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A Conceptual Guide to Natural History Museum Visitors' Understanding of Evolution

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Abstract

Museum visitors are an ideal population for assessing the persistence of the conceptual barriers that make it difficult to grasp Darwinian evolutionary theory. In comparison with other members of the public, they are more likely to be interested in natural history, have higher education levels, and be exposed to the relevant content. If museum visitors do not grasp evolutionary principles, it seems

unlikely that other members of the general public would do so. In the current study, 32 systematically selected visitors to three Midwest museums of natural history provided detailed open-ended explanations of biological change in seven diverse organisms. They were not told that these were evolutionary problems. Responses were coded as: *informed naturalistic* reasoning, featuring some understanding of key evolutionary concepts, *novice naturalistic* reasoning, featuring intuitive explanations that are also present in childhood, and *creationist* reasoning, featuring supernatural explanations. All visitors were mixed reasoners, using one or more of these patterns in different permutations across the seven organisms: 72% used a combination of informed naturalistic reasoning and novice naturalistic reasoning, while a further 28% added creationist reasoning to this mix. Correlational analyses indicated that for many visitors these reasoning patterns were coherent rather than fragmented. The theoretical model presented in this article contributes to an analysis of the developmental and cultural factors associated with these patterns. This could help educators working in diverse educational settings understand how to move visitors and students toward more *informed* reasoning patterns.

Keywords: evolution, museums, conceptual change, intuitive beliefs, creationist beliefs, cognitive development, culture

An understanding of evolution and of the importance of evolution research is central to scientific literacy today. Without this foundation, members of the public are unlikely to grasp many of the health and environmental issues of our time (e.g., Nesse &Williams, 1996). Furthermore, modern theories of evolution provide the basic principles for understanding a broad array of topics from biology to medicine, psychology, and climate change. Yet, surveys and more focused studies indicate that about 50% of Americans are unlikely to accept, let alone understand, the evolutionary principles of descent with modification and natural selection, as evidenced by their belief that humans originated through supernatural agency (Almquist & Cronin, 1988; Gallup, 2007; Numbers, 1992, 2003). Among industrialized nations, the U.S. ranks second to last in acceptance of evolution (Miller, Scott, & Okomoto, 2006).

Even among those who endorse evolution, misunderstandings occur (e.g., Sinatra, Southerland, McConaughy, & Demastes, 2003; Smith & Siegel, 2004); numerous studies demonstrate that students who apparently accept the idea of evolutionary origins routinely misunderstand natural selection, construing evolutionary change in pre-Darwinian terms, instead (e.g., Evans, 2000, 2001; Banet & Ayuso, 2003; Bishop & Anderson, 1990; Brumby, 1984; Clough & Wood-Robinson, 1985a,b; Dagher & BouJaoude, 1997; Good, 1992; Lawson & Worsnop, 1992; Nehm & Reilly, 2007; Shtulman, 2006). Such findings suggest a substantive failure on the part of public education to provide an adequate foundation for comprehending evolutionary theory. Some of this failure can be traced to widely publicized anti-evolution movements (e.g., Scott & Matzke, 2007), whose persistent efforts have resulted in state standards that de-emphasize the role of evolution in science (Beardsley, 2004; Lerner, 2000) and teachers who feel anxious about including evolution in the curriculum (Griffith & Brem, 2004).

Although much of the difficulty accepting evolution is frequently related to deeply held religious beliefs (Mazur, 2005; Numbers 1992), we take a somewhat different approach in

this article. We argue that such widespread problems in both acceptance and understanding stem not only from these cultural influences but also from the intuitive reasoning processes that constrain children's grasp of biological phenomena (Bloom & Weisberg, 2007; Evans, 2000, 2001). Thus, a central purpose of this study is to investigate whether intuitive beliefs that appear early in childhood persist in adult populations, impeding adults' grasp of evolution (Evans, 2001, 2008). More specifically, we examine (1) patterns of explanation: in particular, the extent to which adults use intuitive reasoning alone or with evolutionary or creationist reasoning and (2) the coherence of such reasoning patterns. A clearer understanding of the nature of these intuitive reasoning processes and the role they play in adult reasoning should provide a better foundation for more effective interventions in diverse educational settings. The studies reported in this article build on the considerable body of research, cited earlier, demonstrating that students of all ages misconstrue evolution. It extends this research by providing and testing a developmental and cultural framework for understanding the origin and persistence of these ideas.

Our focus here is on museum visitors because they provide an ideal population for assessing the persistence of intuitive reasoning patterns that limit an understanding of Darwinian evolution. According to the National Science Board (2008), 60% of adults have visited an informal science setting, such as a natural history or science museum, in the previous year. Museum visitors are more highly educated than the population at large (Korn, 1995) and are less likely to endorse creationist ideas (Spiegel, Evans, Gram, & Diamond, 2006). Most importantly, they are interested enough in natural history to voluntarily visit such museums; thus, any misunderstandings on their part are not likely to be attributed to a mere lack of exposure to the relevant content. As research institutions, natural history museums house the evidence that helps scientists describe the world's biodiversity and understand the evolution of life. Sharing that perspective with a public audience is the mission of most natural history museums and drives their exhibits on evolution (Diamond & Scotchmoor, 2006). If museum visitors do not grasp evolutionary principles, it seems unlikely that other members of the general public would do so.

The only systematic study of visitors' understanding of evolution (Macfadden et al., 2007) to date, indicates that U.S. museum visitors do have difficulties, but that study focused on a single problem, microevolutionary change in cheetahs (Bishop & Anderson, 1990), with a limited analysis of visitors' concepts. In the current study, we profile visitors' reasoning about the evolution of seven organisms that were to be featured in *Explore Evolution*, an NSF-funded exhibition developed to make evolution accessible to young people and the public (Diamond & Evans, 2007; Diamond, Spiegel, Meier, & Disbrow, 2004). The focus of the exhibition was seven contemporary research projects that have made major contributions to a scientific understanding of evolution. These included studies of HIV evolution, the emergence of a new diatom species, fungus-growing ants and their coevolving partners, sexual selection among Hawaiian flies, variation in the Galapagos finches, the genetic ties between humans and chimps, and fossilized walking whales. These research projects were selected because they illustrate a common set of evolutionary principles in organisms ranging from the microscopic to the largest of all mammals. In addition, these projects include examples of small-scale and large-scale evolutionary change, representing both micro- and macro-evolutionary processes.

In the current study, we assessed the utility of a particular theoretical framework for understanding museum visitors' reasoning about the evolution of this broad range of organisms. We first provide an overview and later use it to articulate a focused set of research questions.

Theoretical Framework: An Overview

Central to the current framework are three major sources of ideas about biological change (see fig. 1; Evans, 2005). *Intuitive* or commonsense reasoning comprises the everyday explanations that most easily come to mind when humans solve problems (see Evans, 2008). Countering these intuitive biases, the *scientific* and *religious* communities provide the two primary cultural sources of information about evolution, communicated through schools, museums, churches, and the media. In the case of religion, the most influential U.S. source is Biblical literalism whose adherents believe that God created each species individually a few thousand years ago (Numbers, 1992). According to a 2007 Gallup Poll, about 46% of the U.S. public agree that God created humans in this way. This same poll indicated that another 36% accept some variation of theistic evolution, believing that biological evolution occurred over millions of years, with God guiding the process. Only 13% agree that God played no role in biological evolution. This pattern of agreement is virtually unchanged over the past 20 years.

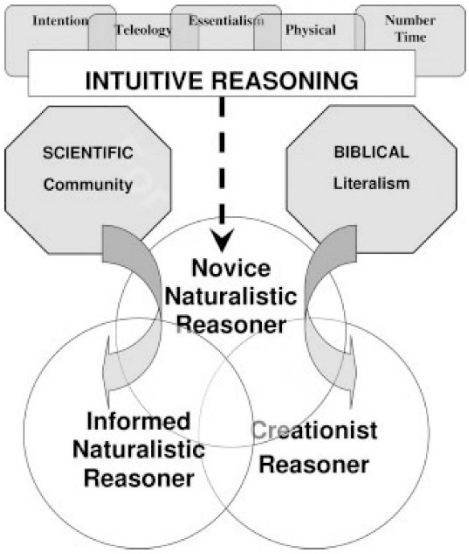

Figure 1. Reasoning about evolution—three major influences: intuitive reasoning, the scientific community, and the religious community.

The commonsense or everyday reasoning of the visitor, however, remains as the more pervasive source of influence. From studies in cognitive science and cognitive anthropol-

ogy, several intuitive reasoning modes (see fig. 1) have been identified that are hypothesized to underlie human reasoning about the biological world, including an everyday or intuitive biology and an intuitive psychology (e.g., Atran, 1990; Carey, 1985; Gelman, 2003; Inagaki & Hatano, 2002; Keil, 1994; Medin & Atran, 2004; Wellman & Gelman, 1998). These reasoning modes appear early in childhood and are associated with distinct cognitive biases that appear to make evolutionary ideas counterintuitive (Evans, 2000, 2001, 2008). The relevant biases are that living things are separate, stable, and unchanging, with an underlying causal nature or essence (*essentialism*) and that animate behavior is goal directed (*teleology*) and intentional (*theory of mind*). From an evolutionary perspective, the biological world is neither stable nor purposeful.

In the current study, we define *novice naturalistic reasoning* as the use of intuitive modes of reasoning. The communities of science and religion build on this intuitive base, resulting in *informed naturalistic reasoning* or *creationist reasoning*, respectively (see fig. 1; Evans, 2005). We apply the term informed naturalistic reasoning to reasoning patterns that are intermediate between those found in novices and in scientific experts. Visitors' spontaneous evocation of one or more of the VIST (*variation*, *inheritance*, *selection*, and *time*) evolutionary concepts is central to the informed reasoning pattern. The acronym VIST from the University of California Museum of Paleontology website (http://evolution.berkeley.edu) provided cognitive organizers for framing and remembering core evolutionary concepts in the exhibition. While *novice* naturalistic reasoners' intuitive explanations are incorrect from a scientific standpoint, they are the precursors of the methodological naturalism of science. Both novice and informed naturalistic reasoners evoke natural causes (naturalism) and thus differ from creationist reasoners who evoke supernatural causes. This crucial distinction between natural and supernatural causation was invoked by Judge John Jones III in the Dover Trial, to explain his rejection of claims that ID (intelligent design) theory is scientific (Mervis, 2006).

Intuitive or Alternative Conceptions?

Although their origins differ, the proposed theoretical framework maps on to a venerable tradition in science education research of *alternative conceptions* that pose barriers to science understanding (for a summary, see Wandersee, Mintzes, & Novak, 1994). While the alternative conception framework is rooted in Piagetian traditions, the current framework has its roots in contemporary post-Piagetian theories of domain-specific conceptual change (e.g., Carey, 1985; Wellman & Gelman, 1998) as well as anthropological studies of *folk* biologies (e.g., Atran, 1990; Medin & Atran, 2004). Thus, the term "intuitive theories," used throughout this article, references framework theories, the building blocks of children's and adults' everyday understanding of the world. Because they play a foundational role in conceptual development, in general we prefer to use the phrase *intuitive* conceptions rather than *alternative* conceptions. The latter will be used judiciously to refer to scientifically incorrect ideas that are meaningful in everyday reasoning (Wandersee et al., 1994).

What Is Novice Naturalistic Reasoning?

One of the main issues addressed in this study is whether visitors' novice naturalistic reasoning is based, in part, on themes apparent in children's intuitive theories of the biological

and psychological worlds. These themes appear in the alternative conceptions research on students' understanding of evolution mentioned earlier. Although disagreements remain, the current consensus is that young elementary school children reason biologically rather than exclusively psychologically, albeit using a somewhat different framework than that used by adults (Carey, 1985; Inagaki & Hatano, 2002). One lingering question is the extent to which children construe goal-directed action as intentional. Kelemen (1999, 2004) claims, for example, the young children are promiscuously teleological, ascribing purpose or function to natural phenomena, a capacity that is tied to their intuitive psychology.

We agree that some form of teleological reasoning is foundational, and that it is often associated with intentional reasoning. However, based on research with infants (e.g., Gergely & Csibra, 2003; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Woodward, 2009), we argue that this is not necessarily the case. Further, we argue that in order to understand the nature of the precursors to evolutionary thinking, it is advantageous to parse these conceptual systems. School-aged children distinguish between functional explanations that satisfy physiological needs, and mental state explanations that satisfy desires, even if they often default to the latter. Six- to seven-year-olds, for example, reason that animals and humans breathe because they *need to*, not because they *want to* (Poling & Evans, 2002). In this analysis, the concept of goal-directedness undergirds both an intuitive psychology and an intuitive biology. It is the reason behind the action that distinguishes the two conceptual systems. Accordingly, we assess whether, when explaining biological change, visitors utilize goal-directed explanations that reference the basic survival needs of the organism or/and intentional explanations that reference mental states.

Pure or Mixed Reasoning Patterns?

An intriguing issue concerns the adoption of what would appear to be contradictory frameworks, with about a third of the U.S. public espousing both evolutionist and creationist ideas (Evans, 2000, 2001; Gallup, 2007). Many leaders in the theological and scientific communities reject one stance and adopt the other, yet there is a lively debate as to the ways in which individuals can combine these stances (e.g., Evans, 2008; Scott, 2004). One resolution is theistic evolution, which can be construed as a causal chain with God as first cause, initiating the process of evolution. In the lay public's reasoning, however, mixed models are more typical (Poling & Evans, 2004a). Typically, creationist explanations are more likely to be applied to humans than to other species (Evans, 2000, 2001; Sinatra et al., 2003), with (pre-Darwinian) need-based evolutionary explanations more likely to be applied to species that are taxonomically distant from humans (Evans, 2008). In synthetic blends (Evans, Legare, & Rosengren, in press; Vosniadou & Brewer, 1992), culturally available scientific or theological stances are fused with intuitive or novice explanations (the overlapping circles in fig. 1).

Thus, a key research question is to what extent do natural history museum visitors adopt pure or mixed models to describe evolutionary change. Further, if mixed models are prevalent, a related question concerns their coherence. One of the premises of the framework theory approach is that coherence is necessary; without this core characteristic such theories could not provide the foundation for children's everyday explanations (e.g., Carey, 1985; Wellman & Gelman, 1998). Yet, there is an intense debate regarding the nature

of novices' reasoning. Vosniadou and her colleagues argue that one of the main barriers to conceptual change in science education is the coherence of the underlying naive intuitive frameworks, which arise from ontological commitments that differ radically from those of scientific theories (Vosniadou, Vamvakoussi, & Skopeliti, 2008). An alternative position is that the novice's knowledge base in any domain consists of discrete unconnected elements and that coherence is achieved only as a function of science instruction (diSessa, 2008). In this study, we shall assess whether specific concepts or themes within visitors' reasoning patterns are correlated: If they are, then this would lend support to the coherence hypothesis; alternatively, the fragmentation argument (diSessa, Gillespie, & Esterly, 2004) would be supported if targeted themes are uncorrelated. One prediction, stemming from the above analyses of children's explanations, was that need-based reasoning would present a unique pattern of significant intercorrelations in adults.

Study Overview: Parts I and II

Visitors were recruited from three Midwest natural history museums where the *Explore Evolution* exhibition was to be installed. Importantly, because this study was carried out prior to the advance publicity or installation, study participants had no exposure to the exhibition content, nor were they told that it was about evolution. Thus, this study is unique in examining whether visitors would spontaneously apply evolutionary concepts, even when they were not cued to do so. Visitors were asked to explain seven problems (see table 1), each of which focused on one of the organisms central to the work of each of the scientists featured in the exhibition. Although each problem appeared to be different, they could all be answered using the same evolutionary principles. (In pilot work, an expert remarked that he would respond similarly to each question.)

Table 1. The seven evolutionary problems presented to museum visitors

VIRUS: I'm going to tell you about a person who has the virus called HIV. You may know that this virus causes the disease called AIDS. Here is a picture of the HIV virus greatly enlarged (*give illustration to subject*). This virus is in a child called George. Now scientists can read the genetic material of a virus to tell what kind it is. When the scientists first looked at George's virus, he had three varieties of HIV, each slightly different. Later, when the scientists went back to check on George's viruses again, there were now 5 types of HIV. Describe how you think George came to have the new kinds of HIV viruses.
DIATOM: Yellowstone Lake is in the middle of Yellowstone National Park (*show map*). There are many types of algae in this lake. However, scientists have found a kind of algae in this lake that is not found anywhere else (*show diatom photo*). These algae first appeared about 14,000 years ago. At that time, the climate was warming. Describe how you think this new kind of algae came to be in Yellowstone Lake.
ANT/FUNGUS: Scientists have learned about a kind of ant that looks after a special type of fungus in "ant farms" (*show picture*). The ants eat the fungus and this type of ant and the fungus have had this relationship for millions of years. However, there is another type of fungus that attacks the farms. But, the ant carries around bacteria that protect the farms from the attacking fungus. These four organisms have been living together for many millions of years. Describe how you think this partnership came about.
FRUIT FLIES: There were once no fruit flies on Hawaii (*show map*). Then, about 8 million years ago, a few fruit flies landed on one of the islands. Now there are 800 different kinds of fruit flies in Hawaii (*show photos of flies*). How would you explain this?

FINCHES: The Galapagos Islands are located off the coast of South America (*show map of chain*). On one of these islands, scientists have been studying one kind of finch. Here is a picture of this finch (*photo has more than one ground finch*). The scientists measure the size of the finch's beak (*show picture*). On their first trip to the island, the scientists found that most of the beaks of this finch were on the small side. Then a severe drought occurred on the island, and it wiped out most of the plants that make the small seeds that the finches feed on. The only seeds that were common were really tough seeds that require a large beak to open. Then the scientists came back a few years later and measured the beaks again. This time, they found that most of the beaks were on the large side. How would you explain that on their return trip to the island, larger beaks were found on more of the finches?

HUMAN/CHIMP: Here is a picture of a human being and a picture of a chimpanzee (*show photographs*). Scientists think that humans and chimps shared a common ancestor as recently as 5 million years ago. Describe how you think that both a chimp and a human could arise from the same kind of ancestor.

WHALE/HIPPO: Here is a picture of a new kind of whale that was found in the desert in the Middle East (*show cover of* Science). Scientists believe that this whale shares a common ancestor with hippos (*show photo of hippo*). Describe how you think that both a whale and a hippo could arise from the same kind of ancestor.

In line with the above theoretical perspective, visitors' explanations were coded into three reasoning patterns: novice naturalistic, informed naturalistic, and creationist. Visitors could evoke a particular theme from any one of these patterns up to seven times (once for each of the seven organisms), giving us sufficient data to assess the intercorrelations between particular themes. Such a coding system required both top-down and bottom-up coding methods. The former corresponds to the nomothetic approach (Wandersee et al., 1994), in which visitors' explanations were compared with the scientific model, and the latter to idiographic approaches in which meaningful themes emerged during the coding process; coding was still constrained, however, by the conceptual framework. Data analyses are reported in two parts, with Part I focused on the nature of visitors' reasoning patterns, to what extent they are pure or mixed, and Part II, on their coherence. The latter was addressed by examining correlations between targeted themes from the reasoning patterns. This two-part examination of the data allowed us to obtain detailed knowledge of visitors' reasoning patterns, using a qualitative analysis, and to derive inferences regarding their coherence, using a quantitative analysis (Miles & Huberman 1994).

Research Predictions

Based on prior research and our theoretical model, described earlier, one key research prediction was that few museum visitors would endorse any one reasoning pattern exclusively across all seven organisms; in fact, mixed patterns seemed likely to prevail (see the overlapping circles in fig. 1). Further, based on developmental research and theory, we also predicted that even if visitors endorsed mixed models, the pattern of intercorrelations between themes would be demonstrably coherent.

For Part I analyses, specific research questions derived from the overall prediction that mixed reasoning patterns would predominate, were: (1) When reasoning about evolutionary problems, would museum visitors spontaneously evoke evolutionary concepts across all organisms? (2) To what extent would visitors use creationist and novice reasoning, as well? (3) Would the intuitive ideas evident in previous research on children's and students' reasoning about evolutionary problems be evident in museum visitors' novice naturalistic

reasoning? Based on findings from earlier research (see Evans, 2008 for a summary), we predicted that themes from the novice reasoning pattern were more likely to be elicited by microscopic or invertebrate organisms and that to the extent that creationism would be apparent in this sample of museum visitors, the human seemed the most likely to elicit this reasoning pattern (Spiegel et al., 2006). Part II analyses address the coherence of the relationships between themes from the reasoning patterns. Specific hypotheses regarding the intercorrelated themes are presented in Part II.

Method: Parts I and II

Participants

Thirty-two systematically selected museum visitors (38% male, 62% female; 97% non-Hispanic white, 3%multiracial) from three Midwest universities' natural history museums were asked to take part in a 25- to 30-minute audiotaped interview with trained interviewers.

Demographics

At the conclusion of the interview, each visitor completed a demographic form. All the results were compiled and averaged across the three sites. Visitors' age groups were: 18–24 years (10%), 25–65 years (84%), and 65+ years (6%). Educational levels completed by the visitors consisted of: High School (19%); 2-Year College or Vocational School (22%); 4-Year College (38%); Graduate School (22%). Overall, the visitors' education levels were similar to those found at other natural history museums and science centers with about 60% having completed a 4-year college or higher levels of education (Korn, 1995). Only one participant, who taught earth science, had a biology-related profession; the other occupations were science or engineering ($n = 4$), other professional ($n = 13$), artistic ($n = 3$), homemakers ($n = 4$), service and retail ($n = 5$), and retired ($n = 2$). Fifty-eight percent had a religious affiliation (42% did not). The average number of museum visits per year was 5.2 (*SD* 5.9; Range: 0–25).

Procedure and Protocol

As visitors entered the museum, every other museum visitor was approached (for groups, one adult was selected) and given a brief overview of the purpose of the research, and then asked to participate in the study (participation rate was 55%). Visitors were told that their feedback would be used to provide information about a new exhibition and that they would be asked to explain "some new scientific discoveries about a variety of living things." They were not told that these were evolutionary problems, nor was the term evolution used. After visitors agreed to take part they were informed of their rights as study participants (as specified by IRB approvals from all three institutions) and specifically asked for permission to record the interviews, which were anonymous. At the conclusion they were presented with a token gift for their participation.

Interview Protocol

First, visitors were told, "I would like to ask you a few questions about current research on how living things have changed over time. I want to know what you think about some new scientific discoveries about a variety of living things." Each visitor was then asked to explain the seven evolutionary problems. These problems were based on the core questions addressed in each of the exhibits. Although each problem could be solved by applying the same evolutionary principles, each question was worded differently because the kind of biological change portrayed differed by organism. None of them mentioned the word evolution. The seven questions, accompanied by relevant photographs, were presented to the museum visitor in the following fixed order: Flies, Finches, Diatom, HIV Virus, Ant/Fungus, Whale/Hippo, Human/Chimp. For conceptual ease, however, in this article the questions and data will be presented in order of size, from the smallest to the largest organism (see table 1). From a religious viewpoint, the human/chimp comparison was perceived to be the most problematic, so it was presented last to avoid influencing visitors' responses to other questions. If interviewees gave an extremely brief response, or said they didn't know, they were asked: "Can you tell me more" or "Can you take a guess at what you think might have happened."

In a pilot study, we found that a majority of a representative sample of 60 natural history museum visitors interpreted the VIST terms as biological concepts (e.g., defining inheritance as the transmission of genes rather than artifacts). This finding indicated that our expectation that visitors in the current study might use the VIST framework was realistic. In addition, we assessed visitors' familiarity with and interest in the organisms to be featured in the current study, which provided background information that was used to interpret the results of the study.

Visitors' responses were transcribed and coded into the three main reasoning patterns. The overall coding system development is described first, followed by a description of the coding systems for each of the reasoning patterns, in turn. For each reasoning pattern, we provide a more detailed theoretical rationale before describing the themes.

Coding System

Coding System Development

The development of the coding scheme was carried out by a team made up of science educators and cognitive developmentalists; three with biology backgrounds, and three with extensive experience in content analyses of explanations. The team conducted a content analysis of the transcriptions of visitors' responses and identified those units of analysis (utterances) that expressed concepts related to the question. These *conceptual units* ranged in size from single words (e.g., the term "evolution") to several speech fragments that expressed a particular concept. Based on our theoretical framework, an a priori codebook was created and used to carry out a preliminary mapping of the conceptual units onto distinct themes (codes), which, in turn, mapped onto the three main reasoning patterns. Conceptual units that did not map onto any of the themes were initially coded as other.

Further content analyses of the *other* category revealed additional themes and the codebook was updated to include these emergent themes. All the themes were operationally defined (Miles & Huberman, 1994).

In the final round of coding, two trained coders coded each response. To ensure that they were not influenced by a visitor's overall responses, coders coded all visitors' responses to one question but did not view the entire transcript of any one visitor. Initial interrater reliability ranged from 86% to 100% for any one question. Subsequently, all responses were coded to 100% agreement with the entire team's agreement. The codebook was divided into three sections: Informed naturalistic reasoning (table 2), novice naturalistic reasoning (table 3), and creationist reasoning (table 4). Operational definitions of each theme, along with brief examples, are given in these tables and in the text, and the prevalence of each theme along with detailed examples of visitors' explanations are given in the Results section.

Informed Naturalistic Reasoning (INR)

Conceptual Framework

One crucial issue was whether visitors would spontaneously realize that these were evolutionary problems. Their mention of an evolutionary term was one sign of this realization and this was coded as an *informed naturalistic reasoning theme* (see table 2). Ideally, evolutionary reasoners should be able to reason about the biological mechanism underlying a biological phenomenon *How does it work?* and link it to the more distal or evolutionary cause: *Why does it work that way?* (Mayr, 1982, pp. 67–68). Citing only a proximate biological mechanism does not address the evolutionary cause. Given previous research, it seemed unlikely that even the more expert visitors would access a fully developed evolutionary framework. On the other hand, an informed naturalistic reasoner might well exhibit some understanding of the VIST concepts and the related concept of common descent. Common descent was coded separately from selection and time because earlier research indicated that while children and adults (or pre-Darwinian evolutionists) might accept the idea of descent with modification, this does not mean that they understand the Darwinian mechanism of natural selection (Evans, 2001, 2008). The nomothetic approach prevailed in the coding of the informed reasoning pattern, with textbooks on evolution (e.g., Futuyma, 1998) providing the scientific model. Some modification of the major themes occurred during coding development.

Table 2. Informed naturalistic reasoning pattern: themes, definitions, and examples

Theme	Operational Definition	Examples
Evolution term	Mention of main evolution term	"Evolution," "Darwin(ian)," "Survival of the fittest"
Variation	Differences among individuals in a population	"There were finches with larger beaks and some with smaller beaks"
Inheritance	Traits (genes) are inherited and passed on to the next generation	"The big-beaked finches had babies that looked the same"

Common descent	Reference to a common ancestor or a descendent (implication that these were different "species")	"They could have been derived from the same early ancestor"
(Natural) Selection	Organisms with adaptive traits are more likely to survive	"The large-beaked finches were better able to eat the large seeds and they survived"
Time	Implication that there had to be enough time for natural selection to occur	"I supposed they just changed over time"
Chance	Any reference to happenstance, chance, or accident	". . . then this relationship accidentally happened"
Sexual selection	Any reference to sexual selection	No examples
Ecological pressure	Mention of ecological pressures as a causal agent in diversification or change	". . . adapt to the different ecological niches on the islands"

Codebook

Responses coded under the informed naturalistic reasoning pattern expressed a rudimentary understanding of evolution by invoking a Darwinian evolutionary term, one of the evolutionary subconcepts—*variation*, *inheritance*, *selection*, *time*—from the VIST framework or a related concept (see table 2). The VIST definitions that informed our coding were as follows: *Variation* referred to differences among individuals in a population, such as differences in traits (features, behaviors), a mutation, or genes. *Inheritance* referred to traits that are passed from one generation to the next. *Selection* referred to the idea that organisms with traits that are adaptive (in one environment) are more likely to survive (and pass these factors on to the next generation). *Time* referred to the idea that the number of generations produced over a given time period determines whether evolution change will occur rapidly (HIV) or slowly (whales).

To distinguish those responses that included evolutionary terms (e.g., "evolution") from those responses that referenced evolutionary concepts a separate code for the terms (evolution term) was created. Although we did not specifically code for an *expert* understanding of evolutionary theory, any visitor that consistently provided the VIST subconcepts for each problem would be considered an expert. The evolutionary subconcept *variation* was coded as a theme only if there was a reference to within-species variation. References to differential survival, coded as *selection*, and differential inheritance, coded as *inheritance*, were coded separately, as the content analysis indicated that visitors often referenced only one these concepts (both are required for a full understanding of natural selection). In the following example, variation and selection each appeared as two sentence fragments (1–2):

> FINCH EXAMPLE (INR) Visitor's Response: . . . the finches with the larger beaks survived [*selection-1*], I suppose—the ones who didn't have large beaks [*variation-1*] died out [*selection-2*]—and so they kept propagating and the beaks got larger and larger, which is good for them because they were able to get the tough seeds, and the ones with the small beaks lost out [*variation-2*]. . .

References to a common ancestor or descendent were coded as *common descent*, if it was clear that these were different species. Any mention of the significance of time for biological change over generations, was coded as *time*. *Sexual selection* was included as an a priori code, as it is the evolutionary mechanism that explains fruit-fly speciation. Random events or *chance* and *ecological pressure* also emerged as themes in visitors' responses.

Novice Naturalistic and Creationist Reasoning Patterns

Conceptual Framework

Although a more idiographic approach (Wandersee et al., 1994) prevailed in the coding of the novice naturalistic and creationist reasoning patterns, coding was guided by a conceptual framework (Miles & Huberman, 1994), but we were also sensitive to the emergence of previously unreported themes. First we describe the conceptual framework, and later we describe the themes in detail. For the *novice naturalistic reasoning pattern*, coding focused on the goal-directed and intentional explanatory concepts found in prior research, particularly in research with children. We argued earlier that there are important differences between these two conceptual systems; moreover, these differences become even more critical when we consider the *creationist reasoning pattern*. Coding of the latter included references to supernatural causes, ranging from explicit statements about God's creative powers to more implicit references to *belief*. However, as goal-directed and intentional concepts are also essential to the expression of creationist ideas, we review some theoretical distinctions between the two. Finally, we provide evidence for the early emergence of these ideas in young children.

Goal-directed reasoning is one of a family of teleological concepts that imply purpose, a progression toward an endpoint or goal (see Mayr, 1982, pp. 47–51). Psychologically, there is a key distinction to be made between internal/intrinsic and external/extrinsic teleological processes (for a philosophical equivalent, see Kampourakis & Zogza, 2007, p. 395). Properties of living kinds serve the intrinsic purpose, or needs, of the organism itself, whereas properties of artifacts serve the extrinsic purpose of a designer (Keil, 1994). The shape of the butterfly's wings, for example, helps the butterfly fly, whereas the shape of a cup makes it easier for humans to drink liquids—the shape confers no benefit on the cup itself, it just benefits the human designer.

A belief in God's creation of the natural world can be derived, analogically, from this kind of *artificialist* reasoning (Evans, 2000, 2001, 2008; Kelemen, 2004; Piaget, 1929): To the extent that a living kind is thought to be *designed*, then it is treated as if it were an artifact. Such explanations are embedded in a folk theory of intentionality. For it to become a creationist argument, it is necessary to incorporate a belief in a supernatural designer—God. This example is illustrative of a synthetic model, in which ideas derived from an intuitive psychology are fused with culturally available ideas about a supernatural being, a central planner. This fusion both reinforces and amplifies the impact of creationist beliefs (Evans, 2001). Accordingly, references to the purposes or desires of a supernatural designer were

coded under the creationist reasoning pattern. Whereas, naturalistic references to the intrinsic needs or desires of the organism itself were coded under the novice naturalistic reasoning pattern.

What Do Children Say?

Given the core question regarding the prevalence in adult reasoning of intuitive concepts found earlier in life, it is important to know what children say. When asked about the origins of "the very first Xs" (where X is an animal or a human), 5- to 7-year-olds from Christian fundamentalist communities simply stated that "God made it." Their nonfundamentalist counterparts often cited God, but they also stated that the animal "just appeared," or "came out of the ground" (Evans, 2000). It appears that children in this age group do not necessarily grasp that the organisms were previously nonexistent; they explain where the animal came from, the *proximate* cause, rather than how it came into existence, the more distal or ultimate cause (Evans, 2000; Southerland, Abrams, Cummins, & Anzelmo, 2001). In response to the same question, most 8- to 9-year-olds, regardless of community background, give creationist responses. By early adolescence, children's responses to this question reflected the beliefs of their community of origin. The "evolutionist" explanations of children from nonfundamentalist communities, however, were pre-Darwinian, referencing the intrinsic need of the organism to adapt. In addition to the effect of parent beliefs, unique variance in children's evolutionist ideas was explained by children's exposure to evidence that animals change, from fossils, to adaptive change, to metamorphosis (Evans, 2000, 2001, 2008). While this evidence of biological change appeared to challenge children's intuitive essentialist ideas that animal kinds are fixed in time and place, it also had the effect of reinforcing children's intuitions about intrinsic needs. In contrast, Christian fundamentalist children's intuitive essentialist ideas were reinforced by their community belief system: "it can't change, because God made it that way" (Evans, 2001). This interaction between community beliefs and children's intuitive concepts yields novel synthetic blends, reflecting the fusion of intuitive and cultural conceptions (Evans et al., in press).

Given this analysis, in our coding scheme if visitors explained biological change as satisfying the needs of the organism, this was coded as a goal-directed novice naturalistic theme. References to mental state explanations, such as thoughts and desires (e.g., "the ant tried to find the fungus"), that align with the conscious intentions of the organism, were coded as an intentional, novice naturalistic theme. On the other hand, if visitors referenced *God's purpose*, this was coded as a supernatural theme, which is intentional and teleological but not naturalistic.

Codebook: Novice Naturalistic Reasoning (NNR)

Responses coded as NNR used intuitive naturalistic modes of reasoning to explain the problems (see table 3). *Goal-directed* explanations that referenced the intrinsic needs or goals of the organisms were coded separately from *intentional* explanations that referenced mental states, skills, or a conscious effort to change. Both of these explanations referenced individual change, not population change. Distinct forms of *goal-directed* reasoning emerged in the coding process (Evans, 2005). In one theme, there was a clear analogy to

developmental change or growth toward an end-point; in the other theme, the organism changed its body or behavior in order to adjust to a novel environment (*need-based adaptation*). Another emergent theme, also found in children (Evans, 2000), was a simpler mode, in which the visitor merely noted the adaptive relationship between the organism and the environment but did not mention environmental change (*static adaptation*).

Table 3. Novice naturalistic reasoning pattern: themes, definitions, and examples

Theme	Operational Definition	Examples
Intentional	Use of mental states, skills, or conscious effort to explain change	". . . had to try and work harder, probably, to develop their beaks"
Essentialist	Category-based induction (referencing species stability)	"Humans and chimps are the same kind"
Static adaptation	References the organism-environment fit as the reason a particular organism might be found in a particular location	"Well, this area is generally colder and you find this type of algae in this type of location"
Adaptive feature list	Simply lists adaptive features of one or more organisms	". . . toes and webbed feet for the land, instead of fins, most whales have fins . . ."
Goal-directed "need-based adaptation"	The organism changes to meet a need or purpose, a functional or adaptive goal-directed behavior	"The first fungus needed to be protected from the second fungus so it developed a natural defense mechanism in the ant to stave it off"
Goal-directed "develops"	The organism develops toward an inbuilt goal [no mention of need]	"As they grow they develop into other types of HIV"
Proximate cause—agent	An agent brought the organism in from some place else	"Obviously, people brought the fruit flies in . . ."
Proximate cause—other	The organism was always there, but was not detected	"The new strains of HIV were there, scientists hadn't seen them"
Reproduction	Reference to reproduction or an increase in numbers, no clear reference to inherited features	"Then they multiplied when they got to Hawaii"
Hybridization	Two unrelated animals interbred	"Then the different kinds of flies bred and they had different offspring"

An emergent theme, *proximate cause*, defined simply as a cause that immediately precedes the effect, was also evident in visitors' transcripts. For example, accidental or intentional transmission by an animate agent was invoked to explain variation in the fly population (e.g., "people brought the flies"). In effect, these visitors did not address the "origins" question, in that they failed to recognize that an evolutionary cause was required; they responded as if the organism was always here. If the visitor denied that any change occurred, this was coded as *proximate cause–other*. This type of response has been noted in children, as described earlier (Evans, 2000, 2008; Southerland et al., 2001). As neither of

these proximate causes addressed Mayr's (1982, pp. 67–68) concerns with proximate biological mechanisms that relate to the "functions of an organism and its parts," they were coded as novice themes.

Several other emergent novice themes included references to the stability of species (*essentialist*), their reproductive capacity (*reproduction*), and *hybridization*. One very common response included repeated references to the adaptive features of organisms (rather than the whole organism), which was simply coded as an *adaptive features list*.

Codebook: Creationist Reasoning Pattern (CR)

Responses invoking a supernatural rather than a naturalistic cause, citing God or the creative process were coded as creationist reasoning (see table 4). As described earlier, this was an intentional and teleological mode of construal in which natural kinds were intentionally created to serve an extrinsic purpose: God's purpose. They were, in effect, treated as artifacts created by God. Typically, creationists who are Biblical literalists reject common descent and argue that God created each organism a few thousand years ago with a specific essence (essentialism) that is eternal and unchanging, or they reference intelligent design (Evans, 2001, 2008). In addition to these themes, several more emerged during coding development. Overall we attempted to differentiate between themes expressed by sophisticated creationists who explicitly rejected evolutionary principles, and those expressed more by more intuitive creationists who vaguely referenced their beliefs (see table 4 for details).

Table 4. Creationist reasoning pattern: themes, definitions, examples

Theme	Operational Definition	Examples
God's creation	God created each organism	". . . God was the creator and he designed and created every organism"
God's variation	God created the diversity seen in organisms	"God created the algae with the DNA to expand into different kinds"
God's adaptation	God made organisms so that they are adapted to fit in with their environment	"He created this almost symbiotic relationship between the ant and the fungus"
God's essence	God created each organism with a specific "essence" and it does not change	"I think they were created as they are with their own unique set of chromosomes"
Young earth creationists	Specifically rejects geological time and the age of the earth	"I don't think the world is more than 1,000 years old"
Rejects common descent	Rejects the idea of common ancestry or common descent	"Well, I wouldn't believe the ancestor theory"
Intelligent design	Refers to the design of organisms by a sentient entity, but no reference to God	No examples
Vague belief	Declaration of religious or biblical belief—not explicit	"I believe in a catastrophic flood" "I'm religious" "I am a Christian"

Scoring

In sum, each of the three reasoning pattern was made up of distinct themes, with the number of themes differing by pattern. Each visitor's response to a question about each of the seven organisms (32 × 7 = 224 responses) might reference a theme from one or more of the three reasoning patterns. For every response, each theme was coded as either present (1) or absent (0). Therefore, even if a visitor repeated the same theme in his or her response to the question on any one organism, it was coded as present once, only. Thus, for each visitor's response to each question, the potential range for a single theme was 0–1. However, one visitor could report the same theme (e.g., variation) seven times, once for each question/organism. If a visitor responded "Don't Know" this response was coded as zero for all themes for that particular question. Across all participants (and organisms), 601 non-repeating conceptual units were identified that mapped onto distinct themes; in addition, 31 conceptual units were coded as "other." The coding scheme successfully captured most (95%) of the conceptual content of the visitors' responses. In addition, four participants responded "don't know" to one of the questions and two more responded similarly to two of the other questions, resulting in eight "don't knows" (see table 5). For any one question/organism, the number of themes that any one visitor might potentially mention for the informed naturalistic reasoning pattern (INR) could range from 0 to 9, for the novice naturalistic reasoning pattern (NNR) the potential range was 0–10, and for the creationist reasoning pattern (INR) the potential range was 0–8 (see tables 2–4).

Table 5. Response patterns for the seven organisms: percentage of participants endorsing a particular pattern

Organism	INR Only (%)	NNR Only (%)	CR Only (%)	INR NNR (%)	INR NNR CR (%)	INR CR (%)	NNR CR (%)	Don't Know (%)
Virus	16	34	0	44	0	0	0	6
Diatom	19	38	0	28	3	0	3	9
Ant	9	34	3	44	0	6	0	3
Fly	9	47	6	38	0	0	0	0
Finch	19	13	0	66	0	3	0	0
Whale	22	19	0	47	0	6	0	6
Human	25	6	3	41	9	9	6	0
Average	17	27	2	44	2	3	1	3

INR, informed naturalistic reasoning; NNR, novice naturalistic reasoning; CR, creationist reasoning.

Results: Part I, What Is the Nature of Visitors' Reasoning Patterns?

The overall reasoning patterns are described first, followed by the most frequent themes that visitors use for each reasoning pattern, along with examples.

Overall Reasoning Patterns

Overall

None of the visitors employed any of the three main reasoning patterns exclusively across all seven questions/organisms. Mixed reasoning patterns predominated for individuals and for questions, as predicted (see fig. 1), with visitors using one pattern for one question and another for a different question, or even using a mixed pattern for a single question. Overall, the most common pattern for individual museum visitors was informed naturalistic/novice naturalistic reasoning (72%). A less common pattern was informed naturalistic/novice naturalistic/creationist reasoning (28%). While all of the visitors used mixed patterns of reasoning, most of them exhibited a dominant reasoning mode, which they used most frequently. Using this metric, 34% could be classified as consistent informed naturalistic reasoners, 53% as consistent novice naturalistic reasoners, and 6% as creationist reasoners (6% were equally novice and informed naturalistic reasoners).

Reasoning Patterns by Organism

Even if visitors changed their reasoning pattern from one question to the next, they could still apply one pattern exclusively to each question/organism. In table 5, the percentage of participants using a particular pattern for each organism is shown. The predominant profile is still a mixed novice/informed naturalistic reasoning pattern with 44% of participants using it on average, ranging from 28% for the diatom to 66% for the finch. Yet, as seen in this table, participants often employed a single reasoning pattern for a particular organism. Again, novice naturalistic reasoning predominates, with 27% of participants, on average, using this reasoning pattern exclusively, ranging from 6% for the human to 47% for the fly. The virus, diatom, ant, and fly were the most likely to elicit this pattern. The informed naturalistic reasoning pattern was used exclusively by 17% of the participants, on average, across the seven questions. The human (25%) was the most likely to elicit this pattern and the ant (9%) and fly (9%) least likely to do so. Creationist reasoning was most often used for the human, usually in combination with the other patterns.

Another way of presenting this information, which maintains the focus on each organism, is to ask what percent of the participants endorse at least one theme from each of the three reasoning patterns, for each organism. The results are averaged across the 32 visitors for each organism and presented in a single figure, with the organisms arranged from the smallest to the largest. As can be seen in figure 2, the finch, human, and whale are most likely to elicit a theme from the informed naturalistic pattern (INR), while the other organisms are more likely to elicit novice naturalistic themes (NNR); the human is most likely to elicit a creationist theme (CR).

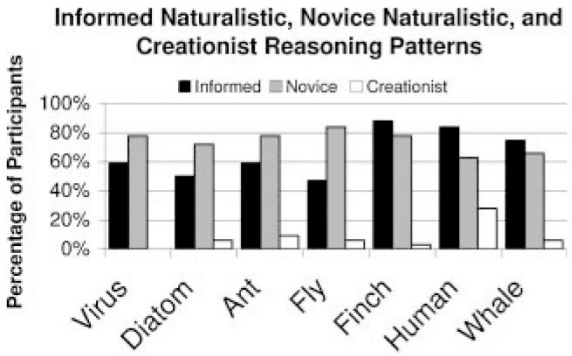

Figure 2. The percentage of participants endorsing at least one theme from each of the three reasoning patterns, for each organism.

This finding suggests a divide between single-celled/invertebrate and vertebrate animals. Taking into account the results from the pilot study, it appears that, regardless of familiarity or interest, invertebrate organisms elicit novice naturalistic reasoning and vertebrates more informed reasoning. In the pilot study, visitors' interest and biological knowledge cut across these groupings. The fly and the finch were the first two questions presented, therefore there does not appear to be an effect of presentation order. The wording of the questions differed from one organism to another, but not in a way that would clearly predict these findings. Additionally, as predicted, the human was most likely to elicit creationist reasoning.

Themes and Reasoning Patterns

So far our results have demonstrated that mixed reasoning patterns prevail. In this section, the focus is on a description of the themes most likely to be endorsed for each reasoning pattern. A list of the themes endorsed by 20% or more of the sample for the informed and novice naturalistic reasoning patterns can be seen in table 6. Given the comparative rarity of creationist responses, all creationist themes mentioned by 6% of the sample, or more, were included in the table. Summing across all seven organisms, the mean and standard deviation for the number of themes (recall that each theme was coded as present or absent for each question/organism) mentioned by each visitor, for each reasoning pattern was: INR (M = 9.4, SD = 6.1, Range 2–25), NNR (M = 8.1, SD = 4.3, Range 1–19), and CR (M = 1.3, SD = 3.5, Range 0–16). For ease of presentation, under the novice naturalistic reasoner pattern, two similar themes, need-based adaptation and development, were combined under a "goal-directed" theme and the two proximate cause themes (agent and other) were also combined (see table 6).

Table 6. For each organism, the main themes for the naturalistic and informed reasoning patterns (endorsed by 20% or more of participants), and for the creationist reasoning pattern (endorsed by 6% or more of participants)

Organism	Informed Naturalistic Reasoning	Novice Naturalistic Reasoning	Creationist Reasoning
Virus	Variation (38%) Ecological press. (22%)	Proximate cause (34%) Goal directed (22%) Reproduction (22%)	None
Diatom	Ecological press. (31%) Evolution term (22%)	Static adaptation (53%) Proximate cause (31%)	Vague belief (6%)
Ant	Evolution term (28%) Selection (22%)	Static adaptation (53%) Goal directed (41%)	God's creation (6%) God's adaptation (6%)
Fly	Evolution term (25%) Variation (25%) Time (22%)	Proximate cause (50%) Reproduction (34%) Hybridization (22%)	Young earthers (6%) Vague belief (6%)
Finch	Ecological press. (62%) Evolution term (50%) Selection (44%) Variation (25%)	Goal directed (53%) Reproduction (22%)	
Human	Evolution term (56%) Common descent (38%) Time (28%) Ecological press. (25%)	Adaptive features (44%) Goal directed (22%)	Rejects descent (22%) Vague belief (16%) God's creation (9%) God's essence (6%) Young earthers (6%)
Whale	Ecological press. (47%) Evolution term (47%) Common descent (25%) Time (25%)	Static adaptation (34%) Adaptive features (34%) Goal directed (28%)	

Informed Naturalistic Reasoning (INR) Pattern (Table 2)

The most frequent themes from the informed naturalistic reasoning pattern, summed across all organisms and averaged across visitors, were: evolution terms ($M = 2.3$, $SD = 2.0$, Range 0–7), and the concepts of ecological pressure ($M = 2.0$, $SD = 1.5$, Range 0–6), variation ($M = 1.4$, $SD = 1.6$, Range 0–5), time ($M = 1.3$, $SD = 1.5$, Range 0–5), selection ($M = 1.0$, $SD = 1.4$, Range 0–5), and common descent ($M = 0.8$, $SD = 0.8$, Range 0–2) (see table 2). Sexual selection was never mentioned; inheritance and chance were mentioned by fewer than 20%.

Evolution Terms

Evolution terms were the most frequently mentioned INR theme. In figure 3 the percentage of visitors endorsing at least one evolution term for each organism is presented. The most frequent evolution terms were: evolution, Darwin(ian), and survival of the fittest (although the latter is technically incorrect, for the purposes of this study we included it). Typically visitors did not mention VIST terms though they did describe them conceptually. Between 47% and 56% of the museum visitors used an evolution term to explain the finch, human, and whale biological change problems. For the other organisms, visitors invoked

such terms less often (6–28%). Presentation order was unlikely to have influenced this pattern, as the human and whale were presented last and the finch second.

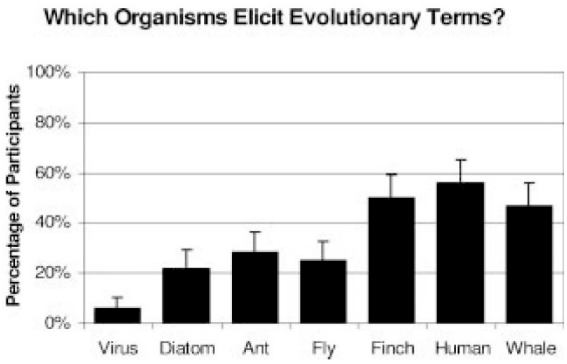

Figure 3. Percentage of participants using evolutionary terms for each organism (+SEM).

Variation and Selection

In terms of the VIST concepts, the most commonly invoked were: variation, time, and selection. Fewer than 40% of the sample invoked the concept of within-species variation (see table 2). It was most likely to be associated with the virus (38%), the fly (25%), and the finch (25%) (table 6). A more stringent test of evolutionary reasoning is the application of a natural selection theme. In figure 4 the percentage of participants who mentioned a selection theme for each organism is presented (see also table 6). The finch (44%) was the only organism that elicited a significant number of selection responses. None of the visitors applied a selection theme to the virus and, with the exception of the ant (22%), fewer than 20% applied it to the other organisms. The information provided in the finch question probably helped elicit such responses but only for those participants who were ready to recognize the selectionist contingencies. See the following example:

> FINCH: Well, in that case I would assume that the birds evolved [*Evolutionary Term*]—well, the birds with the larger beaks [*Variation*] were the ones better able to survive, since the larger beaks were more useful in getting the seeds. So that trait is the one that was selected for, and the birds that had the smaller beaks died out [*Selection*], I would assume.

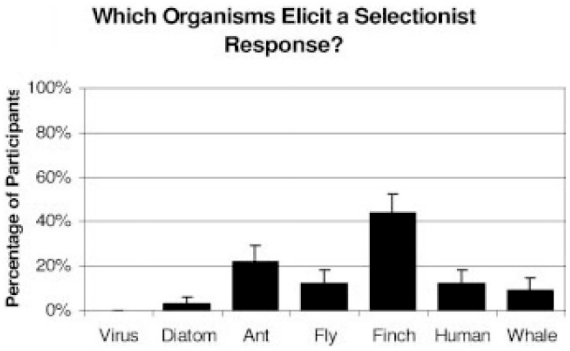

Figure 4. Percentage of participants using a selection theme for each organism (+SEM).

Time

Specific information about *time* was incorporated into all of the problems to some degree. Fewer than 30% of the visitors, however, regularly invoked time in their responses to the problems (see table 6). The fly (22%), whale (25%), and the human (28%) problems elicited time responses in more than 20% of the sample. The consistent creationists (Young Earthers—see table 4) routinely denied the possibility of geological time. In the case of the finch there was an interesting negative reference to time; a few participants did not think that there had been enough time for "evolution" to occur, as in the following example:

> FINCH: Well, you wouldn't expect to see evolution occurring so rapidly . . .

Common Descent

The whale and the human/chimp problems were the only ones that explicitly incorporated information about *common ancestors* into the question. Even so, visitors were either reluctant or unable to use that information to explain the problem: Whale (25%), human/chimp (38%) (see table 6). Additionally, some visitors who did address common descent for the human/chimp problem were genuinely puzzled as to how the "chimps" could still be here. In this common misunderstanding, visitors failed to realize that apes and humans have a common ancestor that is neither chimp nor human, as follows:

> HUMAN/CHIMP: . . . I just got done saying that everything else can evolve over time to fit the environment, but if we evolved over time from the chimp, I guess my big question is why is the chimp still here in his original form. Like on the other ones, they evolved and their earlier format disappeared. The chimp hasn't disappeared, he has continued to survive as he is. So, I don't know how I would explain that we evolved from them . . .

Ecological Pressure

Based on earlier research, we had hypothesized that the realization that changed environments exert significant pressure on organisms is an important insight, which is not necessarily accompanied by an understanding of natural selection, per se. In the development

of the coding system we had observed three kinds of themes that addressed the environment, one of which, *ecological pressures*, we coded as informed naturalistic reasoning. In this case, participants might note differences in habitats and their effects on organisms (Flies: "the fact that there's lots of different fruit"; Finches: "they adapted fairly quickly to the change in food"). The theme, ecological pressure, was elicited by most of the organisms (see table 6): finches (62%), whale (47%), diatom (31%), human (25%), and virus (22%).

Novice Naturalistic Reasoning (NNR) Pattern (Table 3)

As described earlier, the virus, diatom, ant, and fly were more likely to invoke an NNR pattern (see fig. 2). The most frequent themes from the novice naturalistic reasoning pattern, summed across all organisms and averaged across visitors, were (see tables 3 and 6): static adaptation (M = 1.7, SD = 1.1, Range 0–4), need-based adaptation (M = 1.6, SD = 1.6, Range 0–6), proximate cause agent/other (M = 1.5, SD = 1.2, Range 0–5), adaptive feature list (M = 1.0, SD = 1.1, Range 0–4), and reproduction (M = 1.0, SD = 1.0, Range 0–3). The first three themes are also prevalent in children's reasoning patterns (Evans, 2001, 2008).

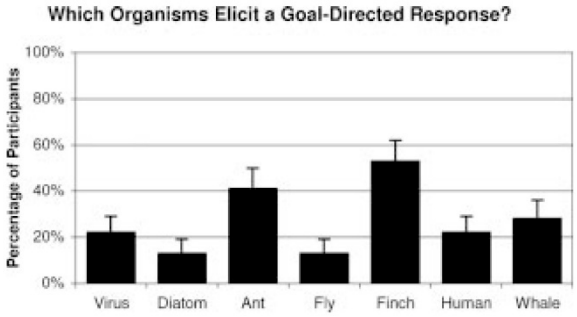

Figure 5. Percentage of participants using goal-directed themes for each organism (+SEM).

Goal-Directed Responses

The classic misconstrual of Darwinian evolution is the adaptationist response in which the individual organism adapts itself to environmental conditions, which we have called need-based adaptation. For ease of presentation, we combined responses for this more prevalent theme with the less prevalent development theme (see table 3) and called them goal-directed responses, as they both imply progression toward a goal. In figure 5, the percentage of participants endorsing a goal-directed theme at least once for each organism is presented. The two organisms most likely to elicit this response were the finch (53%) and the ant (41%). Typically these responses referenced an endogenous process in which new features just emerge, grow, or develop when the need arises:

> FINCH: Evolution for survival. . . . Well, in order to survive, their body parts had to adjust to certain things, similar to the way giraffes' necks probably grew long as they reached for the plants at the top of the trees, so the beak grew longer in order to deal with the tougher seeds.

> ANT: The first fungus needed to be protected from the second fungus, so it developed a natural defense mechanism in the ant in order to stave it off.

Proximate Cause

Two kinds of *proximate cause themes* were identified: *agent* and *other*. In figure 6 the percentage of participants endorsing either type of proximate cause at least once for each organism is presented (see also table 6). Fifty percent of the visitors applied this theme to the fruit fly and just over 30% applied it to the virus and diatom. For the virus, visitors tended to deny that the scientists were correct in their assessment that the organism did not exist: "They were there but they weren't detected" (proximate cause–other). The assumption that the organism was always present (but some place where it could not be seen) is illustrated in the following example. The visitor responds as if the organism always existed, but just had to be transported from someplace else (proximate cause-agent), a pattern also seen in younger populations (Evans, 2000, 2001).

> FRUIT FLIES: Obviously people have brought the fruit flies in. And Dole probably, Dole pineapple people probably brought them in.

Reproduction

These themes were elicited mostly by the fly (34%), finch (22%), and virus (22%). They could easily be distinguished from inheritance. For reproduction, visitors merely referenced the multiplication of the species but did not refer to the passing on of traits from one generation to the next, as in the following example (which also included *hybridization*).

> FRUIT FLIES: However they came here I don't know, but they just started mating and then they cross mated as far as animals do, I'm guessing.

Ecological Responses: Static Adaptation and Adaptive Features List

The two environmental responses that were coded under the NNR pattern were static adaptation and adaptive features list (see table 3). For static adaptation, visitors typically just referenced the environment-organism fit without noting changes in environmental conditions. This was most often applied to the diatom (53%: "this type of algae grows better in colder climates"), the ant (53%), and the whale (34%). In the case of *adaptive features list*, visitors merely listed adaptive features of organisms. This was most often found for the whale (34%) and the human (44%).

> WHALE: The webbed feet, it once was a land, maybe, um . . . *toes and webbed feet instead of fins*, most whales have fins, dorsal fins, so if he was once a land animal. But the hippo is hoofed, so it must have something to do with, maybe the vertebrae . . .

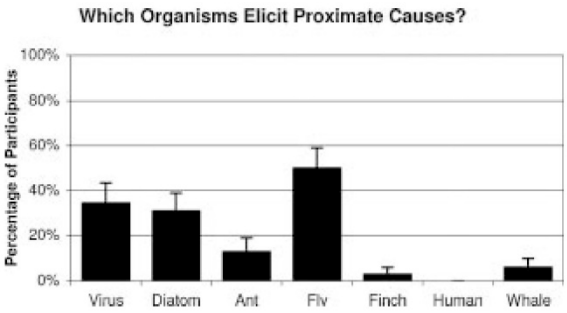

Figure 6. Percentage of participants using proximate causes for each organism (+SEM).

Creationist Reasoning Patterns (Table 4)

A creationist theme was mentioned by 28% of the visitors. In figure 2 the percentage of participants endorsing a creationist reasoning theme at least once for each organism is presented. The virus never invoked a creationist response, whereas the chimp/human was the most likely to do so (see table 6). When confronted with a possible relationship between the chimp and the human, many participants expressed a range of responses from outright rejection of common descent (22%) to a vague doubt (16%), as in the following example of mixed reasoning:

> HUMAN/CHIMP: I don't believe that they do, because I don't believe necessarily in evolution. I mean yes, I believe there's a Darwinism where the stronger species survived, but, I'm Christian so I believe God created man and God created chimpanzees [CR/INR]

Interestingly, one of the more consistent creationist reasoners shifted between a creationist and selectionist response for the finch, as in the following example:

> FINCH: That's a good question. I probably can't explain that. But like I said, because of my biblical world view, I don't believe in evolution. So I don't believe that they evolved because it takes too long. There are too many failures before they evolve into something that finally works, so I just reject that view. Um, my guess would be that there probably were larger beaked finches but there weren't as many of them and the small beaked ones would have died out because they couldn't get the food. But I don't think that it went the other way—that there were no large beaks and so they grew into large beaks. So is that clear enough? [CR/INR]

The following creationist reasoner acknowledged variation in a population, but ascribed it to God's intervention: God built it into the DNA.

> FRUIT FLY: Um, first of all I have a problem with your 8 million years. I believe in creation in the biblical account, so that pretty well defines how I believe things.

> God created them and due to the great flood, that is how the diversity came and that would be my explanation. . . . OK, I believe um, God created a pair, a male and female of everything with the ability to diversify. So I guess what I meant at the time of the flood, I believe that's when the continents broke apart and so even though only a few of each things were saved in the flood, they had the genetic background to be able to diversify into all of the, like for instance, dogs, and all the different kinds that we have. And so um, does that help? Just a creationistic view.

Results: Part II, Are Visitors' Frameworks Coherent?

First, the second overall research question, which was whether visitors' endorsement of mixed reasoning patterns was coherent (see Vosniadou et al., 2008) or fragmented (see diSessa, 2008) is addressed. Next, given that mixed reasoning patterns prevailed in visitors' responses, these analyses also allowed us to examine whether certain themes might represent a transition or bridge between reasoning patterns; that is, whether there were significant correlations, either negative or positive, between particular themes from two different reasoning patterns.

To assess whether visitors' responses were coherent, hypotheses regarding the relationship between the major reasoning patterns and particular themes were evaluated using zero-order correlations. Only themes that were conceptually central to each of the main patterns and were endorsed by 20% or more of the sample are presented in table 7. This evaluation was achieved by assessing the relationship between the overall patterns (measured as the percent of total themes committed to each pattern), and the main themes (measured as the number of times each theme was endorsed across questions, with a possible range of 0–7 per participant).

Following a brief discussion of the relationship between the reasoning patterns and the demographic variables, we then discuss each of the three major reasoning patterns in turn. Conceptually central themes were those hypothesized to be key indicators of a particular reasoning pattern. In part, these were identified on the basis of previous research. The overall pattern of intercorrelations, excluding the demographic variables, is presented in table 7.

Table 7

Zero-order correlations among the main themes and the three reasoning patterns (% total responses): informed naturalistic reasoning (INR), novice naturalistic reasoning (NNR), and creationist reasoning (CR) (n = 32)

	1. INR Evol. Term	2. INR Variation	3. INR Comm. Descent	4. INR Selection	5. INR Time	6. INR Ecological Pressures	7. NNR Static Adapt.	8. NNR Adapt. Features	9. NNR Goal Direct.	10. NNR Proximate Cause	11. INR Overall	12. NNR Overall
1. INR ev. term	—											
2. INR variation	0.27	—										
3. INR co. des.	0.29	0.21	—									
4. INR selection	0.23	0.64***	0.10	—								
5. INR time	0.07	0.49**	0.23	0.35+	—							
6. INR eco. pre.	0.27	0.16	0.52**	0.20	0.31	—						
7. NNR st. adap.	0.29	0.19	0.62**	−0.16	0.19	0.54**	—					
8. NNR ad. feat.	−0.01	0.01	0.36*	−0.11	0.09	0.42*	0.46**	—				
9. NNR goal dir.	−0.13	−0.27	0.31	−0.46**	0.01	0.46**	0.53**	0.65***	—			
10. NNR proximate	0.08	0.21	0.11	0.04	0.26	0.18	0.21	0.16	0.08	—		
11. INR overall	0.48**	0.68***	0.24	0.61**	0.51**	0.33	0.07	0.23	−0.35*	−0.03	—	
12. NNR overall	−0.50**	−0.50**	0.11	−0.66***	−0.30	0.02	0.29	0.39*	0.66***	0.09	−0.73***	—
13. CR overall	0.22	−0.10	−0.34+	−0.03	−0.25	−0.36+	−0.30	−0.27	−0.39*	0.08	−0.21	−0.41*

+ <0.06.

* ≤0.05.

** ≤0.01.

*** ≤0.001.

For informed naturalistic reasoning, the focus was on the VIST concepts, particularly variation and common descent, because endorsement of these themes indicated that intuitive essentialist constraints that animal kinds cannot change had been modified. Likewise an endorsement of selection suggested that visitors were no longer endorsing intuitive goal-directed reasoning, which could be verified by assessing the relations between those two variables. For the novice naturalistic reasoning pattern, the focal question, as described earlier, was whether goal-directed reasoning was the most diagnostic of that pattern. Given the emergent themes in Part I, of additional interest was the extent to which visitors were sensitive to environmental issues, which are key to grasping evolutionary change; these included ecological pressures, for the informed reasoning pattern, and adaptation for the novice pattern. Analyses of the latter variables were exploratory; similarly, exploratory analyses of conceptually interesting variables, even if endorsed by less than 20% of the sample, were included.

Demographic Variables

Older participants tended to be more highly educated ($r = 0.41$, $p = 0.03$). Additionally, the number of museum visits made by the visitors was positively related to their use of evolutionary terms ($r = 0.36$, $p < 0.05$). There were no other significant relationships.

Informed Naturalistic Reasoning (INR) Pattern

Given that the VIST concepts are core evolutionary concepts (Futuyma, 1998), it was predicted that they would be central to the informed naturalistic reasoning pattern and that they would be positively correlated with the overall INR pattern and negatively correlated with the novice (NNR) reasoning pattern. (The pattern of intercorrelations between the most prevalent INR themes—variables 1–6—and the overall reasoning patterns—variables 11–13—can be found in table 7). As described earlier, creationist reasoners may endorse selection, an INR concept, providing they construe it as within-species change, but reject common descent, another INR concept, because they view God as the exclusive creator of new forms of life (Jones, 2005). If these hypotheses hold, then the overall INR and CR patterns would be uncorrelated.

Evolution terms (Var. 1), variation (Var. 2), and selection (Var. 4) were significantly positively correlated with the overall informed (INR) pattern, negatively correlated with the novice (NNR) pattern, and uncorrelated with the creationist (CR) pattern (table 7). These seemed to be diagnostic concepts for distinguishing between informed and novice reasoning. On the other hand, common descent (Var. 3) and ecological pressures (Var. 6) were negatively correlated ($p < 0.06$) with the CR pattern, but were not clearly diagnostic of the informed reasoning pattern. Notably, selection and common descent were uncorrelated.

Based on earlier descriptions of creationist reasoning patterns, this pattern was predictable because, as described, some creationist reasoners endorse selection (God created the potential for diversity in DNA) but reject common descent, which, for them, is the definition of evolution (Jones, 2005). Also, creationist reasoners' mention of evolutionary terms was usually done in a negative fashion; it did indicate, however, their recognition that the problems required more than a proximate cause explanation, even while they provided

God as the final cause. The time concept (Var. 5) was significantly related to informed naturalistic reasoning but uncorrelated with the other patterns. Some participants mentioned time along with common descent, which is reflected in the significant positive relationship between these variables. Yet, although other participants seemed to recognize the importance of the time concept, they were unable to frame it in evolutionary terms. Variation and time were also significantly related.

The significant positive relationship between selection, variation, and time (table 7), and selection and inheritance ($r = 0.36$; $p < 0.05$) indicates that participants often accessed the full VIST framework, in a coherent manner, even if they did not do so across all the questions.

Novice Naturalistic Reasoning (NNR) Pattern

Based on prior research with children and adults, one clear prediction was that goal directed reasoning (Var. 9) should be positively correlated with the overall NNR pattern and negatively correlated with the other two patterns. This was the case. (The pattern of intercorrelations between the most prevalent NNR themes—variables 7–10—and the overall reasoning patterns—variables 11–13—can be found in table 7).

Moreover, goal-directed reasoning was significantly negatively correlated with the selection theme, which demonstrates that visitors who understood natural selection were less likely to use goal-directed language when explaining evolutionary problems. One possible interpretation of this pattern is that differential survival, which means some individuals in the population die, is incompatible with purpose. Goal-directed reasoning was also positively correlated with all the ecological variables: the informed ecological pressures theme, as well as the two novice themes, static adaptation (Var. 7), and adaptive features (Var. 8). A possible interpretation of this pattern is that for the goal-directed reasoner the goal or purpose is adaptation to the environment. Thus the recognition that the environment is a critical component in evolutionary change appears to be a crucial transitional step in the shift from a novice to an informed reasoning pattern. Intentional/mental state reasoning was not one of the main themes (mentioned by fewer than 20% of sample), but it was positively correlated with goal-directed reasoning ($r = 0.48$; $p < 0.01$), particularly need-based adaptation ($r = 0.52$; $p < 0.01$), and the adaptive feature list ($r = 0.46$; $p < 0.01$), but not with any of the other variables.

The significant positive relations between the two NNR themes, static adaptation (Var. 7) and adaptive features (Var. 8), and common descent, an INR theme, indicates that those novice reasoners who acknowledged the importance of the environment also endorsed common descent. In addition, the overall negative relationship between the NNR reasoning pattern and selection, suggests that they did not grasp the evolutionary mechanism, natural selection. Overall, as predicted, the novice reasoner was most likely to suggest goal-directed mechanisms of change.

Proximate cause (Var. 10) reasoning was not diagnostic of any particular reasoning pattern. It appeared to be a causal explanation associated with either evolutionary or creationist reasoning. To have a full explanation for any particular biological phenomena, both proximate and evolutionary causes are necessary. What is noticeable in the results described in Part I is that participants were more likely to use proximate cause reasoning for

the organisms (virus, diatom, ant, fly) for which they lacked any kind of evolutionary explanation.

Creationist Reasoning (CR) Pattern

The pattern of intercorrelations between the creationist reasoning pattern (CR) and the other variables can be seen in table 7 (Var. 13). As there were few creationist themes, they were not presented individually but as a composite variable only. Complicating this reasoning pattern, the previous results demonstrate that some participants, who were not Biblical literalists, expressed creationist ideas for the human/chimp question but were naturalistic reasoners for the other questions. The few consistent creationist reasoners in this sample, who were highly sophisticated Biblical literalists, were very clear that they endorsed variation within species but not common descent or geological time. (Unfortunately, with this small sample of creationist reasoners it is not possible to distinguish these two groups in the pattern of correlations.)

Of particular interest was the significant negative relationship between goal-directed reasoning and creationist reasoning (see table 6), which was predicted earlier. Creationist reasoners did not endorse the idea that goals are intrinsic to the organisms themselves, even while they endorse the idea that God created species for an extrinsic purpose (like artifacts). Such a pattern is consistent with the theoretical analysis, described in Part I, of a dissociation between intentional and goal-directed reasoning, with the former related to extrinsic goals (and creationism) and the latter to intrinsic goals (and an intuitive biology). Relatedly, the negative relationship between ecological pressures and creationism (see table 7) is consistent with the essentialist idea that God created a stable unchanging world. It also represents a refusal to acknowledge one of the natural extrinsic causes of speciation (and common descent)—environmental change. Finally, this negative relationship provides support for the decision to code the ecological pressures theme under the informed naturalistic reasoning pattern.

General Discussion

If a well-educated population of people who are interested enough to go to a natural history museum fail to understand basic evolutionary principles, then it bodes ill for the population at large. Unlike the general population, which typically registers 45% against evolution (Gallup, 2007), these natural history museum visitors were much less likely to reject evolutionary theory. Only 28% indicated discomfort with evolutionary principles. This finding accords with reports from museums where visitor studies on the topic of evolution have been conducted (Spiegel et al., 2006).

On the other hand, while the majority accepted evolutionary ideas, only a third could be said to have a reasonable grasp of Darwinian evolutionary mechanisms. Not one visitor consistently used evolutionary reasoning to explain all seven problems. This is unlikely to be the consequence of a lack of interest in or exposure to the pertinent content. These natural history museum visitors were more highly educated than the population at large, and the pilot study demonstrated that they were also interested in and relatively knowledgea-

ble about the organisms and concepts presented in the study, to the extent that they provided biological descriptions of the terms. Moreover, the more frequently they visited natural history museums, the more likely they were to spontaneously mention evolution terms. We shall argue, instead, that consistent with our earlier theoretical analysis, these findings result from the conceptual difficulty of Darwinian ideas, which run counter to commonsense (Evans, 2001; Bloom & Weisberg, 2007; Mayr, 1982, pp. 514–519). That the same pattern of misunderstandings is found among adult museum visitors in Canada and Australia, which have a much higher acceptance rate of evolutionary origins, provides support for this position (Abrahams-Silver & Kisiel, 2008). Before addressing the implications these findings might have for informal and formal science education, we summarize the overall results and address their theoretical implications.

Overall Findings

To address the main purpose of this study, in Part I of the analyses we profiled the reasoning patterns of museum visitors. This analysis was based on a theoretical model (see fig. 1) in which intuitive modes of reasoning, present in childhood, interact with the cultural influences of religion, especially Biblical literalism, and science to produce distinct reasoning patterns. As hypothesized, we found that the typical visitor used mixed patterns of reasoning, depending on the organism.

Visitors who used informed naturalistic reasoning themes when explaining evolutionary change in mammals and birds, often used novice naturalistic reasoning themes for invertebrate or microscopic species. The most frequent novice themes were those also found in children's intuitive beliefs (Evans, 2001, 2008), which appear to persist in adulthood. Creationist reasoning was used most frequently when explaining human evolution, alone or in combination with novice and/or informed naturalistic reasoning. The overlapping circles in the model (see fig. 1) capture some of these more nuanced positions: there is no single path to an understanding of evolutionary change but many possible transitions. Overall, visitors used one or more of these reasoning patterns in different permutations across the seven organisms. Seventy-two percent used a combination of informed naturalistic reasoning and novice naturalistic reasoning to explain the evolutionary problems. Just over one-quarter used a combination of creationist reasoning with one or both of the naturalistic reasoning patterns. One third, however, did use informed naturalistic reasoning in more than 50% of their responses. These results indicate that about two-thirds of these museum visitors were unlikely to spontaneously invoke a Darwinian evolutionary explanation to solve a biological change problem. Of this group, a minority were creationists, while the majority invoked novice modes of reasoning.

Each of the seven organisms elicited a distinctive reasoning pattern. The finch, human, and whale were most likely to elicit an evolutionary term, with the finch most likely to invoke a selectionist concept. The human and whale questions explicitly addressed macroevolutionary processes and were also the most likely to elicit the common descent theme. In contrast with the vertebrates, the ant, fly, diatom, and virus questions were more likely to elicit novice naturalistic reasoning, with the latter three organisms often eliciting a proximate cause theme. In these cases, the visitors did not seem to recognize that an evolutionary explanation was needed to explain the presence of new species, a pattern also found

in childhood (Evans, 2000; Southerland et al., 2001). Creationist reasoners fell into two groups. One was a sophisticated vocal minority, who rejected most references to evolution, especially common descent, and who explained variation as part of God's plan. For the majority of creationist reasoners, however, their reasoning was organism specific: humans were created by God, while the other organisms evolved.

A common complaint in the science education research literature (e.g., Bishop & Anderson, 1990; Greene, 1990) is that students do not understand the importance of chance or randomness, so we were interested to see whether visitors would spontaneously evoke this concept. Fewer than 20% of the visitors did so. Nor did the idea of sexual selection spontaneously occur to any of the visitors, though this is a central concept in fruit fly speciation.

Theoretical Implications

Bridges to an Evolutionary Understanding?

In Part II of the analyses, we focused on the coherence of the patterns by assessing the interrelationships between themes from the three reasoning patterns. One interpretation of these findings was that two themes in particular, goal-directedness and variation, were key transitional concepts, bridging the gap between novice reasoning patterns and informed reasoning patterns.

The finding that creationist reasoners endorsed selection (as differential survival) and rejected common descent, while novice naturalistic reasoners endorsed common descent but not selection, indicates an interesting disassociation between these two evolutionary themes. Further, common descent as well as goal-directed reasoning were positively related to all ecological variables from both the informed and the novice reasoning patterns. As argued earlier, this pattern suggests that novice reasoners who recognized the importance of ecological pressures endorsed common descent but utilized goal-directedness as the mechanism of evolutionary change rather than natural selection. In effect, they expressed pre-Darwinian ideas of evolutionary change. Goal-directed reasoning is a process that is intrinsic to the organism, with the goal being adaptation to a changed environment. Creationist reasoners, in contrast, did not endorse goal-directed reasoning or the ecological variables.

These findings provide support for the thesis that goal-directed reasoning and the related recognition of ecological pressures are important bridges to a Darwinian understanding of evolution, particularly natural selection (Evans, 2008). The significant negative correlation between goal-directed themes and the selection theme indicates that the latter directly supplants the former as the mechanism of change. For the majority of visitors, the goal-directed theme was one in which, of necessity, the organism needed to change in order to survive in a changed environment. Importantly, this was not an intentional concept that reflected the organism's conscious desire or intent to change. The latter was coded separately from goal-directedness and was rarely expressed by the visitors. As described earlier, the ability to distinguish between goal-directed reasoning, from an intuitive biology, and intentional (mental state) reasoning, from an intuitive psychology, appears to be a crucial step in gaining a handle on evolutionary thinking in childhood (Evans, 2008).

Once visitors, of any age, realize that the organism's survival in a changed environment depends on its possession of particular features, then they are in a position to grasp key aspects of natural selection: differential survival and differential reproduction.

Given that these intuitive beliefs appear to constrain current thinking on evolution, it is likely that they exerted similar effects in historical contexts. Thus, it would not be surprising if similar patterns of conceptual change were found historically. Goal-directed reasoning, as a progressive theme, was a dominant idea among the assortment of teleological evolutionary ideas that were part of the intellectual milieu influencing Darwin (Bowler, 2009; Chambers, 1994; Mayr, 1982, pp. 47–51). Yet, even in the historical context, it was considered important to exclude terms indicating that change came about because of an organism's conscious desire for change. Lamarck, for example, did not endorse *wants* but did endorse *needs* (Evans, 2001; Kampourakis & Zogza, 2007): "One misconstrual was that he [Lamarck] claimed animals have an inherent power to enlarge organs or capacities in response to their *wants* (a misreading of the French *besoins*)" (Quammen, 2006, p. 71). This historical analysis is evidence that an acceptance of evolutionary ideas and an understanding of the mechanisms do not go hand in hand.

From an essentialist perspective (Mayr, 1982, pp. 304–305), natural kinds (in this case, species) are endowed with an underlying essence that gives members of a particular kind distinctive features that are stable and unchanging. It follows, therefore, that one kind cannot change into another, which makes evolutionary change, particularly common descent, strongly counterintuitive (Evans, 2000, 2001, 2008; Mayr, 1982). Essentialist beliefs are characteristic of childhood reasoning (Gelman, 2003). Individuals who are strongly essentialist tend to focus on features that are common to a species and ignore small differences between individual organisms. Given this perspective, and in contrast with previous researchers, we coded for a variation concept independently of the idea of randomness. The realization that small differences among members of a species are key to differential survival and reproduction is an important insight, one that does not depend on an understanding of the genetic origin of those differences (of which Darwin was ignorant). Of all the VIST subconcepts, we found that variation was the one most likely to be mentioned by informed naturalistic reasoners, which distinguished them from the novice naturalistic reasoners (see also Shtulman & Schulz, 2008).

In keeping with prior research (Evans, 2000, 2008), this finding suggests that highlighting within-species variation provides an important means of modifying an essentialist perspective, one that could provide a bridge between the novice- and informed-naturalistic reasoning patterns. There is a crucial caveat: creationist reasoners also endorse variation and differential survival but within a different framework. Some visitors in this study claimed that God built the capacity for variation into the DNA: "OK, I believe, um, God created a pair, a male and female of everything with the ability to diversify"; "God created the algae with the DNA to expand into different kinds." This nuanced means of reconciling the obvious fact of within-species variation with a creationist perspective is common among members of a sophisticated creationist community (Jones, 2005; Morris & Parker, 1982). The expression of this diversity is limited to members of a particular kind, where a kind is defined, for example, as all wolf-dogs from dachshunds to dingoes. It does not extend to change from one kind of animal to another, such as from land animals to whales.

The latter change runs counter to the fundamentalist belief that each kind was endowed by God with a unique essence (Numbers, 1992), which, it is argued, is a cultural extension of the essentialist intuition that species are stable and do not change.

Explanatory Coherence or Fragmentary Knowledge?

One feature of informed naturalistic reasoning was the rudimentary nature of the knowledge base. Such reasoning provided an opportunity to examine the conceptual underpinnings of what have been called fragmented (diSessa et al., 2004) or synthetic concepts (Vosniadou & Brewer, 1992), which may well be typical of the layperson's understanding of most scientific topics. Our coding of selection, for example, focused on differential survival, rather than differential survival and differential reproduction (the latter was captured in the inheritance code). The relative strength of the relationships between the VIST subconcepts and the overall pattern indicates that variation and selection (as differential survival) were the most characteristic of the informed reasoning pattern. Yet, while the visitors may have accessed the concept of within-species variation and differential survival, they did not consistently use this knowledge to explain the diverse evolutionary problems encountered in the study. Nor did they consistently tie their knowledge of variation and selection to the other related concepts, inheritance and time. Part of the problem was visitors' failure to recognize that all the biological change problems that we presented to them were variations on one theme: Darwinian evolution. Often their solution was to offer proximate cause explanations rather than ultimate or evolutionary cause explanations, especially for invertebrates (Evans, 2001; Southerland et al., 2001; Mayr, 1982, p. 67).

Overall, these findings suggest that in the process of assimilating strongly counterintuitive ideas, such as evolutionary concepts, to an intuitive set of beliefs, locally coherent models are constructed (Evans et al., in press; Vosniadou et al., 2008). These synthetic blends often give the appearance of fragmented beliefs, in the sense that visitors may have accessed only one of the VIST subconcepts. But the significant correlations between key variables from novice and informed reasoning patterns indicate that the resulting pattern was coherent, which might well be typical of synthetic concepts (Vosniadou et al., 2008). Conversely, some visitors were clearly struggling, especially those who listed adaptive features of organisms but did not tie them sensibly to the question at hand. These were the visitors who were more likely to use intentional-mental-state-reasoning, with explanations that are best described as fragmented (diSessa et al., 2004).

In sum, we propose that whether visitors' reasoning seems fragmented or coherent depends on where they are in their understanding of the problem at hand. They have access to multiple representations (Evans, 2000, 2008; Legare & Gelman, 2008) of biological change: novice and informed naturalistic models as well as creationist models. How these models are integrated and utilized clearly depend on the visitors' interpretation of the problem as well as on the explanatory depth of the underlying knowledge structures. The integration of intuitive and cultural (religious or scientific) beliefs is a long process, one which might well follow a developmental trajectory. The gap between intuitive and expert conceptions appears to be bridged by a variety of transitional concepts, reflecting various blends of intuitive, scientific, and creationist ideas (Evans et al., in press). In figure 1, such

states are indicated by the overlapping circles. Charting the process of conceptual change requires, at a minimum, better theories of how learners manage to integrate multiple models to solve problems.

Implications for Science Education

> If belief in evolution means simply assenting to microevolution, small changes over time within a species, . . . I believe it to be true. [But] Man was not an accident and reflects an image and likeness unique in the created order. Those aspects of evolutionary theory compatible with this truth are a welcome addition to human knowledge. (Brownback, 2007)

A key observation from these studies is that the majority of museum visitors do not realize that the term evolution applies to both microevolutionary and macroevolutionary processes; in fact, they are more likely to apply this term to the latter process. Moreover, as in the above quote and seen in these studies, creationist reasoners may accept microevolution but not macroevolution, whereas novice naturalistic reasoners may accept the latter but misunderstand the former.

There are several reasons why this disassociation occurs, all of which point to the necessity of linking the two concepts in a variety of settings. Biomedical researchers appear to avoid the "E-word" when describing antibiotic resistance (Antonovics et al., 2007). Similarly, while school curricula typically include discussion of within-species change, they rarely address macroevolutionary processes or speciation in the biology classroom (Catley 2006; Poling & Evans, 2004a). One exception may be an introduction to dinosaurs in elementary school; yet, while young elementary school children may be skilled at classifying dinosaurs, this does not mean they understand their role in an evolutionary framework (Evans, 2000; Poling & Evans, 2004b). Natural history museums, on the other hand, are the repositories of the evidence for macroevolution (Diamond and Scotchmoor, 2006), but they do not necessarily explain the mechanisms. More often they present evolution as a linear concept, with single individuals from particular lineages linked across geological time (Diamond and Scotchmoor, 2006).

The finding that visitors failed to generalize their understanding of evolution across diverse species indicates that they did not realize that evolutionary processes are a fundamental attribute of living things, at both the microscopic and the macroscopic level. Biological change in HIV, for example, is a process that can best be understood using an evolutionary lens. The majority of the visitors, however, used intuitive reasoning to explain the changes. This suggests that public health campaigns, medical schools, and health curricula should emphasize an evolutionary perspective when describing such health issues (Nesse & Williams, 1996). Furthermore, exhibitions and curricula that provide opportunities for generalizing across diverse species are more likely to be successful in relaying this fundamental concept.

Finally, from the theoretical implications outlined above, there are some specific proposals for providing transitions or bridges between intuitive and evolutionary reasoning

patterns. Essentialist intuitions should be explicitly challenged by providing multiple examples of within- and between-species diversity. Change rather than stability is part of the natural order. Further, goal-directed concepts should be explicitly decoupled from an intentional reasoning pattern that involves mental state terminology.

Future research in informal and formal settings should focus on ways of bringing about these transitions. One of the limitations of this study is the focus on open-ended interviews and visitors' explanations, which are language-based. One advantage of this procedure, however, is that visitors' explanations revealed their implicit understanding, rather than the ability to merely recognize evolutionary concepts. Moreover, we were able to offer detailed quantitative as well as qualitative analyses. Finally, this focus gave us a rich database that can be exploited to provide stems for a nuanced set of closed-ended questions that explicitly target these core concepts (Spiegel et al., submitted).

Conclusion

These findings highlight the need to help the public understand that microevolutionary and macroevolutionary processes occur in all living kinds. While the majority of the museum-going public might be willing to accept evolutionary origins, it appears that they are not familiar enough with the fundamental principles of evolution to understand the mechanisms of Darwinian evolutionary change. Understanding and acceptance do not go hand in hand, historically, or in contemporary populations, even for those exposed to Darwinian evolutionary ideas. For the museum-going public, the normative reasoning pattern appears to be that of a synthetic blend, a fusion of evolutionary concepts and intuitive beliefs. The model presented in this study and these results can be used to help educators, in formal and informal settings, identify the reasoning patterns of their students and visitors and the factors that elicit these different reasoning patterns. A single museum visit, or even several, are unlikely to effect radical conceptual change. Yet, incremental shifts toward more informed naturalistic reasoning could potentially usher in a cascade of more dramatic changes.

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