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Complex ideas like evolution-which run counter to common, but mistaken, intuitive knowledge are challenging, both for exhibit developers and for the evaluation and research teams who assess the impact of exhibitions. It is always difficult to document measurable changes in deep conceptual understanding following a single visit to an exhibition (Allen, 2008, p. 58); Is this even possible with complex topics, such as evolution?

Integrating Developmental and Free-Choice Learning Frameworks to Investigate Conceptual Change in Visitor Understanding

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A 9-year-old boy was shown an Archaeopteryx cast and asked about the evidence in favor of the bird-dino link. He accurately reported the evidence and even agreed that it was good evidence. When asked if he agreed with the scientists he responded:

"*No, not really. I just don't see how it is possible for a ferocious, meat-eating dinosaur to change into a bird. They aren't the same kind of thing. How could that be possible?*" (Evans, 2008a).

Could an exhibition convince him otherwise? Our studies suggest that it can.

Complex ideas like evolution—which run counter to common, but mistaken, intuitive knowledge like the 9-year-old's quoted above—are challenging, both for exhibit developers and for the evaluation and research teams who assess the impact of exhibitions. It is always difficult to document measurable changes in deep conceptual understanding following a single visit to an exhibition (Allen, 2008, p. 58); Is this even possible

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Study One: Coding Visitors' Responses (Evans et al., 2009)

A. EVOLUTIONARY If the visitor mentioned one of the evolutionary subconcepts or an evolutionary term, even in a non-expert manner, that item was coded under a particular theme (e.g., selection) in the evolutionary reasoning pattern (examples from Diamond & Evans, 2007): Well, the with complex topics, such as evolution? In this article, we summarize a series of studies that may offer some help to exhibit developers and evaluators, as well as others who design and assess informal learning experiences. The studies chart changes in visitors' learning based on a framework that integrates findings from recent studies on age-related changes in children's conceptual understanding —a developmental framework—with findings from studies on free-choice learning.

A Developmental Framework

Perhaps one of the most important lessons of the constructivist movement in psychology (Piaget, 1929), was the realization that a child's mind is not a blank slate. Even infants have a remarkable capacity for making sense of the "blooming buzzing confusion" that greets them at birth (Evans, 2007; James, 1890/1983). Subsequently, researchers focused on establishing the nature of children's commonsense or everyday understanding of the world around them, because this intuitive knowledge is the foundation on which new knowledge is built (Evans, 2000, 2008b; Bloom & Weisberg, 2007). By constraining the child's view of the world, intuitive knowledge makes rapid learning possible. Yet, it is also a source of resistance (not the only one) to novel or counterintuitive ideas. Scientific breakthroughs often require a radical reconceptualization of such core intuitions. By targeting these core intuitions and capturing children's (and adults') interest, informal learning environments could contribute both to the process of conceptual enrichment and to more profound conceptual change.

process of evolution. So, at certain points there were, uh, mutations that just naturally occurred. Um, . . reproduction. And then, those mutations, if they were adapted to that environment, they were further reproduced….

B. CREATIONIST On the other hand, if the visitor brought up a supernatural explanation, it was coded as a theme in the a creationist reasoning pattern, as in the following example: Ok, I believe um, God created a pair, a male and female of everything with the ability to diversify…
C. INTUITIVE Finally, if the visitor mentioned a concept that was derived from an intuitive reasoning pattern it was coded as intuitive reasoning, as in the these examples for Galapagos finch evolution: Goal-Directed Explanation. "Its evolution. They had to – for survival, the beaks had to grow so the finch could eat. So they just adapted . . . their bodies adapted so that they could survive." Anthropomorphic Explanation. "… had to try and work harder, probably, to develop their beaks"

Study Two: Main Findings (Spiegel et al., 2009)

- Following the visit and regardless of age, demographic characteristics of the visitor, or the targeted organism, there was a significant increased acceptance of evolutionary concepts and the core evolutionary explanations of selection and common descent. This positive result was found with both the closed- and open-ended questions.
- Endorsement of goal-directed reasoning

“Measure a Finch Beak.” Museum visitors explore the Galápagos finch research of Rosemary and Peter Grant in the Explore Evolution gallery. Photo courtesy the Science Museum of Minnesota

(the animal needed to change) also increased.

- There was a significant decreased endorsement of anthropomorphic reasoning (wanted to change)
- Visitors who stated that evolution was compatible with their religious beliefs were more likely to endorse evolution themes and goal-directed reasoning, and were also more interested in the exhibition and spent more time on the gallery visit.
- Visitors who both stated the evolution was incompatible with their religious beliefs and who were more religious were less likely to endorse evolutionary themes and more likely to endorse intentional design ("it was created that way")
- The 11- to 14 year-olds were less likely to endorse evolutionary themes and more likely to endorse anthropomorphic themes (the animal wanted to change or tried to change) than adults.

A crucial aspect of exhibition development is an assessment of visitors' understanding of the topic—their prior knowledge—before the creation of the learning experience. This assessment can be used to inform exhibition development; additionally, later, it can be used as a baseline to determine what visitors have learned from the experience. In carrying out this assessment, evaluators often uncover misconceptions. Some are idiosyncratic, others may be more widespread. In a typical assessment, evaluators may be able to identify what people believe, but the methods they use do not reveal why. What is needed is a deeper understanding of the underlying framework or core intuitions that provide children and adults' alike with both useful everyday explanations—and, sometimes, misunderstandings of scientific and other complex concepts.

What are everyday explanations? Current thinking among many developmental psychologists is that children, even very young children, possess a stock of intuitive theories, from an intuitive physics to an intuitive psychology, that inform their everyday understanding of the world—their core intuitions (e.g., Evans, 2001, 2006; Wellman & Gelman, 1998). A key example, of relevance to a number of learning environments, from zoos to botanical gardens to science and natural history museums, is that of an intuitive biology.

Even one-year-olds distinguish between living things and inanimate objects, such as rocks (Wellman & Gelman, 1998). They recognize animal movement as purposeful and directed towards a goal. Movement of inanimate objects, on the other hand, is caused by physical contact and is not goal-directed. Imagine, for example, a rock and a fox moving down a hillside. You would explain this activity differently, depending on the object: The rock rolls, because it had been pushed; the fox runs, to catch a rabbit, perhaps? Preschoolers know that living things eat, move, and grow and they construe these activities in purposeful terms.

Moreover, preschoolers possess a notion of essence that allows them to differentiate one kind of animal from another, on the basis of unique, unknown, but underlying properties. Once children find out about the category of tigers, for example, they do not need to relearn this information every time they encounter a different tiger. Even if three-legged or painted white, it still possesses the essential underlying characteristics that make it a tiger. It does not change into a different kind of animal. This kind of reasoning allows the young child to experience the world as stable and unchanging, a prerequisite for rapid learning.

These two core intuitions, that the world is both stable and purposeful, make it easy for a young child to learn about the world. Yet, such intuitions make it difficult to conceive of evolutionary change, which is neither stable nor purposeful. In the example given in the introduction, the nine-year-old contends that a ferocious meat-eating dinosaur is not the same kind of thing as a bird. How could one be the ancestor of the other? A similar rejection of the idea that one kind of animal could be the ancestor of another is also found in communities that embrace creationism: God made it that way, so it cannot change (Evans, 2001).

Surprisingly, even courses on evolutionary biology rarely make a significant dent in this kind of reasoning. Following such a course, medical students still demonstrated a classic misconstrual of biological adaptation (Bishop & Anderson, 1982), derived from their intuitive biology. They reason that the adaptation was purposeful and directed towards the goal of satisfying the animal's need: The cheetah grew longer legs because it needed to catch fast prey. What they should have said is that those cheetahs who had longer legs were more likely to survive and reproduce, leading to an overall change in the population of cheetahs—natural selection.

If the misunderstanding of evolutionary theory has its roots in our everyday intuitive explanations of the biological world, how is it possible to change these ideas? By beginning our investigations with a clear appraisal of visitors' prior knowledge, we felt that we were already in a better position to devise appropriate learning experiences. Next, we describe the way we integrated this developmental framework with established ideas about informal learning and used the integrated framework as a basis for two studies that expanded our understanding.

Integrating Developmental and Free-Choice Learning Frameworks

One influential free-choice learning framework that reflects the visitor's experience, developed by John Falk and Lynn Dierking, is made up three main contexts, personal, sociocultural, and physical. To this framework we added visitors' intuitive knowledge and their cultural background. Clearly, visitors' core intuitions are part of the prior knowledge, skills, and motivational states—the personal context—that visitors bring to the learning environment. Moreover, this prior knowledge is also influenced by the visitor's background. Visitors raised in Christian fundamentalist communities are going to react differently to an exhibition on evolution than visitors who are raised in more secular communities (Jennings, 2007). Thus the sociocultural context is as much a function of past interactions, as it is the actual visitor interactions in the museum setting, which is how Falk & Dierking (2000) define it. In Leinhardt and Knutson's (2004) framework the (prior) sociocultural context would constitute the core of a visitor's identity. Finally, the visitor's experiences of the actual exhibition—the physical context—is mediated by this expanded notion of personal context, one that includes the core intuitions that guide visitors understanding of the world.

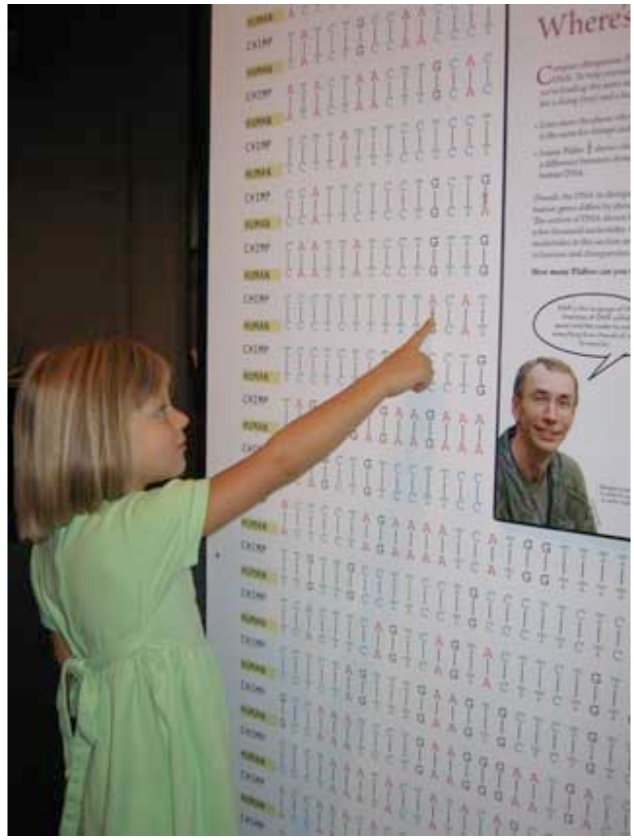
Explore Evolution-Study One: Museum Visitors' Concepts of Evolution

“Fly Karaoke.” Visitors listen to and imitate fly songs as they investigate Ken Kaneshiro’s research on the Hawaiian Drosophila in the Explore Evolution gallery. Photo courtesy the Science Museum of Minnesota.

To illustrate how this framework can be put into action, we describe two studies conducted at Explore Evolution, an NSF funded project on contemporary evolutionary research, led by Judy Diamond of the University of Nebraska. A significant part of the project was a permanent exhibition, copies of which are now on display in five Midwest museums. In contrast to the more typical display in natural history museums, where the focus is more likely to be on established collections of prehistoric life (Diamond & Scotchmoor, 2006), the goal of this exhibition was to show evolutionary research in action. This exhibition introduced the public to leading evolution researchers, with seven exhibits, one on each researcher's project, in which the visitors entered the scientist's lab or field site. Visitors were encouraged to reason like evolutionary scientists and to understand the evolutionary process in living things as diverse as whales, humans, finches, fruit-flies, ants, diatoms and HIV viruses (Diamond & Evans, 2007). As most museum visitors come as multi-generational groups, with adults interpreting the experience for the children (Crowley, Schunn, & Okada, 2001), the focus of our first study was adults' understanding. We began by asking adult natural history museum visitors open-ended questions about the evolutionary problems to be presented in the exhibition, as well as gathering demographic information (Evans, et al., 2009). We were interested in whether visitors would spontaneously mention evolutionary ideas, without prompting. Evolution was not mentioned in our recruitment materials or the questions and, at this point, of course, the exhibition was not on display. For example, anticipating the exhibit on fruit-fly evolution, we posed this question: Scientists think that about 8 million years ago a couple of fruit flies managed to land on an Hawaiian island. Before that time, there were no fruit flies in Hawaii (show map). Now scientists have found that there are 800 different kinds of fruit flies in Hawaii. How do you explain this? We then did an exhaustive coding of visitors' responses into explanations from evolutionary, creationist, and intuitive reasoning patterns (see Sidebar 1 and Evans et al., 2009, for details). This coding system captured visitors' prior knowledge, their core intuitions, and their sociocultural background. From the 32 adult visitors’ responses, over 600 distinct relevant codable units were identified. What did we find?

- Not one visitor employed evolutionary reasoning exclusively across all seven organisms.
- Creationist reasoning was most likely to be elicited by the human/chimp problem
- Different reasoning patterns were elicited by different organisms: The finch was most likely to elicit evolutionary reasoning, particularly selection; The invertebrate and microscopic organisms, HIV, diatom, fly and ant/fungus, were most likely to elicit intuitive reasoning patterns.
- Overall, mixed reasoning patterns predominated: 72% combined evolutionary naturalistic and intuitive reasoning patterns; another 28% also included creationist reasoning.
- For 34% of the sample, evolutionary reasoning predominated; for 6%, creationist reasoning predominated (was used more than 50% of the time).
- The more frequently visitors visited museums, the more likely they were to endorse evolutionary concepts.

This study revealed that even though adult museum visitors are better educated than the population at large (Korn, 1995) and are interested enough in natural history to visit these museums, their understanding of evolution is sketchy, if it exists at all. Further, these problems elicited the same kind of intuitive reasoning in an adult population that was found earlier in children. However, these museum visitors were much less likely than the general population to endorse creationist ideas (28% in this study, versus 45%, Gallup, 2007).



"Where's Pääbo?" This exhibit compares the genomes of humans and chimps as part of a display on the research of Svante Pääbo for the Explore Evolution gallery. Photo courtesy Amy N. Spiegel.

How did the results change the exhibition design—the physical context? Serendipitously, the decision to include seven diverse organisms in the exhibition had already been made, but now, with the hindsight offered by this study, this seemed like a prescient move. Although, we were already aware that the chimp/human exhibit might well elicit creationist reasoning (Spiegel, Evans, Gram & Diamond, 2006), we did not anticipate that visitors would fail to apply evolutionary explanations to diverse organisms. Additionally, we scoured the exhibition text, removing any goal-directed or anthropomorphic explanations, which were the most typical intuitive patterns used by the visitors (see Sidebar 1, C). Finally, the dominant profile of a mixed reasoning pattern provided fodder for the subsequent summative research study.

Explore Evolution—Study Two: Changing Visitors' Concepts of Evolution

The summative evaluation was based on what we had learned in the initial research study. Major themes elicited in visitors' responses to the open-ended questions were turned into eight closed-ended statements, representing the main themes from the three reasoning patterns. In a questionnaire format, we presented the original seven evolutionary problems along with the eight closed-ended statements, with which visitors could agree or disagree, using a five point scale (for details, see Spiegel et al., 2009).

Sixty-two visitors, 30 adults and 32 youth, aged 11- to 17 years, were recruited to take part in a typical gallery visit to the exhibition. Before the visit they were given four of the seven evolutionary problems in the above questionnaire format. (We adopted this design in order to avoid priming the visitors that we were interested in their responses to all seven organisms.) Following the visit, they were asked about all seven problems and three of the open-ended questions from the initial research study, as well as detailed demographic questions that probed their religious beliefs, attitudes toward evolution, and interest in the exhibit.

What did we find? A single visit to an evolution exhibition improved visitors' ability to explain evolutionary problems. Although the age and religious beliefs of the visitors influenced the extent of the change, this improvement was seen across participants (Spiegel et al. 2009; see Sidebar 2). Moreover, visitors realized that evolution occurred regardless of the nature of the organism. The choice of diverse organisms was prescient; it forced visitors to confront the unfamiliar notion that evolution occurs in all living things.

But there were some interesting caveats. The exhibition was less successful for the 11- to 14 year-olds, though this might well have been because each visitor saw the exhibition alone, thus the kind of interpretive talk that might have helped children was absent (Crowley et al., 2001). Additionally, one form of intuitive reasoning, need-based or goal-directed reasoning, appeared to be a transitional tool, helping the visitor make the connection between the survival of the organism and characteristics of the environment (see Sidebar 1, C). The more explicit anthropomorphism, that an animal was consciously making a decision to change, decreased following the gallery visit. This shift in explanatory language, from explanations rooted in an everyday intuitive psychology (wanted to change) to explanations rooted in an intuitive biology (needed to change), to some grasp of the mechanisms of evolutionary change (natural selection), reflected an implicit change in visitors' reasoning. As described earlier, we had scoured the text of purposeful language, but we did not explicitly state that such language was incorrect. The visitors experience of the physical context, the exhibition text, objects, and manipulatives, encouraged this shift.

Implications for Informal Learning Frameworks

By assessing visitors' intuitive explanations of the exhibition topic in a front-end research study, then measuring changes in those explanations following a gallery visit, we were able to document conceptual changes in visitor understanding. We did this by augmenting the notion of personal context or identity found in current models of informal learning. Not only did we thoroughly assess visitors' prior knowledge, we also assessed their core intuitions. Moreover, the form and function of the physical context, the exhibition, included elements that directly engaged and ultimately confronted these core intuitions. The diverse examples of evolutionary change as well as the close attention to the explanatory language used in the text helped effect conceptual change. Additionally, by measuring visitors' beliefs about the topic, in an expanded demographic instrument, we were also able to demonstrate the relationship between socio-cultural identity and visitor learning.

Of course, we do not know that such changes persist, but we suspect that they will, because they were largely unconscious changes in explanation, not easily forgotten facts. Given budget and time constraints, we did not assess the actual interactions at the exhibit, though measures of interest and time served as a proxies for visitor engagement. We do, however, have a study in progress in which we examine parent-child conversation at the same exhibit. This is likely to reveal the kind of scaffolding that parents use to help children grasp the core concepts.

Implications for Diverse Learning Environments

By incorporating the concept of intuitive knowledge into current models of informal learning, and developing methods that can be used to chart changes in visitors' explanations, we hope we have demonstrated one way in which the informal science learning community could document conceptual change. It is important to note, however, that we do not view informal learning contexts as environments that necessarily eliminate scientific misconceptions, but rather as contexts that give visitors the opportunity to fine-tune their explanatory repertoire (cf., Falk, Storksdieck, & Dierking, 2007). In the current studies, following the gallery visit, visitors' intuitive psychology was less likely to be used to explain an evolutionary process, though, of course, it continued to be used to explain the actions of other visitors in the gallery. This focus fits in with research on the importance of explanation and concept elaboration in visitors' conversations in informal settings (e.g., Crowley et al., 2001; Leinhardt & Knutson, 2004). The current studies extend that research by providing evidence that exhibitions bring about changes in visitors' explanations -even in the absence of explicit conversation. Finally, these results explain the relationship between the frequency of museum visits and the greater endorsement of evolution explanations, found in the first study. This is not merely association, there is a causal direction: Museum visits bring about conceptual change.

Although "visitors set their own agenda" (Friedman, 2005), by expanding our understanding of their intuitive knowledge, we are more likely to devise a range of informal learning experiences that map onto that agenda. Importantly, this should help improve the educational accountability of such projects. In Life Changes, an NSF funded exhibition and research project in progress (see Evans, 2006; Weiss, 2006), the charge is to devise a learning environment that explicitly engages children's intuitive concepts of evolution. Based on knowledge gained from the Explore Evolution studies, and others, dino-bird evolution is being used as a central construct, one that is likely to challenge even a 9-year-old's intuitions that such relationships are impossible, yet, at the same time it maps onto children's fascination with dinosaurs. In the Life Changes project, the research component should provide generalizable knowledge about the strengths and limitations of such projects.

This is but one potential model for building targeted learning experiences; there are others that employ more modest resources. The kind of multiple methods we describe above could be incorporated into the evaluation of any project, be it a radio program, a new docent guided tour of a national park, or a novel thematic grouping of some artifacts (see Allen et al., 2007, for some further examples). In particular, projects that focus on one of the core domains of intuitive knowledge, such as an intuitive theory of astronomy, matter, physics, or mathematics (e.g., Brown & Hammer, 2008; Vosniadou & Brewer, 1992; Wiser & Smith, 2008), would be in a key position to benefit from research that has already documented age-related changes in these domains. Regardless of the nature of the project, what is important is to have clear "explanatory" goals. Increased visitor understanding of a topic should translate into a shift in visitors' capacity to explain something –something that eluded them before the targeted experience.

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