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Museums Teach Evolution

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Natural history museums play a significant role in educating the general public about evolution. This article describes Explore Evolution, one of the largest evolution education projects funded by the National Science Foundation. A group of regional museums from the Midwestern United States worked with leading evolutionary scientists to create multiple permanent exhibit galleries and a curriculum book for youth. This program invites the public to experience current evolutionary research on organisms that range in size from HIV to whales. Learning research is being conducted on museum visitors to understand how they reason about evolution and to determine what influences the process of conceptual change.

KEY WORDS: **Conceptual change, informal science education, museum exhibits, natural history museums.**

> *The difficulty, with which everyone must sympathize, is that all museums of natural history are used not merely by those who wish to answer questions in their minds about evolution and the like but also by those who believe that Darwinism is an abomination* (Nature Editors 1981 p. 395).

Museums and other informal science education facilities play an important role in teaching the public about evolution. Most adults in the United States have at one time in their lives visited the galleries of a natural history or science museum (National Science Board 2006), and for some, this is their only opportunity to learn scientifically sound information about evolution. Much of the American public has only a limited understanding of evolution and about half accept biblical creationist explanations (National Academy of Sciences 1998; National Science Board 2006). Almost two-thirds of U.S. state science standards now recommend teaching general principles of evolution, but fewer than 40% mention human evolution (Lerner 2000; Skoog and Bilica 2002; Scott 2004).

Museums have responded to the need for a more proactive role in the public understanding of evolution, and natural history museums are leading the effort.

In the past few years, new exhibitions on evolution have opened at Muséum National D'Histoire Naturelle in Paris, the Melbourne Museum in Australia, the American Museum of Natural History in New York, the Field Museum in Chicago, and the Darwin Centre at the Natural History Museum, London, among others. One museum, the University of California Museum of Paleontology, has pioneered a website (http://evolution.berkeley.edu) that serves as a one-stop source for information on evolution. Many evolution exhibits organize information by geological time, or they emphasize historical approaches, specific fossil assemblages, or less commonly, mechanisms of evolution (Diamond and Scotchmoor 2006). There are significantly fewer opportunities for the public to learn about the nature of the scientific research process and the people who conduct evolutionary research information about the nature of the scientific research process.

The need for public education about evolution is particularly evident in the parts of the United States not served by major metropolitan centers. In the past several years, bills that would allow or require science teachers to mention alternatives to evolution were introduced in Michigan, Mississippi, Missouri, Oklahoma, and Utah, and the state boards of education in Kansas and Ohio attempted to adopt guidelines that single out evolution for critique.

Many school districts throughout the United States appear to have quietly decreased the amount of time spent teaching evolution. A recent survey by the National Science Teachers Association found that nearly a third of its members felt pressured to play down evolution (National Science Teachers Association 2005).

Explore Evolution

In 2003 a group of regional natural history museums in the Midwestern United States formed Explore Evolution, a partnership designed to enhance public education about evolution. Organized by Diamond at the University of Nebraska State Museum and funded by the National Science Foundation, Explore Evolution is a major effort to provide positive and understandable learning experiences about evolution and the nature of scientific research. The goals were to show evolutionary research as an endeavor engaged in by real people, to show real data and the experimental process, to engage audiences to learn to think like evolutionary scientists, and to show a range of evolution research projects in a diversity of organisms.

Leading evolutionary research teams worked with science educators, science writers, and museum designers to create exhibit galleries and outreach materials for youth (Table 1). Through interactive and multimedia exhibits, the new permanent exhibit galleries give visitors opportunities to experience aspects of the research conducted by each of the scientist teams. Built around exploration, identification with strong role models, critical thinking, and skill development, the Explore Evolution exhibits create a learner-centered communication, learning, and assessment environment that provides support for evolution learning experiences in school. Because the galleries are permanent in five of the six museums, youth organizations and schools have the opportunity to build ongoing programs and family groups can repeat their visits over time.

The Explore Evolution project focuses on the work of scientists who are making leading discoveries about the evolution of life. From rapidly evolving HIV to whales that walked, the public is invited to explore evolution in organisms ranging from the very smallest to the largest:

- HIV: Charles Wood and his team at the Nebraska Center for Virology investigate the rapid evolution of HIV as it is transmitted from mother to infant. In the exhibit, visitors explore a giant HIV model, examine what is inside, and learn how HIV replicates using host cells. They see how HIV and SIV evolved from a common ancestor and how evolution of the virus is tied to the evolution of their hosts. On an interactive lab bench, visitors can measure the migration of the HIV genes along a gel to see which strains in an infant have evolved the greatest differences from the baseline at birth.

Table 1. Explore evolution developers and advisers.

Scientist developers
Cameron R. Currie, University of Wisconsin
Sherilyn C. Fritz, University of Nebraska – Lincoln
Philip D. Gingerich, University of Michigan
B. Rosemary Grant, Princeton University
Peter R. Grant, Princeton University
Henrik Kaessmann, University of Lausanne, Switzerland
Kenneth Y. Kaneshiro, University of Hawaiiat Manoa
Svante Pääbo, Max Planck Institute of Evolutionary Anthropology
Edward C. Theriot, University of Texas – Austin
Charles Wood, University of Nebraska – Lincoln
Museum partners
Exhibit MUseum of Natural History, University of Michigan
Kansas Museum and Biodiversity Center, University of Kansas
Sam Noble Oklahoma Museum of Natural History, University of Oklahoma
Science Museum of Minnesota
Texas Memorial Museum, University of Texas at Austin
University of Nebraska State Museum
Exhibit developers and writers
Exhibits:
Science Museum of Minnesota
Angie Fox, University of Nebraska State Museum;
John Klausmeyer, Exhibit Museum of Natural History
Writers:
Carl Zimmer, Linda Allison, Sarah Disbrow
External advisors:
Gibor Basri, University of California Berkeley
Carmen Cid, Connecticut State University
Douglas J. Futuyma, State University of New York
Richard Ponzio, University of California Davis
Judy Scotchmoor, University of California Museum of Paleontology
Eugenie C. Scott, National Center for Science Education
Rose Tyson, Museum of Man, San Diego

- Diatom: Edward Theriot and Sherilyn Fritz study the emergence of a new diatom species in Yellowstone Lake, demonstrating one of the most complete records for the evolution of a species in the fossil record. Visitors to this exhibit can touch a giant diatom model and appreciate the beauty of these little-known creatures. They can look through microscope to see real diatom samples, experience diatom diversity in a multimedia presentation, and explore how a new species emerges in response to climate change.

- Ant and fungus: Cameron Currie discovered that leaf-cutter ants have three coevolved partners: a fungus, a parasitic microfungus, and bacteria that live on the ant's abdomen. In this exhibit, visitors can watch videos of leaf-cutter ants at work and see Currie explain how he determines evidence for coevolution. Visitors can track the experiments in Petri dishes that led Currie to understand the role of the bacteria that associate with the ants.
- Fly: Kenneth Kaneshiro explores the ways that sexual selection has shaped the evolution of *Drosophila* diversity in Hawaii. From one ancestral species of fly that blew ashore on the islands, over 800 species have evolved. In this exhibit, visitors can play fly karaoke to mimic song traces of Hawaiian *Drosophila* and experience the diversity of the courtship songs. They can observe fly courtship dances and view specimens of Hawaiian flies to see their remarkable dimorphism and diversity.
- Finch: Rosemary and Peter Grant's classic studies of populations of Darwin's finches on the Galápagos Islands show how the selective effects of environmental change, acting through the abundance of different food types, influence variation in finch bills. In this exhibit, visitors use giant calipers to take bill measurements of two individual ground finches to learn how small changes in bill size and shape can lead to evolutionary changes. They can turn a carved diorama to see how two life-sized medium ground finches from the same island at the same time can vary significantly in the size of their bill and see the plants favored by each. Visitors can learn how the proportion of large- and small-beaked finches in the population changes from wet to dry years, and they can turn a globe to trace Darwin's voyage and learn where the Galápagos Islands are located.
- Human: Svante Pääbo and Henrik Kaessmann use the techniques of molecular biology at the Max Planck Institute for Evolutionary Anthropology to investigate the genetic ties between humans and chimpanzees. The exhibit invites visitors to compare 2700 base pairs from a section of X chromosomes from humans and chimps. The nucleotides are aligned on a huge wall in a game of "Where's Pääbo?" where tiny Pääbo figures indicate nucleotide differences. Visitors then can walk to the other side of the wall to compare their own images to those of a family of chimpanzees. Flip books allow visitors to explore the similarities and differences between humans and chimps on such characteristics as behavior, brain size, blood type, and DNA.
- Whale: Philip Gingerich's remarkable discovery of the fossil bones of *Rodhocetus* confirmed evidence from DNA studies that whales evolved from mammals much like the ancestor to modern-day hippos. Visitors to this exhibit investigate Gingerich's finds from an ancient shore in Pakistan to discover how the double pulley anklebone of *Rodhocetus* compares to that of a modern hippo and contrasts to that of a modern wolf, and how the skull of *Rodhocetus* shows a transition between the skull of a modern whale and that of one of the earliest known whales, *Pakicetus*.

Exhibits on each research project are linked together by highlighting the interaction of four primary principles of evolution—variation, inheritance, selection, and time—a unifying conceptual framework used with permission from the University of California Museum of Paleontology. These are repeated in each section of the exhibit, providing a common thread of evolutionary principles that are at work in all organisms.

The Explore Evolution project also includes a book of inquiry-based activities for middle-school youth, titled *Virus and the Whale, Exploring Evolution in Creatures Small and Large*, published by the National Science Teachers Association Press in 2005 (Diamond 2005). This book extends the learning experiences of the museum exhibits to any environment for youth groups and schools.

The project has already generated a significant amount of local, national, and international publicity. Each partner museum created an array of public programs that include teacher development workshops using the *Virus and the Whale* book (at Texas, Oklahoma, Kansas, Nebraska and Michigan), public evolution lecture series (at Michigan, Kansas, Minnesota, and Oklahoma), evolution camps for children (at Nebraska, Michigan, Kansas and Oklahoma), public evolution days (Kansas and Michigan), and other programs.

Reasoning about Evolution

ADULT MUSEUM VISITORS

Effective evolution exhibitions should not only present intriguing and current information that engages the visitor, they should also enhance visitors' understanding. To do this successfully requires some knowledge of the reasoning processes that visitors, young and old, bring to the exhibition. For the past two years, we have been investigating how museum visitors reason about evolution before, during, and after their visits to the Explore Evolution galleries and programs (Evans 2005; Evans et al. 2006). The exhibit and related educational materials serve as devices for eliciting people's thinking patterns which are then analyzed for evidence of conceptual change. Through this process we can begin to identify the specific elements that can help people better understand evolutionary processes.

Darwinian evolutionary explanations pose unique conceptual problems. Considerable research on everyday explanations for natural phenomena reveals a set of cognitive biases that would appear to make evolutionary explanations particularly counterintuitive (Evans 2000, 2001; Evans et al. 2005). Though these biases emerge in childhood, they are manifested in all age groups. Evolutionary ideas challenge the everyday intuition that the world is stable and unchanging (essentialism), and that animate behavior is purposeful (teleology) and intentional (e.g., Wellman and Gelman 1998; Gelman 2003; Medin and Atran 2004). Moreover, human evolution, in particular, challenges the intuition that humans are privileged and destined to escape the fate of other species on this planet (Evans 2001; Poling and Evans 2004).

In our research, visitors who exhibited one or more of these cognitive biases when explaining an evolutionary problem were categorized as using *novice naturalistic reasoning*. Visitors who had a basic grasp of Darwinian evolutionary explanations, though they were not experts, were categorized as using *informed naturalistic reasoning*. Visitors that invoked supernatural explanations used *creationist reasoning*. Subsumed under each of these three reasoning patterns were a number of themes that referenced concepts judged to be characteristic of that particular pattern. For example, visitors using the informed naturalistic reasoning pattern might reference one or more of the evolutionary principles, variation, inheritance, selection and time, that provided the conceptual framework for the exhibit (Evans et al. 2006).

In one of our visitor studies, adult museum visitors in Nebraska, Oklahoma, and Michigan were interviewed before the exhibit had opened. Each visitor was presented with a set of seven observations on evolutionary change that were based on the core issues addressed by the seven scientist teams featured in the exhibit. Visitors were then asked how they would explain the observations. The term evolution was not mentioned. We were interested in the extent to which visitors would spontaneously invoke an evolutionary concept, and whether they would apply the same explanation across the diverse organisms to be presented in the exhibition. From the 32 visitors' responses, over 600 distinct relevant conceptual units were identified. These were then categorized as referencing one of the themes from the three major reasoning patterns. To ensure that this coding system was reliable, each response was coded separately by two trained coders; initial interrater reliability was around 90%, and all responses were subsequently coded to 100% agreement (Evans et al. 2006).

Fruit fly problem

Museum visitors were asked:

Scientists think that about eight 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?

An example of informed naturalistic reasoning by a museum visitor:

> Well, the 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, and if they were not adapted, the mutations just ceased - those fruit flies died off. So that would explain the variety.

This visitor invoked several evolutionary concepts, though the visitor was clearly not an expert.

An example of novice naturalistic reasoning by a museum visitor:

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

In this example, intuitive modes of reasoning are invoked, which indicate that the visitor is not conceptualizing this problem as one of evolutionary change.

An example of creationist reasoning by a museum visitor:

> Um, first of all I have a problem with your eight 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.

This visitor invoked supernatural rather than natural explanations, in particular, God's direct role in the origin of species.

Galápagos finch problem

In this problem, museum visitors were asked:

During one year, scientists measured the beaks of one kind of finch on a remote island. They found that most of these finch beaks were small. In the following year, a drought wiped out almost all the plants that produce small seeds. Only the plants that make large tough seeds remained. A few years later, the scientists returned to the island and measured finch beaks again. This time they found that more of the finches had bigger beaks. How would you explain why more of the finches had bigger beaks?

An example of informed naturalistic reasoning by a museum visitor:

> Well, in that case, I would assume that the birds evolved – well, the birds with the larger beaks 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 over time. . . . They didn't produce as many offspring.

An example of novice naturalistic reasoning by a museum visitor:

> 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. That's not evolution, is it, it's another word. Is it development? Then their babies had those beaks.

This visitor demonstrates a teleological misconception, which, while incorrect, does acknowledge the importance of adaptation and change over time.

A second example of novice naturalistic reasoning by a museum visitor:

> 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 . . .

This visitor invokes the classic "Lamarckian" teleological evolutionary explanation.

Four key findings emerged from this initial visitor study:

1. All visitors exhibited mixed reasoning patterns: 72% combined *informed* naturalistic and *novice* naturalistic reasoning patterns across the seven questions, whereas a further 28% added *creationist* reasoning to this mixture.
2. Different organisms elicited different reasoning patterns. The finch question was the most likely to elicit *informed* reasoning patterns, particularly selection. The HIV, diatom, fly, and ant/fungus questions were more likely to elicit *novice* reasoning patterns. Where *creationist* reasoning was demonstrated, it was most likely to be applied to the human/chimp problem.
3. The majority of visitors did demonstrate a dominant reasoning mode, one that they used most frequently: *informed* naturalistic reasoning predominated for 34% of the sample and *novice* naturalistic reasoning for 54% of the sample, whereas only 6% consistently used *creationist* reasoning for the majority of the organisms.
4. Visitors' explanations also differed depending on their prior museum experience. Those who visited museums more often, even as children, were significantly more likely to use evolutionary terms in their responses.

Mixed reasoning is probably pervasive. National surveys as well as more focused studies show that as many as a quarter of respondents find the biblical account of the origins of life and the idea that humans evolved over time to be compatible with one another and consider both to be true (Evans 2000, 2001; Keeter 2005). In a recent study of adults' and children's ideas about origins, it was found that at all ages, even in Christian fundamentalist communities, respondents were much more likely to apply rudimentary evolutionary explanations to frogs and butterflies than to nonhuman mammals, and least likely to apply them to humans; the converse was true for creationist explanations (Evans et al. 2005).

In response to the finch problem, the following mixed reasoner shows both creationist and informed naturalistic reasoning, simultaneously denying evolutionary origins, while providing a rudimentary description of natural selection:

> But like I said, 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.

Not surprisingly, in comparison with national samples, U.S. natural history museum visitors are much less likely to endorse creationism. However, even for a group that is more highly educated and probably more interested in natural history than the general public, only about a third demonstrate a basic grasp of Darwinian evolutionary principles. Not one visitor offered *informed* naturalistic responses to all seven questions. Interestingly, museum visitor research in other English-speaking countries demonstrates a similar lack of understanding. Using different measures, Silver and Kisiel (2006) found that only about 30% of visitors to selected natural history museums in Australia, Canada, and the United States exhibited a basic understanding of natural selection; this despite the fact that creationist ideas were less likely to be endorsed in the other countries than in the United States.

These findings offer support for the thesis that many people find evolutionary ideas counterintuitive. Given their educational levels (Korn 1995), museum visitors are likely to have been introduced to Darwinian evolution at school, but these principles do not appear to be retained. Visitors seem to revert to their more compelling intuitive explanations of evolutionary change. This suggests that the task of conveying evolutionary principles to the general public is complex, and it requires that attention is paid to the way this knowledge is initially constructed, particularly the pattern of novice naturalistic reasoning, the dominant pattern for 54% of the above museum visitor sample. One place to begin is with children's understanding.

CHILDREN'S REASONING

How do these responses fit with what is known about children's reasoning? Over the past 15 years or so, Evans and her colleagues have studied the earliest manifestations of children's understanding of natural transformations, such as evolutionary change (Evans 2000, 2001; Poling and Evans 2004). The cognitive biases that seem to constrain adults' understanding of events that are outside their everyday experience emerge quite early in childhood (Wellman and Gelman 1998; Gelman 2003).

Young children's essentialist and teleological biases are manifested in the preschool and early school-age years (if not earlier). They are demonstrated by children's refusal to acknowledge radical biological change such as adaptive change or metamorphosis (Rosengren et al. 1991). In keeping with their biases, children reason that animal features such as wings or fins are for a particular purpose, flying or swimming, but they have little sense of what would happen to those same animals if the environment changes (Evans 2000). If asked about the origins of particular animals, they may say that "God made them" (particularly if they are from a Christian fundamentalist background) or that they came "from someplace else" or "out of the ground." Such reasoning fits with the notion of a static, unchanging world in which living things are eternal. The same question is treated differently by eight- to nine-year olds. Regardless of parental belief system, most eight- to nine-year old U.S. children spontaneously endorse creationist (made by God) explanations for the origin of species. This shift likely occurs because children of this age have a greater appreciation of existential questions, particularly of death. They are also ready to provide a familiar "creative" mechanism, derived from their everyday intuitive psychology, that of intelligent design, to explain the origins problem (Evans 2000, 2001).

By the time they are early adolescents, children in nonfundamentalist families who are exposed to evidence of radical biological change, such as fossils, adaptation, and metamorphosis, are likely to endorse the otherwise counterintuitive evolutionary concept that animals can change from one kind to another, over time. They still retain, however, a *functional* teleological notion, that animals change to adapt to the environment. Conversely, children from fundamentalist backgrounds who attend schools that endorse Biblical literalism, and who know the least about natural history and fossils, are likely to maintain and extend their creationist beliefs (Evans 2001). That these early cognitive biases still constrain adult museum visitors' understanding, even though their expression is muted in an adult population, is a testimony to their persistence.

Conclusion

This process—of deciphering how visitors apply their reasoning patterns— should help museums improve visitor understanding at evolution exhibits. Already, many museum visitors apply evolutionary principles to some organisms, but the majority understand only a few strands of evolutionary theory, and there are many misconceptions. Given the persistence of these cognitive biases, a single visit to an evolutionary exhibit is unlikely to bring about radical conceptual change. By focusing on those concepts that are most susceptible to change, it may well be possible to pry open the chinks in this conceptual armor and bring about subtle shifts in these reasoning patterns. Small changes can usher in large changes, as Darwin amply demonstrated.

In the best of all worlds, museums may be able to play a role in shifting visitors' perspectives from novice naturalistic or creationist reasoning patterns to the informed naturalistic pattern—at least for more kinds of organisms. However we know relatively little about how exhibit learning experiences influence conceptual change. To improve the effectiveness of museums in educating the public about evolution, we need learning research that builds on known principles of developmental and cognitive psychology and that takes advantage of the experimental opportunities inherent in a museum setting. Becoming effective at teaching evolution to the public may only be achieved when museums embrace a research agenda that will adequately inform them of how their educational interventions influence visitors' thinking.

Learning research reports and more information about the Explore Evolution project are available at http://explore-evolution.unl.edu.

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