The Emergence of Beliefs About the Origins of Species in School-Age Children

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Two studies address children's emerging understanding of the origins of species. Elementary-school children, aged 5–12 years, were interviewed about their understanding of biological origins and of natural history (*N*s = 49 in Study 1; 83, with parents, in Study 2). A systematic developmental pattern in children's explanations for biological origins was demonstrated. There were age-related shifts from mixed creationist and spontaneous generationist explanations, to an exclusive creationism, and finally to evolutionist or creationist explanations. A child's age, natural history knowledge, and parents' beliefs were independently related to the expression of these explanations. It is argued that this developmental pattern emerges from the interaction between community beliefs and age-related changes in the inductive potential of children's naive theories.

In this paper the earliest manifestations of children's understanding of how species originate is explored. The specific focus is the circumstances under which children adopt natural, in particular evolutionary, explanations as opposed to intentional explanations for such origins. This is a complex question, but there are at least two reasons to believe that it should be addressed. First, most studies of adults' and adolescents' beliefs about biological origins have revealed intriguing misunderstandings, sug-

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gesting that evolutionary thinking about the origins of species is very difficult to achieve. These misunderstandings range from the outright rejection of evolutionary views (e.g., Almquist & Cronin, 1988) to persistent misinterpretations of Darwin's theory of natural selection (e.g., Bishop & Anderson, 1990). Second, children's interpretation of biological phenomena is currently an important topic of research (e.g., Wellman & Gelman, 1997), and knowledge of the origin of species is central to an understanding of contemporary biology (e.g., Mayr, 1991).

Ever since their inception, Darwin's theories of common descent and natural selection were not only controversial, they were also among the most difficult theories to assimilate, even for scientists (Sulloway, 1997). Although the contemporary scientific establishment is clearly in favor of Darwinian theory (National Academy of Sciences, 1984), there continues to be widespread resistance to his ideas among the general public. According to a 1991 Gallup Poll, about half of American adults believe that "God created man pretty much in his present form at one time within the last 10,000 years" (Numbers, 1992, p. ix). Similarly, 38% of college students surveyed by Almquist and Cronin (1988) agreed that "The Garden of Eden is the point of origin of human life and that the origin itself was an act of creation performed by God as recorded by Genesis" (p. 520). This finding led Almquist and Cronin to conclude that educational techniques need improvement but there may be "limits to what a college education can . . . accomplish on its own" (p. 522).

Even for those who have studied evolutionary biology, Darwinian evolutionary concepts seem difficult to learn. Across a range of studies with students of different ages and expertise, including advanced biology and medical students, a consistent finding is that most fail to understand natural selection (e.g., Brumby, 1979; Deadman & Kelly, 1978; Ferrari & Chi, 1998; Greene, 1990; Samarapungavan & Wiers, 1997). At best, those who do adopt a biological view of species origins invoke a Lamarckian evolutionary mechanism, the inheritance of acquired features, often despite courses specifically designed to dispel such misconceptions (Bishop & Anderson, 1990). It is surprising, given the strong interest in the nature of preschool and young elementary-school children's intuitive reasoning about the biological world (e.g., Carey, 1985; Hatano & Inagaki, 1996; Keil, 1994; Wellman & Gelman, 1997), that there are no studies of young children's understanding of biological origins. Evolutionary explanations ushered in a profoundly different way of viewing the animate world. If, in scientific biology, Darwinian theorizing about origins provides a central organizing principle for a variety of biological phenomena, perhaps intuitive conceptions of biological origins, whatever the nature of those intuitions, may be similarly central for a naive biology.

On the face of it, both creationist and evolutionist explanations are fairly simple (Mayr, 1991). That is, it should be no more difficult to understand the idea that species originated with God than to understand the idea that species originated as a result of change in animal-kinds. If young children's beliefs about origins merely reflect those of the adult community, a likely prediction based on the Gallup Poll results is that in any age group children's origins beliefs would be approximately half evolutionist and half creationist. Under these circumstances no predictable developmental sequence would be observed. In contrast to such a scenario, however, constructivist views of children's understanding of the natural world, from Piaget's studies to contemporary research on children's naive theories (see Wellman & Gelman, 1997, for a summary), suggest that age-related effects might be expected.

Although Piaget did not explicitly address children's understanding of biological origins, he did theorize that there would be predictable developmental changes in children's beliefs about origins and that they would be found across domains. Specifically, Piaget (1929) proposed that preschoolers first believe that natural objects—animate and inanimate—were, like artifacts, made "for man" to satisfy his wants or needs, and then later "by man, or god," where god is simply regarded as an extension of "man" (pp. 352–356). Around the sixth year, the limits of human capacities become evident to the child, and a theological God is invoked as the creator. Only in the later elementary-school years after children are exposed to the relevant scientific knowledge would children appeal to natural rather than artificialist causes.

Piaget's position was challenged on the grounds that preschoolers do appear to understand that the human capacity to create objects is limited mostly to artifacts (Gelman & Kremer, 1991). Moreover, Carey (1985) found that young children do not conflate animacy and inanimacy, in that they reserve intentional or psychological explanations for animate rather than inanimate phenomena. Carey's (1985) findings also indicated that a distinct biological explanatory structure emerges from a naive intentional psychology around the late elementary-school years, and it is only at that point that children's biology is comparable to an adult biology. Thus, from either Piaget's (1929) or Carey's (1985) perspective, a predicted developmental sequence for children's understanding of species origins might include an age-related shift from an initial artificialism or creationism (species created as the outcome of the intentional actions or desires of "psychological" beings such as humans or God) to evolutionism. This shift would be likely to occur around 10 to 12 years of age, when, according to Carey, children begin to group humans and animals together as biological entities—animals—and when, according to

Piaget, there occurs a notable decrease in artificialist reasoning. This shift should be evident to the extent that children have appropriated the relevant knowledge base.

Carey's (1985) claim initiated a vigorous and still unresolved debate on the nature of young children's understanding of the natural, in particular, the animate, world. The crux of this debate rested on the extent to which young children were thought to appeal to intentional rather than natural explanations for biological phenomena. Do children believe, for instance, that a desire to be tall can cause an increase in height? Sufficient research exists to cast doubt on a strong version of Carey's thesis that young children have little recourse to anything other than intentional causation to explain biological phenomena. Young children do seem to have a limited understanding of natural causal mechanisms such as growth and inheritance (e.g., Backscheider, Shatz, & Gelman, 1993; Rosengren, Gelman, Kalish, & McCormick, 1991; Springer & Keil, 1989). Moreover, even when they do not understand the specific mechanisms involved, children often endorse natural rather than intentional causes for biological phenomena (e.g., Gelman & Kremer, 1991; Hatano & Inagaki, 1994).

Based on such evidence, Carey (1995) now argues that young elementary-school children, though not preschoolers, may endorse an intuitive biology but that, unlike older children, it is founded on vitalistic (Hatano & Inagaki, 1994) or teleo-functional principles (Keil, 1994). That is, young children may acknowledge the goal-directed or purposeful nature of animate as opposed to inanimate phenomena, without necessarily assuming intentional causation. Such young children, however, are unlikely to understand biological causation or biological goals (Carey, 1995). Moreover, Carey suspects that with appropriate cultural elaboration this teleo-functional mode of construal could provide the basis for either evolutionary or creationist accounts of origins. This revised interpretation of the nature of young elementary-school children's intuitive biology leads to a prediction that would not differ very much, at least on the surface, from that of the constructivist position outlined earlier. Children are likely to accept a biological, specifically an evolutionary, account of species origins only toward the end of the elementary-school years. Moreover, in contrast to the nonconstructivist position, children's appropriation of community beliefs, evolutionist or creationist, would be successful only to the extent that an analogous conceptual structure, a teleo-functional framework, is in place.

The aim of the current studies was to describe developmental change, if it exists, in the pattern of responses to questions about the origins of species. Two studies of children's explanations for the origin of biological species and their knowledge of natural history were conducted. The first more exploratory study, covering a range of topics, established the basic developmental sequence among elementary-school and early middle-school children from a midwestern university town, who had not been formally instructed in evolutionary theory. A second more focused study, with a similarly aged population from rural and suburban areas in the Midwest, included an analysis of the role of parent beliefs, as well as an analysis of the consistency of children's and adults' beliefs. Essentially both studies were descriptive, consisting of structured interviews. Both studies addressed two basic questions: (a) Do children provide natural or intentional explanations for the origins of species? (b) Are children's explanations related to their age, their knowledge of natural history, and, from Study 2, their parents' beliefs?

STUDY 1

The major goal for the first study was to establish a framework for interpreting children's responses to questions on the origins of species. This was accomplished by asking several questions about the origins of different species and by investigating children's understanding of natural history, especially of fossils and of adaptation, using both verbal and nonverbal tasks.

Coding of children's responses to the origins questions was based on an analysis of responses obtained in pilot work and on Mayr's (1982) historical analysis of the growth of biological thought. From pilot studies of children's understanding of species origins it became evident that in addition to simple creationist and evolutionist ideas there were two further types of response. One type was dubbed hybridizationist because children suggested that new species may have resulted from the mating of two unrelated species (according to Ferrari & Chi, 1998, even undergraduates' explanations of evolution include hybridization responses). A second type invoked a natural mechanism such as movement, growth, or birth, but, unlike the evolutionist responses, it did not involve an explicit transformation or change from one animal-kind to another. Historically, such response types were classified as spontaneous generationist (Mayr, 1982) as they involved the idea that living beings spontaneously emerge from nonliving matter (Roger, 1986). Although such responses could have been further subclassified (e.g., see Samarapungavan & Wiers, 1997), for the purposes of this study they were grouped together.

The aims of the origins coding system were to distinguish intentional from natural responses, and to further distinguish those natural responses that invoked a species transformation from the other types of natural responses just described. Based on the reported research on older students' understanding of evolutionary transformations, the most one might expect to find in younger children is a simple non-Darwinian evolutionary concept, such as the idea that animals change as a consequence of the inheritance of acquired characteristics. However, work by Keil (1989) suggests that elementary-school children are quite resistant to the notion that one kind of animal could be changed into another kind. Most of Keil's manipulations, though, were unnatural (e.g., surgical change). Even so, based on Keil's work it seemed unlikely that children would propose the idea that species could be transformed through natural processes, such as evolution. To ensure that children were advocating a transformation from one kind of animal to an unrelated species, stringent criteria were established: The names of the two kinds of animals had to refer to distinct species. For example, the response that humans might come from cave dwellers was not coded as a species transformation. In this case, pilot work suggested that for young children cave dwellers and modern humans are related kinds; cave dwellers merely dress differently and do not live in houses.

Method

Participants. Fifty children were recruited from elementary- and middle-school summer camps (which included children from diverse socioeconomic backgrounds) and sports teams in a midwestern university town. One 6-year-old boy was excluded because he did not pass a pretest. The remaining children were in three age groups: (young) 16 first and second graders (8 boys, 8 girls), mean age 6.9 years (age range 5.8–7.7 years); (middle) 17 third, fourth, and fifth graders (10 boys, 7 girls), mean age 8.8 years (age range 7.9–10.4 years); and (old) 16 sixth and seventh graders (7 boys, 9 girls), mean age 11.7 years (age range 10.8–12.8 years). Of these children, 82% were Caucasian, 14% were African American, and 4%, Asian American. These children represented 22 schools in the area. No more than five children came from any one school, and no more than two children had the same teacher; they were not, therefore, exposed to the same sources of knowledge. No child had been formally taught evolutionary theory in school.

General procedure. The interviews lasted for approximately 45 min and were conducted by the investigator at the summer camps or at the investigator's home. The interview covered nine topic areas, but only those items that specifically focus on the questions introduced earlier will be described. These included 55 items covering six topic areas. All interviews were audiotaped and transcribed. Coders were blind both to the identity of the child, and the nature of the hypotheses. The specific tasks and coding criteria will be described in two parts: *origins explanations* cover all the questions about the origins of species; *natural history knowledge* (which constituted the bulk of the interview) includes all questions about the related natural history concepts.

Origins explanations. These questions were designed to elicit children's explanations as to how species ("The very first . . .") came to be. Origins explanations were elicited with open-ended questions about humans and two nonhuman species, which differed from the human in similarity and familiarity, the dinosaur, and an imaginary mammal, the spiggle (see Ferrari & Chi, 1998, for a similar use of hypothetical problem scenarios).

For the dinosaur and human, the main origins question was: "How do you think the first dinosaur (the first human) got here on earth?" The spiggle was introduced in the following manner: "Scientists discovered an unexplored island and found a strange animal that could climb trees. . . . It looked like a mixture of a pig and a squirrel; they called it a spiggle. It ate nuts, berries and roots." Children were shown pictures of the island as it is now (green, with trees), and in the past (a desert). A description of the island's history and a series of questions about the spiggle followed, the first of which asked children to describe the spiggle (they were never shown pictures of this or any other animal). The subsequent spiggle origins question was: "How do you think the first spiggle got to be on the island?" This question differed from the other origins questions, because children were explicitly told that the spiggle was found only on one island. If their initial response indicated that they thought that spiggles came from nearby islands or were brought by people, it was reemphasized that spiggles originated on this particular island.

As described earlier, children's responses to the origins questions were coded into four explanation types, and don't know (see the appendix for sample responses). Some children gave more than one explanation for one species, in which case each explanation was counted only once (see the mixed response in the appendix). This coding scheme captured all of the children's utterances. *Spontaneous generationist:* responses indicating any one of a variety of natural but nontransformational origins, including "came from the earth," "appeared," and "grew." *Creationist:* responses indicating that God, a human, or another creature created, planned, or put a species on earth. *Evolutionist:* responses indicating the natural transformation of one species into an unrelated species (indicated by different species names). *Hybridizationist:* this explanation type was included because some children hypothesized that the spiggle came from the interbreeding of a pig and a squirrel. One person coded all responses, and a second coded 30% of the responses. Interrater agreement for assignment to explanation type for the origins questions was: dinosaur origins, 92%; human origins, 86%; spiggle origins, 75%. All disagreements were subsequently resolved by discussion.

Natural history knowledge. The major purpose of this part of the study was to obtain a measure of children's understanding of various sorts of natural history knowledge, called *natural history expertise.* This measure was a summary variable based on 51 items that were judged to be critical in the development of an understanding of evolution: fossils (and dinosaurs), adaptation (i.e., an understanding that species fit their habitats), and deep time (an understanding that the earth is old) (Mayr, 1982). Additionally, to determine whether children endorsed Lamarckian or Darwinian mechanisms of adaptive change, they were asked a question about the *mechanism of change,* which was not included in the overall natural history expertise score.

Two methods of eliciting information are reported: open-ended questions that required elaborated answers, and nonverbal sorting tasks. Given the range of ages of participants in the study, nonverbal tasks were included to give younger or less-verbal children an opportunity to display their knowledge and to make the tasks more enjoyable. For the sorting tasks, several objects were placed in a large bag and the child was told to take out one object at a time and then place it in one of two labeled boxes. The object order was thus randomized. To create the measure of natural history expertise, points were awarded for each item of correct information, which were then summed across all the relevant tasks. On the sorting tasks, measures were the number of items incorrectly identified, subtracted from those correctly identified. Criteria for judging the correctness of children's responses were derived from popular children's books on these subjects (e.g., Bramwell, 1983). The resulting measure covered all pertinent areas of knowledge but excluded redundant items. The specific tasks for each area of expertise will be described separately: fossil expertise tasks, dinosaur expertise tasks, and adaptation tasks.

The definitional question "Can you tell me what a fossil is?" (*fossil knowledge*) was followed by a sorting task in which 24 objects were sorted into a fossil box or a not-fossil box (*fossil sort*). All children correctly sorted the pretest item (a simulated rock). Of the objects, 12 were real fossils of the kind typically found in fossil kits; the other 12 were nonfossils, including patterned rocks, shells, and geodes. The fossils and contrasts had a similar range of sizes. Each contrast tapped typical misconceptions that children might have about fossils, including the idea that fossils are merely rocks with designs on them, are modern shells, or include artifacts or that fossils include either animal or plant remains, but not both.

Dinosaur knowledge was included as it was judged to be a relevant topic on which children were likely to be expert. The definitional question "Can you tell me what a dinosaur is?" (*dinosaur knowledge*) was followed by a sorting task (dinosaur vs. not-dinosaur) in which 9 models of dinosaurs (British Museum models) were contrasted with 12 models of contemporary and prehistoric mammals, reptiles, and insects (*dinosaur sort*). All children (except the one child subsequently excluded from the analyses) correctly sorted the pretest item (a model of a brachiosaurus) as a dinosaur. The dinosaurs and contrast items had a comparable range of sizes. The contrasts tapped typical misconceptions about dinosaurs, from simple ones that dinosaurs are any large and scary beasts, to more sophisticated misconceptions that pteranodons are dinosaurs.

Next considered are the coding criteria for fossil and dinosaur expertise. Answers to the initial definitional questions were awarded 1 point (except as noted) for mention of each of the following items (incorrect or redundant information was ignored). *Fossil knowledge:* mention of a single example (e.g., imprint; bones), biological origins (formed from plants, −2 points; animals, −2 points; or both, −3 points), deep time (e.g., formed from animals that lived a long time ago), permanent trace (in rock; in mud), or the process of petrification (e.g., turned into rock; preserved in mud, −2 points). *Dinosaur knowledge:* mention of a typical characteristic (e.g., big, horrible thing), animal or creature (2 points), or reptile (3 points), deep time (e.g., lived a long time ago, before people), extinct or prehistoric (2 points). All responses were coded by two people. Initial interrater agreement was 90% for fossil knowledge, and 98% for dinosaur knowledge. All disagreements were subsequently resolved by discussion.

The adaptation tasks focus on how spiggles would adapt to a changing environment. The spiggle task consists of questions about the origins of spiggles (described earlier) and adaptation. Following the introduction to the spiggles' island environment (described earlier), children were told that "There was a rise in sea level and the island became covered in water, with only peaks of land and no grass or trees. . . ." They were shown a picture of the changed island (without any animals) and asked about the fate of the spiggles and any other animals. Finally, children were asked questions about the adaptation of spiggles and other animals to a changed island environment. The spiggle task yielded three measures, only two of which, static adaptation and adaptive change, were included in the natural history expertise score. The last measure, mechanism of change, was scored separately.

Static adaptation is a measure to capture children's understanding that animals are uniquely adapted to their current environment. Children were asked what kind of animals might live in the newly submerged island, and they were given 1 point for identifying the kinds of animals that might occupy each unique niche. The *adaptive change* measure captures the insight that if environments change sufficiently, then animals have to adapt or die. Following the description of the newly submerged island (e.g., ". . . the island became covered in water . . ."), children were asked: "What would happen to the spiggles?" They then were told that scientists had "found that there were still spiggles living on the watery island [a long time afterward]." Then children were asked: ". . . would they [spiggles] look the same as the ones that lived on the [original] green island?"; "What would they eat?"; "How would they move around?" The following points were awarded depending on the type of adaptive feature identified: (0) don't know; (1) no change; (2) behavioral change only (swim, eat fish); (3) biological change (webbed feet, gills, streamlined body). All responses were coded by two people. Initial interrater agreement was 96% for static adaptation, and 84% for adaptive change. All disagreements were subsequently resolved.

Finally, the *mechanism of change*—Lamarckian or Darwinian—was assessed. Children were asked "How did these changes come about?" Unlike the measure of adaptive change, where children merely identified adaptive features, in this measure children had to specifically address the cause. This question was included to determine whether children had any understanding of the mechanisms of biological change and, as such, it served as a check on the coherence of children's separately generated origins explanations. For this reason, it was not included in the overall measure of natural history expertise. The measure represented increasingly biological explanations for change. The following points were awarded: (0) don't know/other; (1) volitional/behavioral, changed because they wished or needed to change, or learned a new skill (e.g., "watched the fishes, copied them, one spiggle got to swim and taught the others"); (2) Lamarckian type, physiological change in one or more animals, often subsequently inherited (e.g., "Over the years some might go in the water, swim . . . get little fins, which the children's children might have"); (3) Darwinian type, some animals had special "qualities" that enabled them to survive and reproduce, the others died. Children did not spontaneously indicate that a different species arose as a result of these change processes, nor was this possibility brought to their attention. Initial interrater agreement was 92%. All disagreements were subsequently resolved.

Order of presentation. There were two fixed orders of presentation: (a) fossil knowledge and sorting task; spiggle origins and adaptation; dinosaur knowledge and sorting; dinosaur and human origins; and

(b) dinosaur knowledge and sorting; dinosaur and human origins; spiggle origins and adaptation; fossil knowledge and sorting. Two of the topic areas excluded from these analyses (see General Procedure) were positioned at the end of the interview, and the third was always positioned before the last task.

Results

Three questions are addressed: (a) What is the relationship between children's beliefs about biological origins and age? (b) What is the relationship between children's beliefs about biological origins and their natural history expertise? (c) Is children's endorsement of various mechanisms of adaptive change related to their beliefs about biological origins?

Age-related change in children's beliefs about biological origins. A measure of children's understanding of the origins of species, termed frequency of an explanation, was computed for children's use of each of the three main explanation types (evolutionist, creationist, and spontaneous generationist). This was summed across all three cases of the questions about origins (human, dinosaur, and spiggle). Thus, for each type of origins explanation each child could obtain a single score from 0 to 3. A score of 0 indicated that the child did not invoke that particular explanation (e.g., evolutionist) for any of the three origins questions (i.e., human, dinosaur, and spiggle). Any number above 0 indicated that an explanation was invoked to answer one or more of the species origin questions, either as the only explanation or as one of multiple explanations. For example, a child could score 3 for evolution, 2 for creation, and 0 for spontaneous generation, which indicated that for each of the three animals an evolutionist explanation was evoked, and, in addition, for two of the animals a creationist response also was invoked (see the mixed response in the appendix), but for none of them was a spontaneous generation explanation evoked. Hybridizationist explanations were excluded from this analysis, as they were rare and given only for the spiggle.

The frequency scores (and standard deviations) for the three age groups are presented in Table 1. One boy and two girls (ages, 6.1, 7.1, and 7.3, respectively) were excluded from any analyses using the open-ended origins questions as they answered them only after several probes. A 3 (Age group: young, middle, old) × 3 (Explanation type: evolutionist, creationist, spontaneous generationist) mixed-design analysis of variance (ANOVA) with explanation type as the repeated measure, conducted on the frequency scores, showed only a significant interaction between age group and explanation type, $F(4, 86) = 8.61$, $p < .0001$. Two-way

Table 1. Study 1: Mean Frequency (and Standard Deviations) of Origins Explanations Among School-Age Children

	Age groups		
Origins explanations	Young (n = 13)	Middle (n = 17)	Old (n = 16)
Spontaneous generationist	1.6 (1.0)	0.8 (0.8)	0.6 (0.6)
Creationist	1.2 (0.7)	1.7 (1.1)	0.7 (0.9)
Evolutionist	0.2 (0.4)	0.5 (1.0)	1.7 (1.0)

Note: Frequency range = 0–3. Mean age of each age group: young (6.9 years); middle (8.8 years); old (11.7 years).

ANOVAs revealed no effect of presentation order or gender on the frequency of an origins explanations. To clarify the nature of the interaction, three one-way ANOVAs were conducted on the frequency scores. There were significant main effects for age for each explanation type: evolutionist, $F(2, 43) = 11.36$, $p < .0002$; creationist, $F(2, 43) = 5.21$, $p < .01$; spontaneous generationist, $F(2, 43) = 6.59$, $p < .004$. Post hoc Scheffé contrasts revealed ($ps < .04$ to $< .001$) that evolutionists were most likely to be found in the old age group, creationists in the middle and young age groups (with a greater trend toward the middle age group), and spontaneous generationists in the young age group. Clearly there were age-related effects in children's pattern of responses to questions on the origins of species.

Natural history expertise and origins explanations. The current data also were examined for the relationship between children's use of origins explanations and their natural history knowledge.

Measures of natural history expertise are considered first. To relate origins explanations and natural history knowledge, a measure of the latter is needed. For this purpose, a summary variable, called *natural history expertise* was created ($M = 18.1 \pm 4.9$ SD; range = 7–26). The latter was the sum of the following natural history measures: dinosaur knowledge ($M = 3.6 \pm 1.3$ SD); fossil knowledge ($M = 2.8 \pm 1.4$ SD); fossil sort ($M = 6.2 \pm 2.8$ SD); static adaptation ($M = 3.3 \pm 1.4$ SD); and adaptive change ($M = 2.2 \pm .7$ SD). As described earlier, these verbal and nonverbal measures covered areas of knowledge thought to provide a conceptual basis for the emergence of evolutionary ideas. Because one focus of this study was on the relation of a global understanding of natural history to the origins explanations scores, the predictive values of the different types of tasks included in the global measure (e.g., conceptual vs. performance) were not reported. The dinosaur sort task was excluded because it was the only natural history measure not significantly correlated with any one of the other natural history variables, or age (see Table 2). A two-way

Table 2. Study 1: Intercorrelations Between Child Age, Measures of Natural History Knowledge, and Natural History Expertise

Measures	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Age (continuous)	—						
(2) Fossil sort	$.40^{**}$	—					
(3) Dinosaur sort	.00	−.10	—				
(4) Fossil knowledge	$.54^{***}$	$.31^{*}$	.00	—			
(5) Dinosaur knowledge	$.61^{***}$	$.39^{**}$	−.04	$.41^{**}$	—		
(6) Static adaptation	.15	−.03	−.21	.00	.27	—	
(7) Adaptive change	.26	$.37^{*}$	.13	.12	.23	.14	
(8) Natural history expertise	$.63^{***}$	$.81^{***}$	−.10	$.59^{***}$	$.72^{***}$	$.36^{*}$	$.50^{***}$

Note: All significance levels are two-tailed. $n = 46$.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

ANOVA revealed no effect of presentation order or gender on natural history expertise.

Considered next is natural history expertise, age, and origins explanations. To establish the nature of the relationship between natural history expertise, age (continuous variable), and the three origins explanations, a series of pairwise correlations was carried out (see Table 3). Of the three origins explanations, only the frequency of evolutionist explanations was positively correlated with natural history expertise. The joint effects of age and natural history expertise were then regressed on the frequency of evolutionist explanations: $R^2 = .44$ ($R = .66$); $F(2, 45) = 16.54$, $p < .0001$ (Adjusted $R^2 = .41$). Standardized regression coefficients were computed to assess the independent effects of each variable, and only age was significant, $ß = .56$ ($p < .001$).

Interestingly, in addition to the lack of correlation with the other natural history measures (see Table 2), scores on the dinosaur sorting measure did not correlate with the frequency of evolutionary explanations. This sorting task ($M = 5.3 \pm 1.4$ *SD;* range 2–8) did require children to make some sophisticated decisions, such as whether plesiosaurs were dinosaurs. Clearly, the ability to distinguish dinosaurs from other species did not necessarily entail an understanding of the concepts (e.g., fossilization) that were needed to do well on the other natural history measures. This result provides some evidence that the association between natural history knowledge and evolutionary belief is confined to the particular concepts associated with the historical emergence of evolutionary explanations (Mayr, 1982), such as fossil knowledge and adaptation, and does not extend to any kind of natural history knowledge.

To summarize, age and natural history expertise jointly accounted for 44% of the variance in the frequency of an evolutionary explanation,

Table 3. Study 1: Intercorrelations Between Child Age, Natural History Expertise, and Frequency of Origins Explanations

Measures	(1)	(2)	(3)	(4)
(1) Age (continuous)	—			
(2) Evolutionist	.65***	—		
(3) Creationist	−.27	−.41**	—	
(4) Spontaneous generationist	−.51***	−.52***	−.24	
(5) Natural history expertise	.63***	.50***	−.32*	−.34*

Note: Frequency: Number of times an origins explanation was invoked (range 0–3). All significance levels are two-tailed. $n = 46$.
*$p < .05$. **$p < .01$. ***$p < .001$.

with age having a significant independent effect. On the other hand, natural history expertise is significantly negatively related to the frequency of spontaneous generationist and creationist beliefs.

Mechanism of change: Darwinian or Lamarckian? How do these children explain change in an animal population over time? If children's evolutionary explanations represent some kind of shift in their capacity to reason biologically, then those children who provide a higher frequency of evolutionary explanations for species origins also should be the most likely to propose some kind of biological mechanism of change. Children were asked a mechanism of change question about the spiggle population (separately from the spiggle origins question), and they were given a context within which to address possible transformations—the newly submerged island. This measure represented increasingly coherent, mechanistic explanations for biological changes: Darwinian-type responses were at the top end of the scale, Lamarckian-type responses were next, then volitional/behavioral ("want or desire") or behavioral ("learned") responses and less coherent responses at the bottom. This measure correlated positively with the frequency of an evolutionary explanation (range 0–3), $r = .47$, $p < .001$, but not with creationist explanations, $r = -.14$, nor spontaneous generationist explanations, $r = -.28$. The correlation with age was also positive, $r = .35$, $p < .02$. Interestingly, of the 13 volitionist/behaviorist responses given for the mechanism of change measure, 11 were given by creationists and 2 by noncreationists, which is significantly different from chance, $p < .02$, binomial test; for the other origins explanations, no significant differences were obtained for volitionalism. Only one child (exclusively evolutionist, for all exemplars) gave a response that was best characterized as Darwinian (see General Discussion). Thus, evolutionists were more likely to appeal to a Lamarckian rather than a Darwinian mechanism of change. On the other hand, creationists were more likely to appeal to volitionist causes, when they appealed to any cause at all.

Conclusion

This exploratory study of elementary-school children's beliefs about the origins of species demonstrated a coherent developmental pattern. It appears that there are systematic, age-related shifts with a developmental increase in evolutionary arguments, a developmental decrease in spontaneous generation, and an inverted "U" pattern for creationism. For most children the evolutionary argument is associated with a Lamarckian rather than a Darwinian adaptive change mechanism. Additionally, there was a positive relationship between the frequency of use of evolutionary explanations and specific kinds of natural history knowledge, namely fossils and adaptation; however, there was also a relationship with age.

STUDY 2

The results from the first study suggest that it would be difficult to argue that children's beliefs merely reflect those found in their immediate environment, as it would be reasonable to assume the environments were similar across age groups (at least with respect to community beliefs), whereas children's beliefs differed by age group. However, this pattern does not rule out some kind of interaction. One important question not addressed in the first study was the role of parent beliefs in this developmental sequence. Moreover, given that the university town environment of the first sample is likely to be more highly educated and secular, and the children arguably more evolutionist than is the norm for U.S. populations, in Study 2 efforts were made to obtain a more diverse and representative population. This was achieved by recruiting children and their mothers from a variety of rural and suburban districts. In an attempt to tease apart the effects of age and natural history knowledge, the sample size was increased so that analyses could be conducted separately within each age group. Additionally, to determine whether children and adults adopted any of these explanations exclusively, analyses of the consistency of their use of these explanations were also included in Study 2.

Method

Participants. Using a fan-out system, 83 children and their mothers or guardians ($n = 45$) were recruited from 18 rural and suburban towns in the Midwest: 88% attended public schools and 12%, parochial schools. Specifically excluded from this sample were children attending Christian fundamentalist schools. Most children were Caucasian, one was Hispanic, and one was Asian. The children were divided into three age groups using the same age and grade guidelines as in Study 1: (young) 25 first and second graders with a mean age of 6.8 years and an age range of 5.3–7.9 years (18 girls, 7 boys); (middle) 29 third and fourth graders with a mean age of 9.1 years and an age range of 8.1–10.2 years (16 girls, 13 boys); (old) 29 fifth, sixth, and seventh graders with a mean age of 11.5 years and an age range of 10.3–12.9 years (11 girls, 18 boys).

Based on a 5-point scale of 1 (some high school), 2 (high school), 3 (some college), 4 (college degree), 5 (some graduate school), the mean educational level (completed) of the mothers was 3.2 (SD = 1.2), the fathers 3.3 (SD = 1.3), and the predicted educational level for the children was 4.2 (SD = 0.75). There were no significant differences between age groups on any of these measures. Although none of these children went to a fundamentalist school, 20 attended a fundamentalist church; of the rest, 35 attended a nonfundamentalist church, and 28 did not attend any church. Again, there were no significant differences between age groups in the type of church attended.

No comparable data were gathered on the participants for Study 1. However, using census data for members of the population (over 25 years) of the university town used in Study 1 ("Almanac Report," 1995), it was possible to compare completed educational levels in the two populations (figures in parentheses are for the Study 2 sample): (1) 6.1% (6.7%) have some high school education; (2) 9.9% (40%) completed high school; (3) 19.4% (26.7%) have some college education; (4) 28.3% (15.5%) have a college degree, and (5) 36.2% (11.1%) have some graduate school education. The two samples differed significantly in educational level: $\chi^2 (4, N = 45) = 363.67, p < .0002$.

The figures for the Study 2 sample were obtained by averaging the educational levels of both parents, except in the case of single-parent families, who were all mothers (n = 8), in which case the mother's educational level was used. Although efforts were made to obtain a representative sample of children in Study 1, it is likely that the parents of the participants were more highly educated than the average for that town, as voluntary participation typically elicits a more highly educated sample. However, if this were so, then the conclusion that parents of participants in Study 1 were on average better educated than those from Study 2 would be strengthened.

General procedure. Individual child interviews lasted approximately 25 min and were conducted by the investigator and two female research assistants. Of the interviews, 93% were conducted in the child's home, 7% in the town library. All interviews were audiotaped. Parent questionnaires were completed either while the child was being interviewed in a separate room, or after the child interview. This questionnaire consisted of demographic data (described earlier), a variety of origins questions, and questions about the hobbies and interests parents were likely to encourage in their children; the latter will not be reported.

Coding of the open-ended origins questions was done by coders uninformed about both the nature of the hypotheses and the age group of the child. The specific tasks and coding criteria will be described in two parts: (a) *origins explanations* covered the three open-ended questions about the origins of species, which were given both to children and adults; (b) *natural history knowledge* included all questions about the child's natural history knowledge, which were given only to the children.

Origins explanations. The child task is considered first. As in Study 1, origins explanations were elicited with three open-ended questions as to how species ("The very first . . .") came to be. In the current study, however, an introductory statement was used to draw children's attention to the fact that species may not always have existed (from Evans & Gelman, 1999). "I am going to ask you some questions. There are no right or wrong answers to these questions, just different kinds of ideas. Think about how the very first things got here on earth. A long, long time ago there were no things on earth. Then there were the very first things ever. Now, think about [the target item]; how do you think the very first [target item] got here on earth?" (if no answer was elicited, the question was repeated twice). The three target items were the sun-bear (described as a kind of bear from Asia), the tuatara (described as a kind of lizard from New Zealand), and the human. All items were presented verbally, only. The human was always last, with the order of the other two targets alternated between children. The tuatara and sun-bear were considered to be unfamiliar and unlikely to elicit well-rehearsed knowledge, and they replaced the dinosaur and spiggle target items used in the first study.

The parent questionnaire included the following statement: "Imagine you were teaching a 10- to 12-year-old child you know, and he or she had asked you the following questions. Please briefly write down your answers." The questions were "How did the very first [target item], [target item description], get here on earth?" The target items, presented in a fixed order, were: tuatara, sun-bear, and human. The wording of this question was designed to elicit the parent's beliefs, albeit indirectly.

Responses to the origins questions were coded into four explanation types (as well as don't know and other), as in Study 1: spontaneous generationist, creationist, evolutionist, and hybridizationist (see the appendix

Table 4. Study 2: Mean Frequency and Standard Deviations of Origins Explanations Among Children and Adults

	Age groups			
Origins explanations	Young (n = 24)	Middle (n = 29)	Old (n = 29)	Adult (n = 37)
Spontaneous generationist	1.3 (1.1)	0.4 (0.7)	0.3 (0.6)	0.1 (0.3)
Creationist	1.5 (0.9)	2.1 (1.0)	1.3 (1.1)	1.5 (1.3)
Evolutionist	0.3 (0.6)	0.3 (0.5)	1.4 (1.3)	1.6 (1.4)

Note: Frequency range = 0–3. Mean age of each age group: young (6.8 years); middle (9.1 years); old (11.5 years).

for typical responses). All responses were coded by two people. Interrater agreement for the assignment to explanation types for the origins questions for the first 50 participants was: tuatara origins, 86%; sun-bear origins, 94%; human origins, 97%. All disagreements were subsequently resolved by discussion.

Natural history knowledge. In Study 1, knowledge of natural history was found to be significantly related to the expression of an evolutionary belief. An abbreviated version of that natural history expertise task was included in Study 2 in an attempt to replicate the effect seen in Study 1. In addition, a measure of children's endorsement of Lamarckian-type adaptation was included, called *dynamic adaptation.* Parents were not asked about their own natural history knowledge.

First, children were asked the same two definitional questions (the order alternated between participants) used in Study 1: "What is a fossil?" (fossil knowledge) and "What is a dinosaur?" (dinosaur knowledge); coding criteria were identical also. These were followed by 12 randomly ordered statements on natural history, 9 of them mostly about fossils and deep time (based on typical misconceptions exhibited by children from Study 1), and 3 of them about dynamic adaptation (a judgment of the extent to which an animal would change in response to changed environmental conditions): 6 statements were true, and 6 were false. Examples of the statements were: natural history knowledge, "Dinosaurs and humans used to live on the earth at the same time"; "A geode is a kind of rock with crystals in it"; dynamic adaptation, "If an animal swims a lot it might get webbed feet, and its babies will have webbed feet, too." Children used an agree-disagree card (with a 4-point scale) to indicate how much they agreed (agreement score) with each statement. On the card there were four expressive faces indicating either disagreement (1 = *a lot;* 2 = *a little*) or agreement (3 = *a little;* 4 = *a lot*); "don't know" was given a 2.5. Children were trained to use the scale, and all mastered its use.

In an effort to replicate and extend the findings of Study 1, only the results from the open-ended origins explanations questions and the natural history knowledge questions will be reported. However, a closed-ended origins beliefs task was presented after the open-ended task and before the natural history knowledge questions. In the parent questionnaire, the task order was essentially the same, though demographic information was reported first; additionally, parents were asked what kinds of origins explanations they would give to children of different ages.

Results and Discussion

Results and brief discussions are presented in three sections. The first section focuses on the open-ended origins beliefs, and the extent to which the developmental pattern seen in Study 1 is replicated. Next examined is the consistency of child and adult beliefs, and finally reported is the relationship between the frequency of child origins beliefs, child natural history knowledge, and a measure of potential contextual influence, parent origins beliefs, within each age group.

Age-related change in beliefs about biological origins. In Study 1 a systematic developmental pattern was found in a sample drawn from a university town. The data to be considered now were gathered from rural and suburban, nonfundamentalist populations, in which most adults had fewer years of formal education than was likely among parents of children in the Study 1 sample. The following analysis focused on the question of whether the original developmental pattern pertains in this community, and what the adult pattern of beliefs might be.

The measure of children's understanding of the origins of species used in Study 1, termed frequency of explanation, was again computed for their use of each of three main belief patterns (creationist, spontaneous generationist, evolutionist). The measure was the sum, across all three open-ended origins questions (sun-bear, tuatara, and human), of the number of times a particular belief was expressed. The dependent measure was a frequency score (0–3) for each of the origins beliefs (spontaneous generationist, creationist, evolutionist). Hybridization responses were excluded from this analysis (as were don't know and other) as they were extremely rare. One child (5.4 years) and eight adults did not complete this measure. Means (and standard deviations) for each age group can be seen in Table 4.

The frequency of belief scores were analyzed in a mixed-design ANOVA, with Age group (4: young, middle, old, adult) as the grouping variable and Origins beliefs (3: spontaneous generationist, creationist, evolutionist) as the repeated measure. There was a main effect for origins beliefs, $F(2, 230) = 29.5$, $p < .0001$, and a significant interaction between origins beliefs and age group, $F(6, 230) = 9.9$, $p < .0001$. To clarify the nature of the interaction, each origins belief was then analyzed separately. Three one-way ANOVAs with Age group (4) conducted on the frequency of belief scores revealed significant effects of age group for each origins belief: evolutionist, $F(3, 115) = 13.4$, $p < .0001$; creationist, $F(3, 115) = 2.8$, $p < .05$; spontaneous generationist, $F(3, 115) = 16.0$, $p < .0001$. Bonferroni-Dunn contrasts indicated several significant age-group differences: Evolutionist beliefs were more likely to be found among the older children and the adults (*ps* < .001); creationist beliefs were found in all age groups with a significantly higher frequency in the middle age group (*ps* < .05); whereas spontaneous generationist beliefs were most frequent in the youngest age group (*ps* < .0001).

The developmental pattern among participants in this community replicates the original pattern seen in the first study. One interesting difference is that among the older children and the adults in the current study both evolutionist and creationist beliefs are found in roughly the same proportions as in the population at large, whereas in the first study evolutionist beliefs predominated in the older age group. Adults were not included in the first study, but the results from the current study suggest that by early adolescence (the old group), children's beliefs have converged on the adult pattern of their community. Moreover, these similar response patterns were obtained in spite of the fact that adults wrote their responses and children answered verbally, indicating that the different performance conditions did not affect the outcome.

Individual response patterns. Reporting the overall pattern of origins explanations by age group does not provide any information about individual response patterns. For example, it was unclear to what extent the overall pattern obtained for the older children and adults was a result of half of them invoking evolutionary beliefs, exclusively, and the other half creationist beliefs, exclusively, versus the majority invoking both creationist and evolutionist beliefs in any combination (called mixed beliefs; for an example, see the appendix). For each age group a secondary analysis of the overall belief pattern (for the frequency measure) was carried out, to ascertain the percentage of individuals invoking either mixed or exclusive beliefs. The two origins explanations that were most highly endorsed by each age group were the focus of this analysis.

For the youngest age group, individual data for only the spontaneous generationist and creationist beliefs will be reported, as evolutionary responses were rarely invoked. Thus, two children who produced two to three evolutionist responses were excluded from this analysis. Of the remaining children ($n = 22$), 14% were exclusively spontaneous generationist (no creation); 18% were exclusively creationist (no spontaneous generation); and the rest, 68%, provided a mixed pattern of both spontaneous generationist and creationist arguments. In contrast, for the middle

Table 5. Study 2: Individual Patterns (Percentage of Group) of Evolutionist and Creationist Beliefs Among Children and Adults

	Age groups (%)		
Patterns	Middle (*n* = 25)	Old (*n* = 27)	Adult (*n* = 37)
(1) Evolution/no creation	0	37	27
(2) Evolution & creation	24	33	35
(3) Creation/no evolution	76	30	38

Note: Participants with two to three spontaneous generation responses were excluded from this analysis: four from the middle age group, and two from the old age group.

age group (*n* = 28; one child with two to three evolutionist responses was excluded), 4% were exclusively spontaneous generationist, 76% were exclusively creationist, and only 20% provided a mixed pattern. Data on the individual patterns for the creationist and evolutionist beliefs of the older age groups and adults are provided in Table 5. (Children who produced more than two spontaneous generationist responses were excluded from that analysis.)

These individual patterns suggest that children in the youngest age group were the most likely to exhibit mixed beliefs (68%). Children in the middle age group (see Table 5) were the most likely to exhibit exclusive creationist beliefs (76%), whereas 67% of the children from the old age group and 65% of adults were either exclusively evolutionist or exclusively creationist, with about a third demonstrating mixed evolutionist and creationist beliefs. In summary, these analyses of the individual patterns suggest that the overall developmental pattern is more accurately portrayed as a shift from mixed creationist and spontaneous generationist beliefs to an exclusive creationism, and from there to exclusive creationist or exclusive evolutionist beliefs.

Relationship among parent beliefs, child knowledge, and child beliefs. In Study 1, the relationship between community beliefs and children's explanations was not directly measured. To obtain a better understanding of the factors that are differentially related to the expression of origins beliefs within each age group, parents' beliefs as well as children's natural history knowledge were examined for their relationship to children's origins beliefs, separately by age group. Seventeen children were excluded as they did not have complete parent data. The remaining child sample (*n* = 67) was: young group (*n* = 17); middle group (*n* = 24); old group (*n* = 26).

A measure called *fossil expertise* (*M* = 8.2 + 2.8 *SD*; range = 2–13.8) was constructed by taking the mean agreement score of the nine fossil and deep time statements (range = 1–4) described earlier and adding it to children's scores on the fossil knowledge and dinosaur knowledge ques-

Table 6. Study 2: Intercorrelations Between Children's Age, Origins Explanations, and Natural History Knowledge, and the Consistency of Their Parents' Beliefs

Measures	(1)	(2)	(3)	(4)	(5)	(6)
(1) Child age (continuous)	—					
Child origins explanations						
(2) Evolution frequency[a]	.46***	—				
(3) Creationist frequency	–.24*	–.69***	—			
(4) Spontaneous Gen. frequency	–.34**	–.36**	–.18	—		
Child natural history knowledge						
(5) Dynamic adaptation[b]	–.19	.23	–.23	–.12	—	
(6) Fossil expertise	.57***	.43***	–.25*	–.16	–.28*	—
Parent beliefs: evolutionist-to-creationist						
(7) Belief consistency[c]	–.10	–.32**	.35**	–.04	.10	–.29*

Note: All significance levels are two-tailed. $n = 67$.
[a]Frequency: number of times an origins explanation was expressed; range: 0–3. [b]Dynamic adaptation: measure of degree of agreement that animals can change in response to environmental change; range: 1–4. [c]Parent belief-consistency (frequency of creationist–frequency of evolutionist beliefs).
*$p < .05$. **$p < .01$. ***$p < .001$.

tions (see Study 1 for descriptions). The mean score of the remaining three true-false statements was used as a measure of adaptationist beliefs, called *dynamic adaptation* ($M = 2.0 + .81$ *SD*; range = 1–3.7); this measured the degree to which children endorsed statements that animals respond to changes in the environment with a change in physical characteristics, and whether their offspring would inherit these characteristics.

It was hypothesized that parents with more consistent (or exclusive) evolutionist or creationist beliefs are more likely to provide an optimal environment for fostering such beliefs in their children. As parents almost never expressed spontaneous generationist beliefs, the focus was on the consistency of their evolutionist and creationist beliefs across the three exemplars. To simplify the discussion of the effects of these two variables, and for theoretical and statistical reasons (see Lewis-Beck, 1980), the frequency of parent creationist and evolutionist beliefs were combined into one measure called *belief consistency* (frequency of creationist beliefs–frequency of evolutionist beliefs); lower scores represented more consistent evolutionist beliefs, whereas higher scores represented more consistent creationist beliefs (range = −3 to +3).

Intercorrelations between the measure of parents' belief consistency (evolutionist-to-creationist), the frequency of children's origins beliefs, children's understanding of natural history (fossil expertise and dynamic

Table 7. Study 2: Intercorrelations Between Origins Explanations, Natural History Knowledge, and the Consistency of Parents' Beliefs Among Older Elementary-School Children

Measures	(1)	(2)	(3)	(4)	(5)
Child origins explanations					
(1) Evolution frequency	—				
(2) Creationist frequency	$-.81^{***}$	—			
(3) Spontaneous gen. frequency	$-.43^{*}$	$-.08$	—		
Child natural history knowledge					
(4) Dynamic adaptation	$.48^{*}$	$-.28$	$-.39$	—	
(5) Fossil expertise	$.47^{*}$	$-.62^{***}$	.10	.14	—
Parent beliefs: evolutionist-to-creationist					
(6) Belief consistency	$-.61^{***}$	$.69^{***}$	$-.15$	$-.14$	$-.47^{*}$

Note: See notes for Table 6. $n = 26$.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

adaptation), and child age (as a continuous variable) are presented in Table 6. As in the first study, children's natural history knowledge (fossil expertise) was negatively related to the frequency of their creationist beliefs, and positively related to the frequency of their evolutionary beliefs. Moreover, the consistency of parents' beliefs was also related, in a predictable fashion, to the frequency of children's origins beliefs (see Table 6): a positive relation with children's creationist beliefs and a negative relation with children's evolutionist beliefs. The previous analyses have already established the existence of interactions between children's age and origins beliefs. Therefore, to assess whether the cited relationships operated independently of age, regression analyses were carried out separately within each age group. Considered, in order, are the frequencies of child creationist beliefs, evolutionary beliefs, and spontaneous generationist beliefs.

The joint effects of the consistency of parent beliefs (evolutionist-to-creationist), fossil expertise, and dynamic adaptation were regressed on the frequency of child creationist beliefs for each age group. No significant relationship was obtained for the young and middle age groups. For the old age group (see Table 7 for the pattern of intercorrelations), $R^2 = .61$ ($R = .78$); $F(3, 25) = 11.6$, $p < .0001$ (Adjusted $R^2 = .56$). Significant standardized regression coefficients were found for the consistency of parent beliefs (evolutionist-to-creationist), $ß = .50$ ($p < .01$), and fossil expertise, $ß = -.36$ ($p < .05$). Overall, children's creationist beliefs were negatively related to their natural history knowledge, as measured by their fossil expertise and dynamic adaptation scores. Moreover, when fossil expertise was removed from the equation, the independent contribution of parents' beliefs increased, $\beta = .66$ ($p < .001$), suggesting that fossil expertise suppressed the positive relationship between the consistency of parents' creationist beliefs and children's creationist beliefs.

The same variables then were regressed on the frequency of child evolutionist beliefs, separately for each age group. No significant relationship was obtained for the young and middle age groups (of course, evolutionary explanations were rarely expressed by those age groups). For the old age group (see Table 7), $R^2 = .55$ ($R = .74$); $F(3, 25) = 9.1$, $p < .001$ (Adjusted $R^2 = .49$). Significant standardized regression coefficients were found for the consistency of parent beliefs (evolutionist-to-creationist), $\beta = -.46$ ($p < .05$), and dynamic adaptation, $\beta = .38$ ($p < .05$). When parent beliefs were removed as a variable, both dynamic adaptation, $\beta = .39$ ($p < .05$), and fossil expertise, $\beta = .35$ ($p < .05$), contributed independently to the equation (see also the intercorrelations in Table 7). The most plausible explanation for these findings is that the relationship between the consistency of parents' evolutionist beliefs and the expression of child evolutionist beliefs is mediated, in part, by a home environment that fosters or, at least, sanctions children's interest in and knowledge of the evidence for evolution, such as fossils (see also Evans, 1999).

Finally, the same variables were regressed on the frequency of child spontaneous generationist beliefs, separately for each age group. No significant relationships were obtained. Theoretically interesting, however, is an independent negative effect for dynamic adaptation, $\beta = -.39$ ($p < .06$), in the oldest age group (see also the intercorrelations in Table 7).

Summary. In the oldest age group, natural history knowledge and the consistency of parent beliefs were independently related to the frequency of child evolutionary and creationist beliefs. In addition, the two measures of natural history knowledge, dynamic adaptation and fossil expertise, also were independently related to the frequency of child evolutionary and creationist beliefs. Among older children, those who were most likely to express creationist beliefs were children who had lower levels of natural history knowledge and who had parents with more consistent creationist beliefs. Conversely, the expression of evolutionist beliefs was more likely to occur among older children who had higher levels of natural history knowledge and who had parents who were more consistently evolutionist. Fully 60% of the variance in creationist beliefs and 55% of the variance in evolutionist beliefs were explained by a combination of these factors in preadolescents. Interestingly, the consistency of parents' beliefs appeared to be unrelated to the expression of beliefs about origins among the younger children.

GENERAL DISCUSSION

Questions about biological origins traditionally have elicited teleological arguments "that everything in nature . . . has a purpose, a predetermined goal" (Mayr, 1991, p. 67). Although present, these kinds of beliefs—in the form of creationism—did not predominate for the youngest elementary-school children in two studies. These children were the most likely of all age groups to explain biological origins in nonteleological terms as the spontaneous emergence of living kinds—spontaneous generationist. Regardless of parent beliefs, it was the 8- and 9-year-old schoolchildren who were the most likely to opt for exclusive creationism. Not until children were in the range of 10- to 12-year-olds was there a regular appeal to evolutionary explanations, although they were more likely to be couched in Lamarckian than Darwinian terms. In this age group, along with children's natural history knowledge, the consistency of parents' creationist and evolutionist beliefs was independently related to the frequency of child creationist and evolutionist beliefs. That this was true only of the oldest children and not the two younger age groups suggests an interactive process.

The communities sampled in these two studies differed on several characteristics. In the first study, participants were children drawn from a variety of schools in a university town. In the second study, participants were families drawn from schools in a variety of rural and suburban communities, where adults had, on average, fewer years of formal education. In the latter study, parents' beliefs resembled those of their oldest children, suggesting that by early adolescence children's beliefs have converged on the adult pattern of their community. All the children attended elementary schools that followed a similar, state-endorsed curriculum, one that does not sanction creationism. Evolutionary theory was not formally introduced until middle- or junior-high school. One difference between these communities was that preadolescents in the university community were much more likely to endorse evolutionist explanations than were preadolescents or their parents from the suburban/rural communities. However, the distribution of beliefs in the latter communities resembled those of the population-at-large, with creationist and evolutionist beliefs endorsed in similar proportions (Numbers, 1992). More interestingly, a detailed investigation of the distribution of these beliefs reveals that about two thirds of the participants were exclusively creationist or evolutionist, with the rest exhibiting mixed evolutionist and creationist beliefs.

The emergence of beliefs about the origins of species, I shall argue, reflects an interaction between cultural meaning systems and the development of inferential reasoning processes—a constructive interactionism (Wozniak & Fischer, 1993). The evidence generated by the present studies will be used to highlight some key elements of this position, and to suggest further research that should be done to flesh out the details. Although descriptive in nature, this survey of the beliefs of various age groups provides a firm basis for investigations of the reasons why individuals may vary in their understanding of the origins of species. The results indicate that these reasons may differ for the age groups represented in the two major shifts, from spontaneous generationist to creationist, and from exclusive creationism to evolutionist or creationist explanations.

The Emergence of Beliefs About the Origins of Species: Toward an Interactionist Model

Spontaneous generationist to creationist. The major focus in the present studies was on the coherence of the overall developmental pattern rather than on an analysis of individual performance. However, these beliefs were not acquired in an all-or-none fashion. At any one point, children were quite likely to entertain competing beliefs, a feature typical of developmental mechanisms (Siegler, 1996). Despite this competition, for each age group the particular explanation(s) described earlier predominates. It is noteworthy, though, that the youngest elementary-school children appeared to be the most variable in their responses. The majority of them produced mixed spontaneous generationist and creationist explanations, whereas the majority of children in the middle age group were exclusively creationist. Spontaneous generationist explanations seem very tenuous and unsatisfactory as explanations for species origins. Given the compelling nature of creationist explanations, the question also arises as to why the younger children were not exclusively creationist. Piaget (1929) would have explained this sequence in terms of the development of causal reasoning processes, with younger children unable to access causal explanations. From a naive theory perspective, however, young elementary-school children are not seen as precausal. Nonetheless, children's capacity to explain events is thought to be constrained by the inductive potential of their intuitive theories (e.g., Wellman & Gelman, 1997). In support of the latter approach, young elementary-school children did furnish explanations, but they were limited in scope.

The spontaneous generationist explanations given by young children offered some clues as to the nature of 5- to 7-year-olds' capacity to reason about origins. Their responses covered a range of plausible nonintentional mechanisms for species origins including biological mechanisms such as growth, metamorphosis, and birth (see the appendix). One important aspect of these beliefs is the implication that modern species always existed, albeit in some primitive form. Growth or birth explanations, for instance, imply that the organism emerges from an embryonic state, such as a seed, but leave unanswered the question of how the "seed" got there in the first place. Such ideas might arise from the commonsense observation that in spring or following a rainy season the earth appears to spontaneously yield new life forms. Five- to 7-year-old children appeared to respond to the origins questions by utilizing whatever ad hoc explanations they had at hand to describe how an organism became manifest, but these explanations failed to address the question of how the organism comes into existence. Supporting such an analysis are more recent studies in which children were asked about the origins and existence of artifacts as well as animals; 5- to 7-year-old children seemed to believe that such entities always existed (Evans & Gelman, 1999). Not until the middle elementary-school years do children appear to consistently grasp the existential nature of the origins question and reliably furnish a teleological explanation, in terms of creationism (Evans, 1999, 2000).

Creationist to evolutionist. Mayr's (1982) analysis suggested that the historical and individual accumulation of natural history knowledge provides the foundation for the emergence of evolutionary explanations. In the current studies, the frequency of evolutionary explanations was positively related to natural history knowledge, in particular of fossils, adaptation, and deep time; in the second study this relationship was found independently of the effect for age. Of course, the causal direction is not clear, but it can still be concluded that an evolutionary explanation, even the deceptively simple "humans come from apes," is embedded in a complex and specific knowledge structure and is not an isolated or ad hoc belief, as a nonconstructivist view might predict.

Moreover, if children's proposal that a new species arises from the transformation of an earlier species were an ad hoc belief, then they would have been unlikely to have any sense of how this transformation could have been accomplished. However, in both studies, children who expressed evolutionary beliefs were the most likely of all to propose variations on a Lamarckian theme, that the environment plays a causal role in bringing about biological change in species. Children in the first study responded to questions about the adaptation of the spiggle, a novel terrestrial species, to an altered environment—previously an island, it was now almost completely covered with water. A typical proposal was that spiggles would develop webbed feet from swimming and catching fish, and that their offspring would exhibit this attribute. These children were not appealing to rehearsed or repeated knowledge, instead they constructed coherent, novel (for them) but incorrect biological explanations. Apart from one child, participants did not propose anything approaching a Darwinian explanation: This girl, a 10-year-old female, exclusively evolutionist for all exemplars, stated "If there are spiggles that weren't streamlined, they wouldn't be well equipped for the life they lived so the streamlined, webbed, spiggles would live and—slowly—the stronger webbed ones would survive and eventually all would be like this."

In contrast, many of the nonevolutionist children, in particular those who frequently expressed creationist beliefs, mentioned volitional or teleo-intentional explanations, that is, animals change because they needed or wanted to (spiggles wanted to copy the fishes, and learned how to swim). Converging evidence for these findings is found in the second study, with a positive relationship between the endorsement of dynamic adaptation, a Lamarckian type of explanation, and the expression of evolutionist, but not creationist or spontaneous generationist, beliefs. These results provide further evidence that the expression of an evolutionary belief signals the presence of a generative natural history knowledge structure. However, the reason why such a structure appears to be a necessary concomitant of evolutionary beliefs is not obvious.

One possibility is that younger children are wedded to an essentialist belief that species are sacrosanct and cannot change (see Gelman, Coley, & Gottfried 1994; Keil, 1989). If this is the case, then it would take much more than mere exposure to evolutionary ideas to convince them otherwise. Essentialist beliefs are postulated to be an important causal crutch, providing an explanation for the apparent stability of living kinds even when surface appearances change, as between the seasons, or over an animal's lifetime (Atran, 1990; Mayr, 1982). A thorough understanding of fossils or of adaptation provides unequivocal evidence that animals can change and that the environment may play a role in this change. Such information would challenge children's strongly held beliefs in the inviolability of an animal's essential nature. It is this knowledge base, I argue, that largely explains the shift from creationism to evolutionism (Evans, 1999, 2000). Motivating this shift is a change in perspective from one in which species are regarded as timeless entities with a God-given essence, to one in which species have a definite historical location (Dennett, 1996; Mayr, 1982). It is not that essentialist beliefs are abandoned, for even modern-day biologists acknowledge DNA sequences that historically define a species. However, with the abandonment of creationism what is granted essential causal power appears to have been transformed or, at the very least, modified (Evans, 1999; Poling & Evans, 1999).

Is there more than one route to an evolutionary explanation? Perhaps. Recent work by Samarapungavan and Wiers (1997) appears to demonstrate that various kinds of spontaneous generationist explanations feature in 9- to 12-year-old Dutch children's conceptions of species origins, along with Lamarckian accounts. Furthermore, such explanations are embedded in coherent and distinctive knowledge structures. Some hints that this might be the case with a few of the older children in the current study is provided by the pattern of intercorrelations with spontaneous generationist frequency (Table 7), in particular the negative relation with dynamic adaptation. However, Samarapungavan and Wiers (1997) excluded children who provided inconsistent responses from their analyses and did not provide any details of the community response pattern, so it is difficult to compare the two studies. Moreover, in the current studies those knowledge structures are not explored in which spontaneous generationist or creationist beliefs might be embedded. Natural history knowledge, for example, is evaluated from the standpoint of modern evolutionary theory, not from that of a creationist belief system in which fossils would be seen as evidence of a Noachim flood rather than the age of the earth (Wise, 1998). Apart from their different goals, the most plausible explanation for differences between the current studies and that of Samarapungavan and Wiers (1997) is that there is more than one route to an evolutionary explanation, and the particular route taken is, in part, a function of the particular social context (Evans, 1999).

The current studies do provide some evidence for multiple routes to an evolutionary understanding. One possible route, outlined earlier, is that an evolutionary explanation emerges spontaneously from a generative natural history knowledge structure, one involving adaptation. Importantly, this relationship, between evolutionary explanation and dynamic adaptation, occurred independently of social context, as indicated by parental beliefs. Nonetheless, there was a relationship between the consistency of parent origins beliefs and the frequency of preadolescents' origins beliefs. This route is hypothesized to operate indirectly, by way of an understanding of the fossil evidence. Preadolescents who knew the most about fossils and who had evolutionist parents were more likely to be strongly evolutionist themselves. Conversely, preadolescents who knew the least about fossils and whose parents were creationist were more likely to be strongly creationist. Moreover, preadolescents' fossil knowledge appeared to block the overwhelming effect of parents' creationist beliefs on preadolescents' expression of creationism. These findings indicate that the effect of cultural beliefs should play a role in any discussion of children's naive biology (see Hatano & Inagaki, 1996), and that religious beliefs might be an important and underresearched factor in the expression of a folk biology among U.S. populations (see Evans, 1999, 2000; Jackson, Doster, Meadows, & Wood, 1995).

CONCLUSION

Stable forms of explanation concerning the origins of species appeared to emerge from the interaction between changes in the inductive potential of children's intuitive theories, and the presence of culturally derived beliefs about origins, represented, in this case, by parents' beliefs. Many questions remain to be answered, but the basic framework involving both cognitive and contextual factors has been validated in separate studies with different populations. A focus at the macrolevel (Thelen & Smith, 1994) apparently reveals age-related shifts in the kind of explanations midwestern U.S. children give for the origins of species, from mixed creationist and spontaneous generationist explanations, to an exclusive creationism, and finally to consistent evolutionist or creationist explanations.

Why was there an apparent shift in beliefs with age? The findings support several plausible explanations. At the microlevel there was a considerable variability in response pattern (Siegler, 1996), especially among the youngest children. These children produced a variety of proximate-cause arguments, such as growth or birth, whose form suggested a difficulty with the core existential question, the concept of existence versus nonexistence. The world of the 5- to 7-year-old appears to be one in which organisms always existed. The necessity for the final-cause or teleological solutions of a creationist argument becomes apparent, I conjecture, only when children confront the existential question; that is, when they realize that species did not always exist. This insight seems to occur sometime during the middle elementary-school years (see also Evans & Gelman, 1999). The subsequent shift from an exclusive creationism to an evolutionist belief is apparently accomplished only by those children who are prepared to relinquish their essentialist understanding that species are timeless God-given entities. Knowledge of adaptation or of fossils, which places species in a historical time frame, provides the kind of evidence that might foster this shift. Moreover, a family environment in which such knowledge is sanctioned also is associated with the expression of evolutionist beliefs in preadolescents. Such an environment does not appear to promote evolutionary beliefs in younger children, perhaps because they are not yet ready to acknowledge the existential question or relinquish their essentialist beliefs in the stability of species.

The pattern of relationships derived from these measures is internally consistent as well as theoretically provoking, and as such it provides a rich basis for further studies of the emergence of children's beliefs about origins. Clearly, there is a need not only for a more detailed study of the social context, such as that provided by religious schools and parents, but also a more systematic investigation of children's intuitive beliefs about origins, at both the micro- and macrolevels. Questions about the origins of human-made, or artifactual entities, as well as natural inanimate entities, for example, would provide an apt contrast (Evans, 1999; Evans & Gelman, 1999). Probing children's understanding of the relationship between death and origins should provide additional insights into children's ability to confront the existential question (Evans, Poling, & Mull, 1999). Besides their theoretical value, such studies have the potential of providing the basis for developmentally appropriate school curricula, which, given the demonstrated difficulties educators have in conveying Darwinian evolutionary arguments to students (see Good, 1992), should be a matter of some urgency.

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Appendix

Sample Responses: Children's Origins Explanations (Age in Years)

Spontaneous Generationist

Spiggle: "Just appeared" (5.8); "Born in the land and crawled out" (7.7)
Dinosaur: "Grew on earth from eggs, like a bird" (7.2)
Human: "Cavemen . . . they were down here, born in a cave" (7.7)

Creationist

Spiggle: "Maybe God put them there" (12.8)
Dinosaur: "Put here, dinosaurs—cavemen did it" (9.0); "God made the dinosaurs, maybe triceratops" (9.1)
Human: "Mother nature made them, put dinos, women, men . . . on earth" (8.2); "God made them" (9.1)

Evolutionist

Spiggle: "Slowly follow the path of evolution, fish-lizard evolve" (12.8) [mixed evolutionist/hybridizationist], "They could start as an insect, they could have evolved from insects, larger insects, bigger bones, mated with something else got hair, part hair part pigskin" (11.7)
Dinosaur: "Dinosaurs did evolve from water creature" (10.0); "Started out as a fish, walked up on land on fins, [became] a lizard, much bigger in size" (11.7)
Human: "Gorillas are people's ancestors" (10.8); "People evolved from mammals, which evolved from dinosaurs" (11.6) [mixed evolutionist/creationist response], "Some people, and also I think so, say they got here from gorillas and monkeys, cause they're intelligent creatures if you really look at them, if you watch their face and actions man could look like monkeys so men came from them. The first monkeys probably evolved from something else or got put here as an individual or changed into man. God could have put them [the monkeys] here" (10.8)

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