in the physical and psychological domains.

Much of the debate revolves around induction projection tasks. In Carey's (1985) landmark series of studies young children projected biological properties based on psychological similarity to human beings, a pattern that was taken as showing that biology was not seen as distinct from psychology. Young children project a property, such as ''has a heart'' to dogs because they interpret hearts as supporting subjective well-being, something they see as a reasonable psychological state for a dog. They did not, however, seem to project ''has a heart'' to worms or other insects, a pattern that was explained on the grounds that such creatures are too psychologically dissimilar from humans. This pattern of projection, however, does not necessarily mean that children can only engage in psychological reasoning about biological properties. Projection experiments using a context/no-context manipulation find different results (Gutheil, Vera, & Keil, 1998; Inagaki & Hatano, 1996). For example, in one study's (Gutheil et al., 1998) biological context condition, children were told how the given property was biologically important to humans before being asked to project it onto other entities (e.g., ''This person eats because he needs food to live and grow. The food gives him energy to move. If he doesn't eat, he will die.''). In that context condition, both 4- and 5-year-olds properly extended this property to low-level organisms but not to nonliving things, unlike young children in Carey's studies or children in that study's no-context or social-context condition. These sorts of findings suggest that children do in fact have a concept of *living thing* as something separate from *animate* or *psychological thing*, but this concept needs to be made salient. In other words, psychology may be the default method of reasoning about the actions of most living things for young children, but a biological understanding may also be present and elicited in the right contexts.

The same message is emerging from cross-cultural studies, where certain cultures seem to provide contexts that early on make biological relations the default option in inductive reasoning tasks. Young children from more rural settings often show patterns of induction that seem to be based on biological principles (Medin & Waxman, 2007; Ross, Medin, Coley, & Atran, 2003). Indeed, it may be that urban and suburban contexts should be thought of as more atypical in that they reduce an emphasis on biological ways of construing the world, a pattern that converges with arguments that biological knowledge may have ''devolved'' in some developed areas of the West (Atran, Medin, & Ross, 2004).

More broadly, young children often seem to understand there are processes distinct to biological entities, and further, they see them as distinct from psychological ones. For example, children as young as 5 years seem to know that animals and plants, but not nonliving natural kinds and artifacts, grow in size over time (Inagaki & Hatano, 1996; Keil, 1983; Rosengren, Gelman, Kalish, & McCormick, 1991) and are capable of self-healing (Backscheider, Shatz, & Gelman, 1993; Inagaki, 2001; Inagaki & Hatano, 1996). Children also show different attribution patterns for biological and psychological processes across different entities (Coley, 1995; Jipson & Gelman, 2007), suggesting they do not treat these processes as one and the same.

In addition to studying which entities young children think are susceptible to biological processes, another way to discover whether or not they see a fundamental distinction between the biological and psychological domains is to look more closely at what children think are the causal mechanisms underlying biological phenomena. Are biological processes seen as being caused by mental states (psychology) or by physiological mechanisms (biology)? Preschoolers do seem to understand that parentage (biological factors) plays a greater role than friendship (social factors) in determining certain biological characteristics (Springer, 1992, 1996). Similarly 4- to 6-year-olds recognize that biological factors (e.g., eating and sleeping habits) play a greater role in one's susceptibility to illness than do social factors (e.g., lying; Inagaki, 1997). Preschoolers also rate explanations of contagions or contamination as better explanations than those of immanent justice for contracting an illness (Inagaki, 1997; Kalish, 1997; Siegel, 1988; Springer & Ruckel, 1992). Other studies have found that young children have a hard time conceiving of biological states (e.g., headaches, toe swelling) arising from psychological causes and that psychosomatic and psychogenic bodily reactions require a more sophisticated understanding seen only in adults (Notaro, Gelman, & Zimmerman, 2001; Shulz, Bonawitz, & Griffiths, 2007). Although in other cultural contexts young children may favor social and psychological explanations over biological ones (Astuti, Solomon, & Carey, 2004), it is clear that young children do have access to biological modes of explanation and they often can link these appropriately to the set of living things.

Because intention plays a large causal role in understanding psychological mechanisms, other studies have looked at whether or not children understand that mental processes are under voluntary control while bodily processes are not. A number of researchers (Inagaki, 1997; Inagaki & Hatano, 1993; Smith, 1978) have found that children 4- and 5-year-olds can correctly identify certain processes as voluntary (e.g., chewing) or involuntary (e.g., feeling pain). Similarly, other studies (Inagaki & Hatano, 1993; Lockhart, Chang, & Story, 2002; Lockhart, Nakashima, Inagaki, & Keil, 2008; Miller & Bartsch, 1997) have shown that children think physical characteristics are more difficult to change than psychological ones, in addition to each being modifiable through different means (mental effort for psychological characteristics and physical practice for physical characteristics). These results suggest that children are able to differentiate between bodily and mental processes, while also having some understanding that the latter are under psychological control whereas the former are not.

There are also specific indications that young children may be relying on causal intuitions when they contrast biological and psychological process. One series of studies has looked at children's understanding of trait origins and the ways in which different kinds of interventions might be connected to psychological and biological phenomena (Lockhart, Aw, & Essig, 2004; Lockhart, Nakashima, & Inagaki, 2004; Lockhart et al., 2008; Nakashima, Lockhart, & Inagaki, 2003). For example, Lockhart et al. (2004) showed that children as young as 5 years of age linked the origins of psychological traits more to effort and instruction and the origins of biological traits more to inborn factors. These beliefs about differential origin accounts were then mirrored by beliefs about interventions, one of the hallmark ways of assessing causal reasoning. When asked what sorts of interventions would be most effective in changing traits, children at all ages thought that taking medicine or simply waiting for maturation to take its course would be more effective in changing physical traits than psychological ones. In contrast, interventions involving effort or instruction were seen as more influential for changing psychological traits.

All of the above studies suggest that by the time children are in kindergarten, they understand that animals and plants are similar in comparison with nonliving things by virtue of having capacities such as reproduction, growth, self-healing, susceptibility to illness, and so on. However, the majority of these studies tended to either test only one biological phenomenon at a time or simply looked to see if children grouped plants with animals, as against nonliving things, when making inductive inferences. The extent to which children's understanding of the biological domain is systematic and coherent remains unclear. Do kindergarten-aged children see some degree of unification and clustering to biological processes, rather than reacting to isolated instances and comparing them on a case-by-case basis? To what extent do young children see these mechanisms and phenomena as hanging together in a larger system unified by causal principles that are different from those operating in other domains?

The following studies address these questions by giving children processes that span the entire domains of biology and psychology, and asking whether or not children classify these processes as belonging to fundamentally different categories distinguished by their underlying causal mechanisms. Experiments 1 and 2 present participants with triads of both human and animal biological and psychological processes and ask which two members of the triad belong together, allowing us to look at the clustering of processes within both domains. Experiments 3 and 4 further examine whether this clustering is based on simple associations or stems from a deeper understanding of the causal principles distinct to each domain. We test participants' understanding of these causal principles by having them reason about interventions, a method often used to assess knowledge of causal relations in various domains (Hagmayer, Sloman, Lagnado, & Waldmann, 2007; Kushnir & Gopnik, 2005; Kushnir, Gopnik, Schulz, & Danks, 2003; Sommerville, 2007; Steyvers, Tenenbaum, Wagenmakers, & Blum, 2003; Woodward, 2003). Indeed, judgments about interventions have often been claimed to be at the heart of identifying underlying causal relations (Woodward, 2003).

Based on the research just reviewed we hypothesize that children will succeed in making a general domain distinction among an array of biological and psychological phenomena by the time they are in kindergarten, thus displaying an understanding of biology and psychology as two fundamentally separate, but internally coherent, domains with different underlying causal structures. We further hypothesize that children may display this competence without explicitly understanding the detailed mechanisms related to those properties. This second prediction follows from studies showing that even adults often have strikingly incomplete understandings of mechanisms in various domains (Rozenblit & Keil, 2002) and that children can cluster phenomena in broad domains such as physical mechanics and social behavior while being unable to explain these phenomena (Keil, Stein, Webb, Billings, & Rozenblit, 2008).

Experiment 1a

Method

Participants. Participants were 24 kindergartners (M = 5 years 9 months) and 24 undergraduates with approximately an equal number of males and females in each age group. The children were recruited from local elementary schools and were predominantly from a White upper-middle-class background. The parents of all children gave written consent and each child agreed to participate. The kindergartners were tested in a quiet room at their school and were compensated with a sticker and a certificate. The undergraduates were recruited from university sign-up sheets and received minimal compensation (a candy bar) for their participation.

Materials. We used the deference method (Danovitch & Keil, 2004; Keil et al., 2008; Lutz & Keil, 2002) to discover the extent to which kindergartners differentiate biological from psychological processes. This method has been successful in discovering how children understand knowledge clusters within different domains. By investigating to whom children defer about a domain-specific process we can gain a greater understanding of what comprises a coherent domain of knowledge for young children. For example, Lutz and Keil (2002) found that preschoolers appropriately deferred to either a mechanical or a biological expert when given phenomena within the two domains, suggesting they are able to differentiate between biological and physical processes. Additionally, Danovitch and Keil (2004) demonstrated that children come to prefer consulting experts with knowledge of underlying scientific principles, as opposed to experts of trivia knowledge, and Keil et al. (2008) showed that even kindergarteners are sensitive to underlying causal structures in many broad domains corresponding roughly to the natural and social sciences. These results suggest that children understand there are different domains of knowledge structured according to deep causal principles. Moreover, children expect that experts who have knowledge of those principles should also have an understanding of a very broad domain of phenomena arising from them. That is, even young children realize that knowledge of certain key causal relations in a domain provide a person with a generative capacity to understand a potentially unlimited range of domain-specific phenomena that are governed by those principles.

In the present study we used the deference task to assess participants' understanding of biology and psychology as two distinct domains. Participants were given 16 questions phrased in the following way: ''If I want to know about X, should I ask someone who knows about Y or someone who knows about Z?'' In half of the questions, Y was a biological process and Z was a psychological process; this order was reversed for the remaining half. For example, a biological question would look like the following: ''If I want to know why people need to drink lots of water (biological), should I ask someone who knows why people get stuffy noses (biological), or someone who knows why people are bullies (psychological)?'' A psychology question would be phrased in the same manner but with a psychological process being questioned: ''If I want to know why people sometimes think out loud (psychological), should I ask someone who knows why people need sleep to grow taller (biological), or someone who knows why people like to learn new things (psychological)?''

We chose 24 biological and 24 psychological processes we thought spanned the full range of both domains. These processes were further divided into two subcategories within each domain: *health* and *illness* in biology and *cognitive* and *emotional* in psychology. The ''health'' subcategory in biology included items such as growth, general nutrition, benefits of exercise, and so on, whereas the ''illness'' subcategory included processes dealing with aging, bodily malfunction, sickness, and self-healing. In the ''cognitive'' subcategory of psychology, we included things such as learning, memory, reasoning, and problem solving, whereas the ''emotion'' subcategory included processes that focused more on personality traits, social relationships, emotions and motivation. We realize there may be more than one way to split up the domains of biology and psychology, but we chose these particular subcategories because they are both salient in the lives of young children (there are many everyday instances of each) and because they are often clearly contrasting areas in adult discussions of these domains. Thus, there are clearly distinct adult groups of experts on wellness, pathology, social psychology, and cognitive psychology.

We included items from two subcategories within each domain not only to ensure we chose a wide range of processes but also to ensure we could compare performance on within- and between-subcategory questions. Half of the questions included in this task were *within subcategory*, meaning that participants need only match processes within the same subcategory. For example, a psychology question asking about a cognitive process would have two answer options: a biological process and a psychological process from the same ''cognitive'' subcategory. The other half of the questions was *between subcategory*, requiring that participants abstract across the full domain in order to answer the question correctly. For example, a psychological between-subcategory question that asked about a cognitive process would have two answer options: a biological process and a psychological process from a different psychological subcategory (emotional). In this case, participants have to recognize how two very different processes (cognitive and emotional processes) are fundamentally similar to one another, and different from those in the domain of biology.

The between-subcategory questions are the strongest test of our hypothesis, namely, that kindergartners recognize a common domain across these two distinct subdomains. However, we chose to include the within-subcategory questions because, it is possible that kindergartners are not yet able to recognize the similarities among all biological processes, or all psychological processes, but are able to recognize similarities on a more local level—within a particular subcategory. For example, we think young children will notice that learning and memory are similar to one another (both cognitive activities) before they are able to grasp that learning and memory are similar to other psychological processes such as feeling scared or wanting to help others. We could find that participants are able to recognize the biology–psychology distinction on a local level when presented with processes that are similar within each domain. In other words, it is possible that kindergartners recognize that cognitive processes are similar to one another, and different from biological ones, but fail to understand that all psychological processes are fundamentally similar in that they share a common set of underlying causal principles related to one's mental life that are different from those at the core of biological phenomena.

Eight of the processes in each domain (four from each subcategory) were used as the target in question whereas the remaining 16 processes were included as answer options. A complete list of the stimuli can be found in Appendix A with an asterisk next to those processes that were used as questions.

The answer choice pairings were counterbalanced across two conditions so one group of participants saw a particular pairing with a biological question whereas the other group of participants saw the same pairing but with a psychological question. The same questions and answer pairings were used with all participants, but in different combinations between the two counterbalanced groups. This counterbalanced design ensured that neither of the answer options was inherently preferable to the other.

We were careful in constructing the question–answer pairings to eliminate the possibility that participants could use a simple heuristic to cluster processes within each domain. For example, although we incorporated anatomical terms into the psychology items, they were more frequent among the biology items. However, if a body part was mentioned in the biology target question, it was not mentioned in the corresponding biology answer option and vice versa. Furthermore, all of the items were subject to latent semantic analysis to make sure neither of the answer options was more statistically related to the target question than the other. Given a large and representative corpus of text, latent semantic analysis looks at all of the contexts in which a given word is or is not used to determine where each word in the English language stands in relation to all other words in terms of how often such words co-occur either directly or indirectly through joint co-occurrence with other words (Deerwester, Dumais, Landauer, Furnas, & Harshman, 1990; Landauer, 1998; Landauer, Foltz, & Laham, 1998). This method therefore helps determine how close words are to each other in a multidimensional, correlational space. For our particular stimuli, this method was used to verify that the set of words in each answer option was not any more related to the set of words in the question given the many other contexts in which these sets of words have appeared (both answer options were equally correlated with the question). Such computations can be made at the following Web site: http://lsa.colorado.edu/. It might well be the case that in typical use, there would be higher levels of correlation between words used in a common domain and that such correlations might be a cue to relatedness. Here, however, we controlled for such statistical relatedness to ask if children could still cluster processes by using a deeper conceptual understanding that went beyond merely noting patterns of co-occurrence among lexical items.

Adult participants were given the questions in a paper-and-pencil task. The kindergartners were asked the questions by an experimenter, each question being accompanied by a pictorial representation of each process for memory purposes. The pictures were all acquired from Clip Art and controlled for gender, age, number of people in each picture, and any other surface features children might use to make a decision. See Experiment 1b for confirmation that kindergartners could not rely on the pictures alone to perform this task successfully.

Procedure. Before beginning the experiment, kindergartners were given a training task to make sure they understood the deference method being used. They were first asked if they ever had a question about how things worked or why certain things happened. If they did not come up with something on their own, they were prompted by the experimenter with a question such as: ''Have you ever wondered why you need to eat vegetables?'' Once there was a question established, the experimenter inquired about who the child asked or would ask if they wanted to know the answer. The children were then instructed that in the following task they were going to be given questions and their job was to give the experimenter advice about who to ask in order to find the answer. They were told there would be two people the experimenter could pick from, and they should think really hard about which person the experimenter should ask as the two people ''know about different kinds of things.'' After children were given these instructions, they were presented with two crucial practice items—both of which they had to pass to continue on with the experiment. The first practice item was the following: ''If I want to know why it sometimes rains outside, should I ask someone who knows about the weather or someone who knows about sports?'' The second practice item was more difficult because the answer options were both topically similar to the question, thus requiring that children use their knowledge of domain-specific principles to answer the question: ''If I want to know how a TV works, should I ask someone who knows all about the parts inside of a TV or someone who knows all about cartoons on TV?'' All of the kindergartners passed both practice items.

After completing the training items, the experimenter then proceeded to the test items reminding children there were no right or wrong answers. As each question was asked, a sheet with three pictures was placed in front of the child—one picture for the question and one picture for each answer option. After the child chose one of the experts, the pictures were removed, new pictures laid before the participant, and another question was asked. Throughout the experiment, participants were randomly asked to repeat the question and answer options, and sometimes to explain their answers. No feedback was given to the participants during this time. This questioning was simply to make sure that participants were engaged in the task and were able to remember the question and each answer option. Adult participants completed this task on paper in a quiet room in our laboratory. They were given written instructions directing them to circle the best answer out of the two given.

Results and Discussion

Accuracy was computed as the average proportion of questions for which participants correctly matched processes within the two domains (biology with biology and psychology with psychology). No differences were found between the two groups that counterbalanced the question and answer pairings for the kindergartners ($M = .77$, $SD = .01$ vs. $M = .82$, $SD = .02$), $t(22) = .92$, $p = .37$, or adults ($M = .96$, $SD = .002$ vs. $M = .94$, $SD = .004$), $t(22) = .94$, $p = .36$, so we collapsed the scores within each age group for the remaining analyses. The results from Experiment 1, including a breakdown by domain (biology and psychology) and by type of question (within or between subcategory), are depicted in Figure 1.

Adults were used as a baseline to compare the performance of kindergartners. Both adults ($M = .95$, $SD = .053$), $t(23) = 41.40$, $p < .001$, and kindergartners ($M = .80$, $SD = .124$), $t(23) = 11.70$, $p < .001$, performed significantly above chance on the overall task, although adults performed better than kindergartners, $t(46) = 5.64$, $p < .001$. Performance was also assessed separately for the biology and psychology items. Kindergartners and adults performed significantly above chance on both the biology—kindergartners: ($M = .83$, $SD = .13$), $t(23) = 12.09$, $p < .001$; adults: ($M = .97$, $SD = .07$), $t(23) = 33.78$, $p < .001$—and psychology items—kindergartners: ($M = .77$, $SD = .21$), $t(23) = 6.39$, $p < .001$; adults: ($M = .94$, $SD = .072$), $t(23) = 29.70$, $p < .001$—with no differences found between the two domains—kindergartners: paired-$t(23) = 1.15$, $p = .26$; adults: paired-$t(23) = 1.63$, $p = .12$. Furthermore, all scores within each of the subcategories were significantly above chance for both groups of participants.

We further analyzed the within- and between-subcategory questions separately to see whether the children's success on the task was driven solely by their performance on within-subcategory questions. The kindergartners and adults performed significantly above chance on both the within- and between-subcategory items—kindergartners: ($M = .80$, $SD = .13$), $t(23) = 11.71$, $p < .001$, and ($M = .78$, $SD = .16$), $t(23) = 8.57$, $p < .001$, respectively; adults: ($M = .95$, $SD = .07$), $t(23) = 30.92$, $p < .001$, and ($M = .95$, $SD = .08$), $t(23) = 27.30$, $p < .001$, respectively—and performed equally well on both types of questions—kindergartners: paired-$t(23) = .68$, $p = .504$; adults: paired-$t(23) = .019$, $p = .99$.

These results suggest that kindergartners accurately distinguish biological from psychological processes. They performed equally well on the biology and psychology items, including consistent performance across each of the subcategories. Furthermore, their similar performance on the within- and between-subcategory items suggests that they have a robust understanding that all of the processes within each of these domains cluster with one another allowing the children to consistently classify them together.

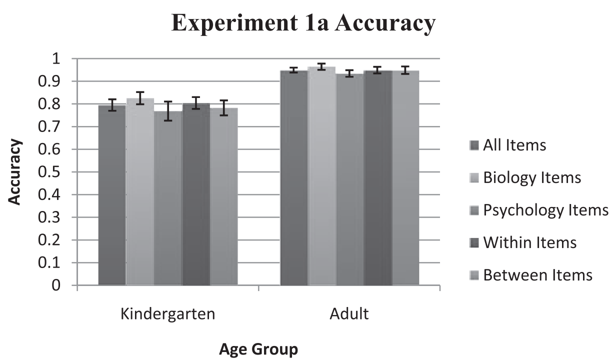

Figure 1. Experiment 1a accuracy scores for both kindergartners and adults. The overall accuracy is represented in the first bar for both age groups. The four remaining bars represent the accuracy broken down in two ways: by type of process (biological or psychological) and by type of question (within or between).

Experiment 1b

The pictures used with the kindergartners in Experiment 1a were intended solely as memory aides and were chosen so as to offer no hints to the correct answer. However, we found while running the experiment that most of the kindergartners answered the questions by pointing at one of the two pictures representing the answer options. We decided to present a separate group of kindergarten participants with the same pictures, but this time without the verbal descriptions of the processes they represent. If kindergartners are finding superficial cues in the pictures to help them pair the correct answer option with the target in question, then they should perform equally well (and above chance) when presented with the pictures alone. If, however, the pictures are solely functioning as memory aides and do not give children any hints to the correct answers, then they should perform no better than chance (50% accuracy) on the task using only the pictures as their basis for judgment.

Method

Participants. Participants were 15 kindergartners (M = 5 years 9 months; 7 males, 8 females) who were recruited from local elementary schools and were predominantly from a White upper-middle-class background. The parents of all children gave written consent and each child agreed to participate. The kindergartners were tested in a quiet room at their school and were compensated with a sticker and a certificate.

Materials and procedure. In Experiment 1a, three pictures (representing three processes) were presented to kindergarten participants during each question. The first picture represented the target process in question, whereas the second two pictures represented the processes in each answer option. For example, three pictures accompanied the following item: ''If I want to know why people need to drink lots of water, should I ask someone who knows why people get stuffy noses, or someone who knows why people are bullies?'' The first picture depicted drinking lots of water, whereas the other two depicted stuffy noses and people being bullies.

These same picture triads were presented to participants in Experiment 1b but without the verbal descriptions of the processes they represent. These participants were instead asked which of two pictures ''went with'' or was ''more similar to'' the third target picture. A total of 32 picture triads (16 from each counterbalanced group in Experiment 1a) were presented to the participants.

Results

Accuracy was computed as the average proportion of questions for which participants matched pictures depicting processes within the same domain (biology with biology and psychology with psychology). Participants performed no better than chance on the triad task when only using the pictures as their basis for judgment (M = .53, SD = .07), $t(14)$ = 1.04, p = .13. This remained true when the data were analyzed separately for the picture triads in each counterbalancing condition (M = .51, SD = .106), $t(14)$ = .34, p = .74, and (M = .55, SD = .08), $t(14)$ = 2.15, p = .09, respectively.

We can conclude from Experiment 1b that kindergartners could not have performed well in the first experiment if they only relied on the pictures to match various processes. This further demonstrates that kindergartner's success on the triad task in Experiment 1a results from a deeper understanding of biological and psychological processes as belonging to two distinct domains.

Discussion

Experiment 1 demonstrates that kindergartners appropriately cluster biological processes with one another while separating them from psychological ones. These results suggest that young children do sense the coherence among biological processes.

Although we chose a wide range of biological and psychological processes in Experiment 1, we were limited in that the biological referent was always a human being. In order to include the greatest range of processes in both domains, we expanded our items in Experiment 2 to also include a more diverse set of biological entities.

Experiment 2a

Method

Participants. Participants were 24 kindergartners (M = 5 years 10 months) and 24 undergraduates with approximately an equal number of males and females in each age group. The scores from two additional kindergartners were dropped, one for failing to complete the experiment and the other for failing the training task and always picking the second answer option for every question. The children were recruited from local elementary schools and were predominantly from a White upper-middle-class background. The parents of all children gave written consent and each child agreed to participate. The kindergartners were tested in a quiet room at their school and were compensated with a sticker and a certificate. The undergraduates were recruited from university sign-up sheets and received minimal compensation (a candy bar) for their participation.

Materials. We used the same deference task as in Experiment 1 but with two major changes. First, instead of focusing on human biology and psychology, we expanded our items to include a range of animals and, thus, a greater range of processes within each domain. Second, we eliminated the within-subcategory items and only included questions that were between subcategory, as these are the strongest test of our hypothesis.

The animals were chosen based on three criteria: (a) they had to plausibly possess psychological states, (b) they had to represent a range of animals to ensure a greater range of biological and psychological processes, and (c) young children should be at least somewhat familiar with them (even if never having a direct encounter). The following were the eight animals we chose: dog, cat, horse, monkey, elephant, camel, fish, and bird.

We once again divided the various biological and psychological processes into two subcategories per domain. The psychological subcategories were the same as in Experiment 1: *cognitive* and *emotional*. The biological subcategories, however, were changed. One subcategory, *anatomy*, focused on an animal's anatomical features and their adaptive value. The second subcategory, *physiology*, consisted of physiological processes such as growth, digestion, breathing, and body temperature regulation. We chose to divide the biological processes into these two subcategories because one concerns static structures and the other concerns dynamic processes, presumably one of the largest possible contrasts within the domain of biology.

There were a total of 24 biological and 24 psychological processes (12 in each subcategory) in Experiment 2. Each animal was associated with 6 processes—3 biological and 3 psychological. This allowed us to present participants with both a biological and psychological question for each animal (the other 4 processes were used as answer options for these two questions). This means that the same animal was mentioned in both the question and its two answer options. For example, if we presented participants with the question, ''If I want to know how cats remember their way home (cat–cognitive), who should I ask?'' both answer options would also apply to cats: ''Someone who knows why cats have blood in their bodies (cat–anatomy), or someone who knows why cats have fun playing with yarn (cat–emotional)?'' Keeping the animal consistent between the question and its answer options ensured that participants were choosing their answer based on the similarities and differences between the *processes* presented rather than the animals subject to those processes.

Each participant was given a total of 16 questions: 8 biological and 8 psychological (4 from each subcategory). A complete list of the stimuli can be found in Appendix B with an asterisk next to those processes that were used as questions.

Just as in Experiment 1, latent semantic analysis was used to make sure that neither of the answer options was more strongly associated with the process in question. We also included two counterbalancing conditions as in Experiment 1 (one group of participants would see a pair of answer options with a biology question whereas the other group of participants would see the same pairing with a psychology question) to make sure there was no inherent preference for either of the answer options. As in Experiment 1, we also controlled for other factors children could use as simple heuristics in making their judgments.

Adult participants were once again given the questions in a paper-and-pencil format. The kindergartners were asked the questions by the experimenter, each question accompanied by a pictorial representation of each process for memory purposes.

Procedure. The procedure was identical to that of Experiment 1 for both the children and adults. This included using the same training task and two crucial practice items with the children.

Results

As in Experiment 1, accuracy was computed as the average proportion of questions for which participants correctly matched processes within the two domains. No differences were found between the two different groups that counterbalanced the question and answer pairings for the kindergartners (M = .75, SD = .07 vs. M = .73, SD = .10), $t(22)$ = .53, p = .60, or adults (M = .82, SD = .07 vs. M = .87, SD = .10), $t(22)$ = 1.23, p = .23, so we collapsed the scores within each age group for the remaining analyses. The results from Experiment 2 are depicted in Figure 2.

Once again, adults were used as a baseline to compare the performance of kindergartners. Both adults (M = .85, SD = .09), $t(23)$ = 19.33, p < .001), and kindergartners (M = .74, SD = .09),

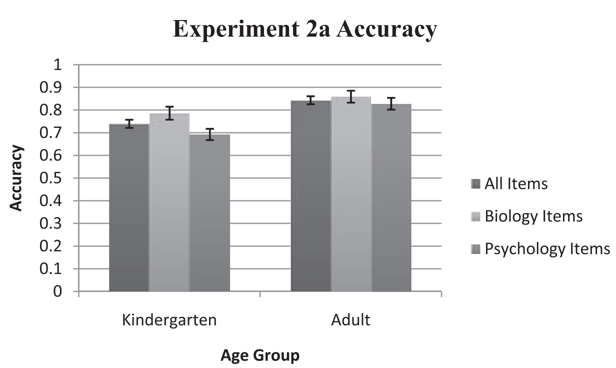

Figure 2. Experiment 2a accuracy scores for both kindergartners and adults. The overall accuracy is represented in the first bar for both age groups. The second two bars represent accuracy for biology and psychology items separately.

$t(23) = 13.65$, $p < .001$, performed significantly above chance on the overall task, although once again adults performed better than the kindergartners, $t(46) = 4.13$, $p < .001$. We also examined performance on the biology and psychology items separately. Adults scored significantly above chance on both the biology ($M = .86$, $SD = .13$), $t(23) = 10.12$, $p < .001$, and the psychology questions ($M = .83$, $SD = .12$), $t(23) = 12.73$, $p < .001$, and performed equally well in both domains, paired-$t(23) = .82$, $p = .42$. Kindergartners scored slightly better on the biology than on the psychology items ($M = .79$, $SD = .14$ and $M = .70$, $SD = .12$, respectively) paired-$t(23) = 2.33$, $p = .03$; however, they performed significantly above chance in both domains—biology, $t(23) = 10.12$, $p < .001$, and psychology, $t(23) = 7.83$, $p < .001$. Furthermore, both kindergarten and adult accuracy reached significance for all four biological and psychological subcategories (anatomy, physiology, emotion, and cognition).

These results demonstrate that kindergartners are capable of distinguishing biological from psychological processes, even when presented with a wide range of living organisms. Furthermore, all of the questions used in Experiment 2a were between subcategory, requiring that participants abstract across the full range of processes within each domain.

Discussion

Experiment 2a replicated the results from Experiment 1a, demonstrating that kindergartners are capable of making very subtle distinctions between biological and psychological processes, distinctions they would only be capable of making if they sensed some underlying coherence uniting all of the biological processes into a single domain.

Experiment 2b

Just as Experiment 1b ensured that participants could not rely solely on the pictures to perform successfully in Experiment 1, we included the same test for the pictures used in Experiment 2.

Method

Participants. Participants were 15 kindergartners (M = 5 years 10 months; 8 males, 7 females) who were recruited from local elementary schools and were predominantly from a White upper-middle-class background. The parents of all children gave written consent and each child agreed to participate. The kindergartners were tested in a quiet room at their school and were compensated with a sticker and a certificate.

Materials and procedure. The same picture triads from Experiment 2a were presented to participants without the verbal descriptions of the processes they represent. These participants were asked which of two pictures ''went with'' or was ''more similar to'' the third target picture. A total of 32 picture triads (16 from each counterbalanced group in Experiment 2a) were presented to the participants.

Results

As in Experiment 1b, accuracy was computed as the average proportion of questions for which participants matched pictures depicting processes within the same domain. Once again, the kindergartners performed only at chance when matching pictures in the triads without knowing the processes they represent ($M = .50$, $SD = .07$), $t(13) = .23$, $p = .82$, even when analyzed separately for both counterbalanced groups ($M = .55$, $SD = .12$), $t(13) = 1.65$, $p = .12$, and ($M = .46$, $SD = .13$), $t(13) = 1.26$, $p = .23$, respectively.

These results confirm our hypothesis that the pictures used in Experiment 2a were not driving the kindergartner's successful performance on the task. Rather, it was knowledge of the processes these pictures represent that allowed children to appropriately cluster items into the domains of biology and psychology.

Discussion

Both Experiments 1 and 2 demonstrate that kindergartners appropriately cluster biological processes with one another while separating them from psychological ones. These results suggest that young children sense some deeper similarity among processes in the biological domain. In other words, even kindergartners understand more than the simple idea that illness is caused by contagions or that physical traits are determined by parentage not friendship. These children are capable of looking at a diverse range of biological processes and classifying them together, separate from processes in the domain of psychology.

However, two critical questions remain to be answered before we can conclude that children recognize the fundamentally different nature of biological and psychological phenomena. First, *what* allows children to distinguish among them? Do children have a clear understanding of how they differ or do they simply sense that one biological process is *more* similar to another process within biology than one that is psychological? In other words, is this a principled difference or simply one that is a matter of degree? Second, *what* do children think are the underlying similarities uniting the range of processes within each domain? We have yet to show that kindergartners understand that phenomena within these two domains are *fundamentally* similar—stemming from similar causal mechanisms. Experiments 3 and 4 address this issue.

Experiment 3

Method

Participants. Participants were 16 kindergartners (M = 5 years 10 months) and 16 undergraduates with approximately an equal number of males and females in each age group. The scores from 2 additional kindergartners were dropped for failure to complete the experiment. The children were recruited from local elementary schools and were primarily from an upper-middle-class background. The parents of all children gave written consent and each child agreed to participate. The children were tested in a quiet room at their school and were compensated with a sticker and a certificate. The undergraduates were recruited from university sign-up sheets and received minimal compensation (a candy bar) for their participation.

Materials. In Experiment 3, we used many of the same processes from Experiment 1 but presented them to participants in a different context. In the two previous experiments participants were asked to match one of the answer options with the target in question. In this experiment, however, participants were given two processes in the question and asked how *causally* similar they were to a third. Both processes in the question were from the same domain (both biological or both psychological), whereas the third process was either from a different subcategory in that domain or from a different domain altogether. The questions asked in Experiment 3 had the following format: ''Something happened to Mary a long time ago. Ever since then, Mary is not as lazy as she used to be (psychological). And ever since then, Mary helps others more than she used to (psychological). How much do you think what happened to Mary also made a difference for how often she gets sore throats (biological)?''

Participants were asked to give a rating on a scale of 1–5 (1 meaning there would be no effect on the third item and 5 meaning there would be a very large effect on the third item). For half of the items, two psychology processes were stated in the question whereas for the other half, the two processes were biological. We used two, rather than one, items in each question to demonstrate that the source of change to one process can result in a change to another. This was intended to demonstrate the salience and plausibility of causal influence. Also, for half of the psychology questions, the target phenomenon to be rated was biological (between domain) whereas in the other half it was psychological (within domain). The biology questions had the same structure. Just as in Experiments 1 and 2, we performed latent semantic analysis on all of the items to make sure the target process was equally related to the processes in question for both the within- and between-domain items. There were a total of 12 questions in this first task.

These questions were designed to tap into children's understanding of the causal mechanisms behind biological and psychological processes. Children should rate the target item as having a high likelihood of being affected if it corresponds to the same domain of processes (biology or psychology) presented in the question and low if it does not. This is because if some change occurs that affects the causal mechanism in a given domain, many processes within that domain (and not other domains) are likely to be affected.

As mentioned in the Introduction, one crucial way to assess whether children are invoking causal reasoning when thinking about biological and psychological processes is to ask them to reason about interventions. To that end, in the second part of Experiment 3, we used a method developed by Lockhart and her colleagues (Lockhart et al., 2002; Lockhart et al., 2008; Lockhart, Aw, et al., 2004; Lockhart, Nakashima, et al., 2004). These researchers conducted the first studies showing how an intervention orientation results in young children clearly distinguishing psychological from biological phenomena. In one set of studies Lockhart, Nakashima, et al. (2004) showed that children as young as 5 years of age saw biological properties (e.g., height and vision) being more influenced by biological interventions than were psychological properties. Similarly, they found that young children saw psychological properties (e.g., being shy or intelligent) as being more influenced by psychological interventions. In addition, they showed that causal reasoning seems to be explicitly elicited in this kind of task format as evidenced by spontaneous comments made by children that invoked causal reasons. This finding on interventions converged strongly with another finding in Lockhart et al. (2004) in which young children attributed the origins of psychological trait differences more to effort and instruction, and the origins of biological trait differences more to inborn factors and a lack of maturation. We used a method similar to that of Lockhart and her colleagues to determine whether the knowledge clustering found in Experiments 1 and 2 was indeed making reference to causal principles.

The second part of this experiment, therefore, explicitly questioned participants about the causal mechanisms underlying the domains of biology and psychology. Participants were given all 12 descriptions from the first part of the experiment (e.g., ''Something happened to Mary a long time ago. Ever since then, Mary is not as lazy as she used to be. And ever since then, Mary helps others more than she used to.''), but this time participants were asked: ''What do you think happened to Mary? Do you think she took a special pill or a special class?'' Participants were asked to choose which of the two sources of influence was more likely to apply to the scenario in question. Through questioning participants about the source of influence, we were able to see whether they consistently identify two different types of causation (physical or mental) whenever biological or psychological processes are manipulated.

Procedure. Before beginning the experiment, kindergartners were given a training task to make sure they understood both the questions being asked and the rating scale being used. They were first given a description about how certain changes will or will not influence other things about a particular entity: ''So what we're going to do today is talk about things that change. When we make a change to something, sometimes other things also change about it, but not always. For example, if we sharpen a pencil then it will also get shorter and it will also write better. But if we just put a sticker on the pencil, it won't get any shorter or write better. Nothing else changes about the pencil other than the sticker being on it.'' They were then given two scenarios to practice using the 5-point scale. In one scenario the experimenter asked how likely a change in engine and a change in tires would influence how fast a car could go. In the second scenario the experimenter asked how likely a change in color and a change in seat comfort would influence how fast a car could go. After the participant answered these questions, whether correctly or incorrectly, the experimenter explained why the first scenario would likely make a big difference for the speed of a car while only a small difference or no difference would be seen in the second scenario. These two scenarios helped to demonstrate the causal process behind a change in some entity.

The last practice item given to participants required they not only understand the causal process of change but also be able to infer such a process by its results, given this was the format of the questions in the rest of the experiment. Participants were told that something happened to Carrie a long time ago. ''Ever since then Carrie owns a better car than she used to and ever since then Carrie has a nicer house than she used to. How much do you think what happened to Carrie also made a difference for how big of a TV Carrie has?'' This question is different from the former scenarios because in this one, owning a nicer house and owning a better car does not *directly* cause Carrie to own a better TV. Therefore participants must infer a third causal mechanism that can influence both of the items given, and then determine whether it would also influence the third target item. The entire training procedure took no more than 5 min, and children's ease with these training questions provides additional support that they understand and reason about underlying causal principles.

Throughout the experiment, participants were randomly asked to repeat the question and answer options and sometimes to explain their answers. No feedback was given to the participants during this time. This questioning was simply to make sure that participants were engaged in the task and were able to remember the question and each answer option.

Adult participants completed this task on paper in a quiet room in our laboratory. They were given written instructions directing them to circle a number on the 5-point scale in the first task and one of the two answer options (special pill or special class) in the second task. The kindergartners were asked the questions by the experimenter, each question being accompanied by a pictorial representation of each process for memory purposes (the same pictures from Experiment 1).

Results

Results from Experiment 3 can be seen in Figures 3 and 4. For the first task in this experiment, the data were analyzed according to whether the item was a within- or between-domain

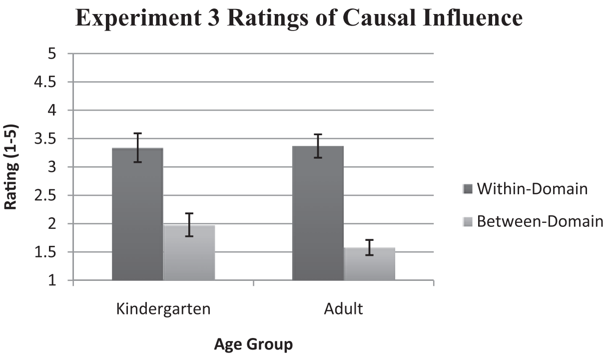

Figure 3. Experiment 3 ratings of causal influence for both within- and between-domain questions. Participants rated on a scale of 1–5 the extent to which changes in processes in one domain affected another process either in the same (within) or in a different (between) domain.

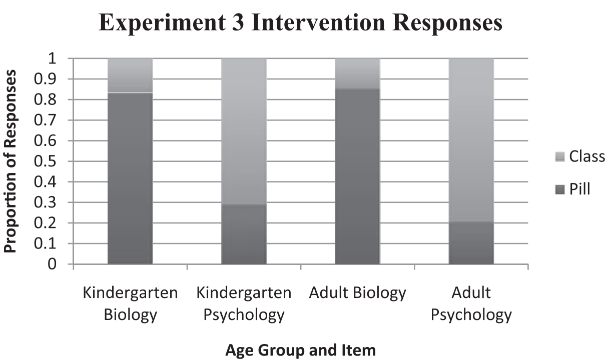

Figure 4. Results for the second part of Experiment 3. Each bar represents the kindergarten and adult responses according to the type of process in question: biological or psychological. Participants chose from two options—taking a ''special class'' or taking a ''special pill''—as the most influential in changing that particular biological or psychological process.

question. The within-domain questions were those in which the target process to be rated was within the same domain as the processes presented in the question. The between-domain questions were those in which the target process to be rated was from a different domain than those previously presented. We expected that the within-domain questions would receive a higher rating on the 5-point scale than the between-domain questions given that if the causal mechanism is affected in one domain, it is likely to affect other processes within, but not outside, that domain.

Our predictions were supported for both adults and kindergartners. Adults gave an average rating of 3.37 out of 5 (SD = .82) for within-domain items and 1.58 (SD = .54) for between-domain items, paired-$t(15) = 9.83$, $p < .001$. Similarly, kindergartners gave higher ratings for the within items (3.34 out of 5, SD = 1.02) than the between items (M = 1.98, SD = .81), paired-$t(15) = 5.59$, $p < .001$. These differences were not driven by higher accuracy for either the biology or psychology questions. Both adults and kindergartners (M = 2.53, SD = .66 and M = 2.42, SD = .55 respectively), $t(15) = 1.49$, p = .16, performed equally well on the items within these two domains (M = 2.67, SD = .83 and M = 2.65, respectively), SD = .75, $t(15) = .29$, p = .78.

The second task required that participants choose the source of change for processes within both the biology and psychology domains. When a participant chose the biological source of change (took a special pill), his or her answer was coded as 0, while choosing the psychological source of change (took a special class) resulted in a score of 1. This allowed us to determine how often participants chose each answer for the biology and psychology items separately. Both adults and kindergartners predominantly chose the biological source of change for the biological processes (M = .146, SD = .120), $t(15) = 11.83$, $p < .001$, and (M = .167, SD = .202), $t(15) = 6.61$, $p < .001$, respectively, and the psychological source of change for the psychological processes (M = .792, SD = .177), $t(15) = 6.58$, $p < .001$, and (M = .708, SD = .177), $t(15) = 4.70$, $p < .001$, respectively.

Results from Experiment 3 reveal that kindergartners grasp the deeper causal mechanisms that structure the domains of biology and psychology. In the first task, we examined the extent to which participants understood that there are deep causal mechanisms affecting all of the processes within, but not outside, a given domain. Ratings of causal influence given by both kindergartners and adults demonstrate the depth of their understanding, giving higher ratings of causal influence to within- than between-domain processes. The second task asked participants to choose between two very different causal interventions (pill vs. class) as the source of change to various biological and psychological processes. Both kindergartners and adults more consistently identified the pill as the source of change for biological processes and the class as having a greater influence on psychological processes.

Discussion

The results from Experiment 3 indicate that even kindergartners have some sense of the fundamentally different causal mechanisms underlying biological and psychological processes, including the kinds of influence these mechanisms can have on such processes.

Just as with Experiment 1, we incorporated a large range of biological and psychological processes but were limited in that the referent was always a human being. We find it unlikely, but possible, that children were using a simpler heuristic on the last task of Experiment 3. It could be that children were basing their answers not on deep intuitions about the causal mechanisms in the biological and psychological domain but rather on social roles associated with the particular processes in question. Children may associate ''taking a special pill'' with doctors and ''taking a special class'' with teachers, thereby judging the processes with reference to what a doctor or teacher would know. In other words, children may associate taking pills with ''catching colds'' and both taking pills and catching colds with ''things a doctor would know'' without having any knowledge of the causal link between these items (that a doctor understands the causal mechanisms underlying illness in the body). It seems unlikely that children would associate biological processes like ''sweating'' with doctors or think that only psychological (not biological) processes would fall under the umbrella of knowledge possessed by teachers. However, we decided to directly address this issue in Experiment 4, using a wider range of biological and psychological processes across a wider range of biological referents so as to fully rule out this alternative interpretation of our results.

Experiment 4

Method

Participants. Participants were 16 kindergartners (M = 5 years 10 months) and 16 undergraduates with approximately an equal number of males and females in each age group. The children were recruited from local elementary schools and were predominantly from a White upper-middle-class background. The parents of all children gave written consent and each child agreed to participate. The kindergartners were tested in a quiet room at their school and were compensated with a sticker and a certificate. The undergraduates were recruited from university sign-up sheets and received minimal compensation (a candy bar or Snapple) for their participation.

Materials. The materials used in Experiment 4 were a subset of the animal biological and psychological processes from Experiment 2. We selected 16 processes (2 biological and 2 psychological) from four different animals (cat, bird, horse, and monkey). Four of the possible 6 processes were chosen from four of the possible eight animals. We chose those processes for which a causal intervention would make the most sense. For example, a process such as ''Fish first grow in eggs'' was not selected as it would be difficult to imagine how that process could be enhanced through any causal intervention, biological or otherwise. A process such as, ''A cat grows sharp claws on its paws,'' however, could conceivably be influenced by some biological intervention—one that could potentially make claws grow quicker or sharper.

Participants were told that some change occurred for each of these processes and were questioned about the source of that change (the change presented always enhanced the process in question). For example, one of the cat biological processes from Experiment 2 was: ''Cats grow sharp claws on their paws.'' In the present task the item was framed in the following way: ''Something happened to this cat a long time ago, and ever since then, the cat grows even sharper claws on its paws. What do you think happened to the cat?'' For all of the items, participants were presented with a forced choice between two answer options: the animal had an ''operation'' or the animal had ''training.'' These two answer options mirrored the ''pill'' and ''class'' options from Experiment 3. This contrast was for the same purpose: to see whether participants consistently identify two different types of causation (physical or mental) whenever biological or psychological processes are affected. We changed the options from ''pill'' and ''class'' to ''operation'' and ''training,'' however, as the processes now under consideration apply to animals, not human beings. We therefore needed more plausible means of influencing an animal's biology and psychology rather than having birds take pills and having horses sit through classes. We also thought that kindergartners, likely being unfamiliar with operations and even animal training, would not have strong associations between these answer options and either specific social roles or the particular biological and psychological processes presented throughout the experiment. In other words, we doubt that any kindergartner has previously heard of a monkey that underwent an operation to make its tail grow even longer. Having no preestablished associations to base their answers upon, participants must rely on a more abstract understanding of causal principles at the foundation of their biological and psychological knowledge to perform successfully on this task.

Participants were presented with all 16 processes and asked to choose between the two sources of change: operation or training. Adult participants were once again given the questions in a paper-and-pencil format. The kindergartners were asked the questions by the experimenter, each question being accompanied by a pictorial representation of each process (the same pictures from Experiment 2).

Procedure. The procedure used in Experiment 4 was nearly identical to the second task in Experiment 3. Participants were presented with 16 biological and psychological processes that had undergone some change. They were instructed to choose which of two causal mechanisms (operation or training) was the most plausible intervention for each of these items.

Kindergartners, being familiar with both pills and classes, required no explanation of these answer options in Experiment 3. However, the level of knowledge kindergartners have regarding operations and/or training is likely to be very little. To make sure all the kindergartners possessed a sufficient amount of knowledge about these answer options, we introduced them to the task in the following way: ''Sometimes things happen and it makes animals different in some way. For example, something could happen to make an animal a faster runner. Or something could happen and it might make the animal nicer to other animals. I am going to tell you about different animals that have changed in some way. I'll tell you how they are different now than they used to be. I want you to tell me what you think happened to the animal to make it different, what you think made it change. There are two things that could have happened to the animal: it could have had an operation, or it could have had training. An operation is when people perform surgery on an animal; they go into the animal and change things deep inside of it. Training is when an animal learns new things from either people or other animals. So, I will tell you about an animal and something that changed about the animal. You will tell me if you think the animal is different because it had an operation, or because it had training. Pick whichever one you think made the animal different now than it used to be.'' These instructions were intended to give kindergartners enough information about operations and training that they could complete this task as they did previously with the ''pill'' versus ''class'' options. However, we left the instructions vague enough that kindergartners were not told explicitly *how* operations or training affected an animal's body or mind. It was up to the individual kindergartners to decide what would most likely affect any given process (e.g., such as getting scared): things changed deep inside the animal or things learned by the animal.

Adults received a shortened version of these instructions and performed the task with paper and pencil in a quiet room in our laboratory. The kindergartners were asked each question by the experimenter, and were tested in a quiet room at their elementary school.

Results

Results for Experiment 4 can be seen in Figure 5. Participants were asked to make a forced choice about the source of change to biological and psychological processes. When a participant chose the biological source of change (had an operation), his or her answer was coded as 0, while choosing the psychological source of change (had training) resulted in a score of 1. This allowed us to determine how often participants chose each answer for the biology and psychology items separately. Both adults and kindergartners predominantly chose the biological source of change for the biological processes ($M = .15$, $SD = .24$), $t(15) = 5.84$, $p < .001$, and ($M = .159$, $SD = .13$), $t(15) = 10.86$, $p < .001$, respectively, and the psychological source of change for the psychological processes ($M = .72$, $SD = .25$), $t(15) = 3.55$, $p < .003$, and ($M = .91$, $SD = .13$), $t(15) = 12.43$, $p < .001$, respectively.

These results demonstrate that even kindergartners understand the fundamentally different causal mechanisms influencing biological and psychological

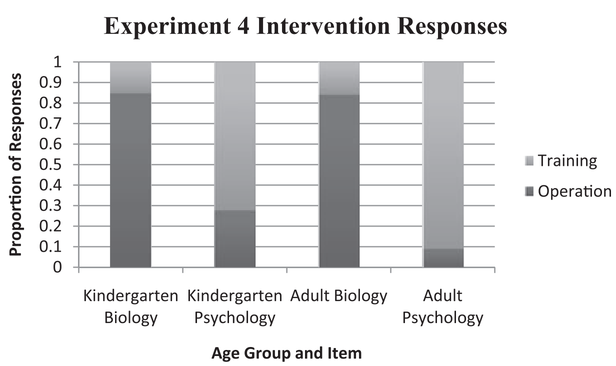

Figure 5. Results for Experiment 4. Each bar represents the kindergarten and adult responses according to the type of process in question: biological or psychological. Participants chose from two options—undergoing an ''operation'' or ''training''—as the most influential on that particular biological or psychological process.

processes, even when taken outside the familiar realm of human biology and psychology and applied across a range of animals.

Discussion

Experiments 3 and 4 went beyond both Experiments 1 and 2, allowing us to gain insight into how children were clustering biological and psychological phenomena. Not only do children understand that these processes are different from one another (as was demonstrated in Experiments 1 and 2), but they understand these processes are *fundamentally* different, that is, based on very different causal mechanisms. Having this understanding of domain-specific causal mechanisms allows children to not only differentiate within- from between-domain processes but also to grasp the fundamental similarity uniting different processes within a given domain. In other words, children not only recognize that biology and psychology are different, but how biological processes are *similar* to one another, as are psychological ones. This understanding provides children with the means to reason successfully about how different processes within a domain are related to one another, how changes in one can lead to changes in another, and how these changes are mediated through specific causal mechanisms.

General Discussion

In addition to having knowledge within the domains of biology and psychology, as was illustrated in the introduction, it appears that children as young as 5 years old also have an understanding that the processes within these two domains are fundamentally similar in that they are subject to the same underlying causal principles. Children know more than simply that some things grow or reproduce, and thus they possess some biological knowledge that is independent of any psychological-explanatory framework. These four experiments suggest that children also understand that processes such as growth and reproduction are phenomena that should be integrated into one domain (biology) united by common causal mechanisms, ones that are different from those operating in the domain of psychology.

We can conclude from Experiments 1 and 2 that young children have strong intuitions about the contrast between the very large domains of psychology and biology. Furthermore, Experiments 3 and 4 demonstrate that children understand this contrast stems from different causal frameworks. What remains to be discovered is *what* children think are the underlying causal mechanisms and *how* they influence various biological processes. Do children have a rich understanding of these causal mechanisms and how they function, or do they only have a skeletal framework that allows them to make limited inferences and inductive generalizations? We have seen a theme emerge in the recent literature that young children often pick up on abstract patterns that differentiate categories before grasping all the concrete mechanisms. For example, Simons and Keil (1995) found that young children understand that living things, nonliving natural kinds, and artifacts have different insides from one another but were unclear about what exact insides are in each. The ability to identify broad domains through sensing abstract causal patterns may be critical to guiding children to look for more mechanistic contrasts as their knowledge develops further. Children may need to have some sense that broad domains of regularities have critically different causal bases before investing the time into trying to master the details of such differences. It may also be that certain kinds of general causal schemata, such as a teleological orientation, increases sensitivity to the biological–psychological contrast by highlighting broad causal-functional patterns that fit differently with two domains although not appealing to specific mechanisms (Opfer & Siegler, 2004).

There is further evidence that learning specific causal mechanisms may vary across cultures. These four studies were performed in the United States, but Lockhart et al. (2004) examined children's beliefs about biological and psychological interventions in both the United States and Japan (see also Lockhart et al., 2008). Although both cultural groups at all ages distinguished biological from psychological properties in terms of which interventions were seen as most important, there was also a cultural difference. Japanese participants were more likely than U.S. participants to select effort as the most effective intervention for changing physical traits whereas U.S. participants chose taking medicine more often than Japanese participants. This cultural difference raises the important question of whether the kinds of expertise clusters found here might be present in many cultures, but might stress different underlying causal influences as most central. Thus, young children may sense a key difference between broad domains but local cultures may guide them toward weighing different kinds of causal patterns as most essential.

Another remaining question concerns how young children come to understand the fundamental differences between these two domains in the first place. The particular tasks used in these studies were verbally laden and thus were not successful in pilot studies with preschoolers. However, future studies might reduce the verbal loads of such tasks to discover how children begin to make the distinction between processes in the biological and psychological domains. There is now considerable controversy about the idea that knowledge of biology stems from a previous understanding of psychology (Waxman et al., 2007). Studies with younger children may help determine the origins of this biological understanding, especially how children learn the causal mechanisms foundational for all biological processes and how these relate to the contrast between the psychological and biological world.

References

Astuti, R., Solomon, G. A., & Carey, S. (2004). Constraints on conceptual development: A case study of the acquisition of folkbiological and folksociological knowledge in Madagascar. *Monographs of the Society for Research in Child Development*, *69*(Serial No. 277).

Atran, S., Medin, D., & Ross, N. (2004). Evolution and devolution of knowledge: A tale of two biologies. *Royal Anthropological Institute*, *10*, 395–420.

Backscheider, A. G., Shatz, M., & Gelman, S. A. (1993). Preschoolers' ability to distinguish living kinds as a function of regrowth. *Child Development*, *64*, 1242–1257.

Baillargeon, R. (1994). Infants' physical world. *Current Directions in Psychological Science*, *13*, 89–94.

Bertenthal, B. I. (1993). Perception of biomechanical motions by infants. In C. Granrud (Ed.), *Visual perception and cognition in infancy* (pp. 175–214). Hillsdale, NJ: Erlbaum.

Bullock, M. (1985). Animism in childhood thinking: A new look at an old question. *Developmental Psychology*, *21*, 217–225.

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

Coley, J. D. (1995). Emerging differentiation of folkbiology and folkpsychology: Attributions of biological and psychological properties to living things. *Child Development*, *66*, 1856–1874.

Danovitch, J. H., & Keil, F. C. (2004). Should you ask a fisherman or a biologist? Developmental shifts in ways of clustering knowledge. *Child Development*, *75*, 918–931.

Deerwester, S., Dumais, S. T., Landauer, T. K., Furnas, G. W., & Harshman, R. A. (1990). Indexing by latent semantic analysis. *Journal of the Society for Information Science*, *41*, 391–407.

Gelman, R., Durgin, F., & Kaufman, L. (1995). Distinguishing between animates and inanimates: Not by motion alone. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 150–184). Oxford, UK: Clarendon.

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

Hagmayer, Y., Sloman, S., Lagnado, D., & Waldmann, M. R. (2007). Causal reasoning through intervention. In A. Gopnik & L. Schulz (Eds.), *Causal learning: Psychology, and computation* (pp. 86–100). Oxford, UK: Oxford University Press.

Inagaki, K. (1997). Emerging distinctions between naïve biology and naïve psychology. In H. M. Wellman & K. Inagaki (Eds.), *The emergence of core domains of thought: Children's reasoning about physical, psychological, and biological phenomena* (Vol. 75, pp. 27–44). San Francisco: Jossey-Bass.

Inagaki, K. (2001). *Young children's distinction between living kinds and complex artifacts: How living and nonliving entities recover from trouble*. Paper presented at the annual meeting of the Society for Research in Child Development, Minneapolis, MN.

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

Inagaki, K., & Hatano, G. (1996). Young children's recognition of commonalities between animals and plants. *Child Development*, *67*, 2823–2840.

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

Jipson, J. L., & Gelman, S. A. (2007). Robots and rodents: Children's inferences about living and nonliving kinds. *Child Development*, *78*, 1675–1688.

Kalish, C. (1997). Preschoolers' understanding of mental and bodily reactions to contamination: What you don't know can hurt you, but cannot sadden you. *Developmental Psychology*, *33*, 79–91.

Keil, F. C. (1983). On the emergence of semantic and conceptual distinctions. *Journal of Experimental Psychology: General*, *112*, 357–385.

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

Keil, F. C. (1992). The origins of an autonomous biology. In M. R. Gunnar & M. Maratsos (Eds.), *Modularity and constraints in language and cognition. The Minnesota symposia on Child Psychology* (Vol. 25, pp. 103–137). Hillsdale, NJ: Erlbaum.

Keil, F. C. (1994). The birth and nurturance of concepts by domain: The origins of concepts of living things. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture*. (pp. 234–254). Cambridge, UK: Cambridge University Press.

Keil, F. C., Stein, C., Webb, L., Billings, T., & Rozenblit, L. (2008). Discerning the division of cognitive labor: An emerging understanding of how knowledge is clustered in other minds, *Cognitive Science*, *32*, 259–300.

Kushnir, T., & Gopnik, A. (2005). Young children infer causal strength from probabilities and interventions. *Psychological Science*, *16*, 678–683.

Kushnir, T., Gopnik, A., Schulz, L., & Danks, D. (2003). *Inferring hidden causes*. Presented at the annual meeting of the Cognitive Science Society, Boston.

Landauer, T. K. (1998). Learning and representing verbal meaning: The latent semantic analysis theory. *Current Directions in Psychological Science*, *7*, 161–164.

Landauer, T. K., Foltz, P., & Laham, D. (1998). Introduction to latent semantic analysis. *Discourse Processes*, *25*, 259–284.

Lockhart, K., Aw, J., & Essig, G. (2004, April 24). *Children's beliefs about the origins of positive and negative traits*. Poster presented at the biennial conference on Human Development, Washington, DC.

Lockhart, K. L., Chang, B., & Story, T. (2002). Young children's beliefs about the stability of traits: Protective optimism? *Child Development*, *73*, 1408–1430.

Lockhart, K. L., Nakashima, N., & Inagaki, K. (2004, August 8-13). *Japanese and American beliefs about the origins of positive and negative traits*. Paper presented at the International Congress of Psychology, Beijing, China.

Lockhart, K. L., Nakashima, N., Inagaki, K., & Keil, F. C. (2008). From ugly duckling to swan? Japanese and American beliefs about the stability and origins of traits. *Cognitive Development*, *23*, 155–179.

Lutz, D. J., & Keil, F. C. (2002). Early understanding of the division of cognitive labor. *Child Development*, *73*, 1073–1084.

Medin, D. L., & Waxman, S. R. (2007). Interpreting asymmetries of projection in children's inductive reasoning. In A. Feeney & E. Heit (Eds.), *Inductive reasoning* (pp. 55–80). New York: Cambridge University Press.

Miller, J. L., & Bartsch, K. (1997). Development of biological explanation: Are children vitalists? *Developmental Psychology*, *33*, 156–164.

Murphy, G. L., & Medin, D. L. (1985). The role of theories in conceptual coherence. *Psychological Review*, *92*, 289–316.

Nakashima, N., Lockhart, K., & Inagaki, K. (2003). *Japanese and American beliefs about the stability of traits*. Poster presented at the annual meeting of the Society for Research in Child Development, Tampa, FL.

Notaro, P. C., Gelman, S. A., & Zimmerman, M. A. (2001). Children's understanding of psychogenic bodily reactions. *Child Development*, *72*, 444–459.

Opfer, J. E., & Siegler, R. S. (2004). Revisiting preschoolers' living things concept: A microgenetic analysis of conceptual change in basic biology. *Cognitive Psychology*, *49*, 301–332.

Poulin-Dubois, D., & Shultz, T. R. (1990). Infants' concept of animacy. *Cognitive Development*, *11*, 19–36.

Rakison, D. H., & Poulin-Dubois, D. (2001). Developmental origin of the animate-inanimate distinction. *Psychological Bulletin*, *127*, 209–228.

Rochat, P., Morgan, R., & Carpenter, M. (1997). Young infants' sensitivity to movement information specifying social causality. *Cognitive Development*, *12*, 441–465.

Rosengren, K. S., Gelman, S. A., Kalish, C. W., & McCormick, M. (1991). As time goes by: Children's early understanding of growth in animals. *Child Development*, *62*, 1032–1320.

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.

Rozenblit, L. R., & Keil, F. C. (2002). The misunderstood limits of folk science: An illusion of explanatory depth. *Cognitive Science*, *26*, 521–562.

Shulz, L. E., Bonawitz, E. B., & Griffiths, T. L. (2007). Can being scared cause tummy aches?: Naïve theories, ambiguous evidence, and preschooler's causal inferences. *Developmental Psychology*, *43*, 1124–1139.

Siegel, M. (1988). Children's knowledge of contagion and contamination as causes of illness. *Child Development*, *59*, 1353–1359.

Simons, D. J., & Keil, F. C. (1995). An abstract to concrete shift in the development of biological thought: The *insides* story. *Cognition*, *56*, 129–163.

Smith, M. C. (1978). Cognizing the behavior stream: The recognition of intentional action. *Child Development*, *49*, 736–743.

Solomon, G. E. A. (2002). Birth, kind and naïve biology. *Developmental Science*, *5*, 213–218.

Solomon, G. E. A., Johnson, S. C., Zaitchik, D., & Carey, S. (1996). Like father, like son: Young children's understanding of how and why offspring resemble their parents. *Child Development*, *67*, 151–171.

Sommerville, J. A. (2007). Detecting causal structure: The role of intervention in infants' understanding of psychological and physical causal relations. In A. Gopnik & L. Shulz (Eds.), *Causal learning: Psychology, and computation* (pp. 48–57). Oxford, UK: Oxford University Press.

Sommerville, J. A., & Woodward, A. L. (2005). Infants' sensitivity to the causal features of means-end support sequences in action and perception. *Infancy*, *8*, 119–145.

Spelke, E. S., Phillips, A., & Woodward, A. L. (1995). Infant's knowledge of object motion and human action. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 44–78). Oxford, UK: Clarendon.

Springer, K. (1992). Children's awareness of the biological implications of kinship. *Child Development*, *63*, 950–959.

Springer, K. (1996). Young children's understanding of the biological basis of parent–offspring relations. *Child Development*, *67*, 2841–2856.

Springer, K., & Ruckel, J. (1992). Early beliefs about the causes of illness: Evidence against immanent justice. *Cognitive Development*, *7*, 429–443.

Steyvers, M., Tenenbaum, J. B., Wagenmakers, E. J., & Blum, B. (2003). Inferring causal networks from observations and interventions. *Cognitive Science*, *27*, 453–489.

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

Waxman, S. R., Medin, D. L., & Ross, N. (2007). Folkbiological reasoning from a cross-cultural developmental perspective: Early essentialist notions are shaped by cultural beliefs. *Developmental Psychology*, *43*, 294–308.

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

Wellman, H. M., & Gelman, S. A. (1998). Knowledge acquisition in foundational domains. In W. Damon (Ed.), *Handbook of child psychology* (Vol. 2, 5th ed., pp. 523–573). New York: Wiley.

Woodward, J. (2003). *Making things happen: A theory of causal explanation*. Oxford, UK: Oxford University Press.

Appendix A

Experiment 1: Human Biological and Psychological Processes

Biology

General health.

1. Why people's bones get stronger from drinking milk.*
2. Why people feel good when they exercise.
3. Why people should take vitamins.
4. How people get energy from food.*
5. How people build big muscles from protein.*
6. Why people breathe faster when exercising.
7. Why people need sleep to grow taller.
8. Why people need to drink lots of water.*
9. Why people get wrinkly skin when they're older.
10. Why people get tired if they do not eat enough.
11. Why people need to eat vegetables.
12. Why people are sometimes allergic to things.

Body breakdown/illness.

1. How people catch a cold.
2. Why people's skin bruises when they bump it.
3. Why people sometimes get tummy aches.
4. Why people get stuffy noses.
5. Why people's cuts scab over.*
6. Why people need more rest when they're sick.
7. Why people get cavities from eating too much candy.
8. How people's broken bones heal.*
9. Why people get better when they take medicine.*
10. Why people itch from chicken pox.
11. Why people get blisters if their shoes don't fit.
12. How people get sick from germs.

Psychology

Cognitive.

1. Why people think clearer when it is quiet.*
2. Why people find it hard to do math in their head.
3. Why people use their fingers to count to ten.
4. Why people sometimes think out loud.*
5. How people remember phone numbers.*
6. Why people sometimes remember things wrong.
7. Why people find puzzles hard to do.
8. Why people sometimes forget things.
9. How people solve riddles.*
10. Why people learn the alphabet easier if they sing it many times.
11. How people imagine things in their mind.
12. Why people learn languages easier when they're younger.

Personality/motivational.

1. Why people feel good when they do well in school.*
2. Why people act shy.
3. Why people like to learn new things.
4. Why people sometimes talk a lot.*
5. Why people like to be alone sometimes.
6. Why people are bullies.
7. Why people are messy.*
8. Why people work harder if they are rewarded.
9. Why people like to do things they're good at.
10. Why people are bossy.*
11. Why people get mad when they don't get what they want.
12. Why people like different things from one another.

Note. Asterisks indicate the items used in the questions. All other items were answer options.

Appendix B

Experiment 2: Animal Biological and Psychological Processes

Biology

Anatomy.

1. Why cats have blood in their bodies.
2. Why cats grow sharp claws on their paws.
3. Why horses' stomachs are so big.*
4. Why dogs get tummy aches.*
5. How birds have beaks and not teeth.
6. How birds grow feathers on their wings.
7. Why fish have scales all over their body.*
8. Why elephants' skin looks so wrinkly.
9. Why elephants grow long trunks.
10. Why camels have long eyelashes.
11. Why camels' humps are full of fat.
12. Why monkeys have long tails.*

Physiology

1. Why cats need to eat meat to stay healthy.*
2. Why horses sweat when it's hot outside.
3. Why horses need more sleep when they're sick.
4. How dogs shed when it's hot outside.
5. How dogs breathe faster when exercising.
6. How birds heal when they get hurt.*
7. How fish breathe underwater.
8. How fish first grow in eggs.
9. Why elephants have to drink a lot of water.*
10. Why camels do not need to eat food very often.*
11. How monkeys need sleep to grow bigger.
12. How monkeys need milk when they're young.

Psychology

Cognitive.

1. How cats remember their way home.*
2. How horses remember people who ride them.*
3. How dogs learn tricks like rolling over or lifting a paw.
4. How dogs know who their owner is.
5. How birds learn different songs to sing.
6. How birds know where to fly in the winter.
7. How fish decide what other fish to swim with.
8. How fish know where the surface of the water is.
9. Why elephants have very good memories.*
10. How camels learn to carry people on their backs.*
11. How monkeys learn to use tools.
12. How monkeys learn to count things.

Emotional.

1. Why cats have fun playing with yarn.
2. Why cats like to be alone a lot of the time.
3. Why horses get scared when they hear a loud noise.
4. Why horses have a lot of fun rolling around on the ground.
5. Why dogs really enjoy being petted.*
6. Why birds feel scared during thunderstorms.*
7. Why fish feel scared when there's lots of splashing.*
8. Why elephants fight when they're angry.
9. Why elephants like to be near their mothers.
10. Why camels like traveling with other camels.
11. Why camels get mad easily.
12. Why monkeys are curious and like to explore.*

Note. Asterisks indicate the items used in the questions. All other items were answer options.