Natural History Museum Visitors' Understanding of Evolution

BRUCE J. MACFADDEN, BETTY A. DUNCKEL, SHARI ELLIS, LYNN D. DIERKING, LINDA ABRAHAM-SILVER, JIM KISIEL, AND JUDY KOKE

Natural history museums are the principal repositories of the collections that represent much of the objective evidence for evolution. With approximately 50 million visitors annually, US natural history museums can significantly influence the public's understanding of evolution. Here we present the results of a study that investigated the knowledge of key evolutionary concepts exhibited by high-school students and adults who visited natural history museums. Ninety-five percent of the study participants understood relative geological time (superposition), but only 30 percent explained biological change (microevolution) in terms of natural selection, and 11 percent explicitly rejected evolution. In general, museum visitors have an incomplete understanding of evolutionary concepts. For example, while participants have a good understanding that fossils represent evidence for evolution, they have a poor understanding of the mechanisms of evolution. Natural history museums can foster visitors' understanding of evolution by integrating this content—particularly concepts that are difficult to understand—throughout all relevant exhibits and public programs.

Keywords: natural history museums, evolution, exhibits, informal education, visitors

Eighty years after the Scopes "monkey trial," one could argue that we as a society have not improved public understanding and acceptance of evolution. Since 1859, when Darwin's *On the Origin of Species* was published, the tenets of religious fundamentalism and the recent intelligent design (ID) movement have done much to influence the understanding and acceptance of evolution. This is particularly true in the United States: politicians have expressed their particular viewpoints, and in certain instances have legislated that creationism and ID be taught in public schools either along with or in place of evolution. Although the US Supreme Court ruled in *Edwards v. Aguillard* (482 U.S. 578 [1987]) that teaching creationism and "creation science" is unconstitutional, proposals that encourage or require teaching creationism along with evolution in public schools have been advanced in 37 states since 2001 (Holden 2004). In the landmark decision *Kitzmiller v. Dover* (400 F. Supp. 2d 707 [M.D. Pa. 2005]), the Pennsylvania federal court ruled that ID is not science, and thus teaching it in public schools violated the establishment clause of the First Amendment of the US Constitution (Jones 2006). In Kansas, despite several years of wavering (Holden and Bhattacharjee 2005), the recent Kansas elections once again shifted the control of the Board of Education to a majority view that evolution is well supported by scientific evidence and should be taught in public schools (Bhattarcharjee 2006).

In a recent Gallup poll, 35 percent of US respondents said that evolution is well supported by evidence, and 35 percent said evolution is not supported by evidence (29 percent said they did not know and 1 percent expressed no opinion). Forty-five percent of the respondents reported that they believe God created humans in their present form within the past 10,000 years. The public's understanding of evolution and their beliefs about it have not changed significantly over the past quarter-century (Gallup 2007, NCSE 2007). In a recent survey administered in 34 countries, the United States ranked second to last in public acceptance of evolution (Miller et al. 2006).

The fundamental evidence for evolution, such as actual specimens and related exhibits, represents the objective scientific knowledge that is displayed in natural history museums (e.g., Suarez and Tsutsui 2004, Thomson 2005,

Bruce J. MacFadden (e-mail: bmacfadd@flmnh.ufl.edu) is a curator and professor, Betty A. Dunckel is a center director and associate research scientist, and Shari Ellis is a project coordinator at the Florida Museum of Natural History, University of Florida, Gainesville. Lynn D. Dierking is a professor at Oregon State University in Corvallis. Linda Abraham-Silver is the president and executive director of Great Lakes Science Center in Cleveland, Ohio. Jim Kisiel is an assistant professor at California State University in Long Beach. Judy Koke is a senior associate at the Institute for Learning Innovation in Annapolis, Maryland.

West 2005, Diamond and Scotchmoor 2006). In 2004, approximately 50 million people visited US natural history museums (principally collections-based museums [AAM 2004]). Although exhibits and related public programs with natural history or evolution content are on display or presented at science centers, botanical gardens, zoological parks, national parks, and other museums (e.g., Hansen 2005), collections-based natural history museums provide unique opportunities to promote the public's understanding of evolution, and these are the focus of this report. Except for a few recent studies (e.g., Spiegal et al. 2006, Storksdieck and Stein 2006), little research has been done to ascertain natural history museum visitors' understanding and acceptance of evolution.

Research methods, demographics, and project design

We conducted interviews at six US natural history museums to examine visitors' understanding of evolution and the nature of science: the Denver Museum of Nature and Science (DMNS), the Florida Museum of Natural History (FLMNH), the Natural History Museum of Los Angeles County (NHMLAC), the George C. Page Museum at the LaBrea Tar Pits (Page), the Smithsonian National Museum of Natural History (NMNH), and the University of Kansas Natural History Museum and Biodiversity Research Center (KU). These museums were selected because they are located in different parts of the United States, represent either predominantly urban or less populated areas, vary in annual visitation (size), and have different governance and support (private versus public).

Study participants were selected using a stratified space sampling method. Responses from only one member of each group (one person in a family, e.g.) were included in the data set. Interviews consisted of three parts (as discussed below), lasted about 10 minutes, included object- or image-based prompts, and were audiotaped. The data reported here are a subset of a larger study that included elementary and middle-school students. A discussion of the younger participants' data and implications, although potentially interesting, is outside the intended scope of this article.

Sample characteristics. Researchers recorded 414 interviews with visitors of high-school age or older at the six natural history museums. Our stratified space sampling resulted in approximately equal representation across the following age groups: high school (15 to 18 years), young adults (19 to 34 years), middle-aged adults (35 to 54 years), and older adults (55 years and older). Rates of refusal were 10 percent at KU and Page, 14 percent at DMNS, 20 percent at FLMNH, 30 percent at NHMLAC, and 50 percent at NMNH. The refusal rate at DMNS was actually higher than reported here because interviewers kept track of refusals resulting only from explicit antievolution sentiments; at other sites, the most commonly cited reason for refusal to participate was lack of time.

Of the 414 interviews, results from 34 are omitted from the analyses because of audiotaping problems or because significant portions of these interviews were not completed. The remaining 380 interviews are distributed among the age groups as follows: 15 to 18 years, 61; 19 to 34 years, 116; 35 to 54 years, 117; and 55 years and older, 86. The high-school-aged respondents were not part of school groups when they were interviewed. The numbers of males and females in each age category are approximately equal.

Demographics. The study participants were from 39 US states, Canada, and five other areas of the world (Latin America, Europe, Middle East, Australia and New Zealand, and Asia). The racial and ethnic composition of the sample was white or non-Hispanic, 75 percent; Hispanic, 8 percent; Asian, 5 percent; African-American, 4 percent; and multiple or other, 8 percent. The educational level of the participants who were not high-school students (> 18 years old) included people with a master's, doctoral, or professional degree (41 percent); with a college degree (22 percent); with some college or post-high-school technical courses (28 percent); and with a high-school degree or less (9 percent).

Research instrument. The goal of our research design was to develop an "on-the-floor" interview to investigate visitors' understanding of different components of evolution, as well as the nature of science. Our interview consisted of three components: fossils and rock strata, cheetah microevolution, and personal beliefs and geological time line.

Fossils and rock strata. We adapted a classroom activity developed by Lawson (1999) to assess visitors' understanding of fossil evidence and geological time. Study participants were shown a variety of fossils (ammonite, trilobite, coral, ancient and modern shark teeth, ancient and modern horse teeth, dinosaur tooth replica, and tortoise shell) and an illustration of a hypothetical rock strata (figure 1). The goal of this component was to evaluate knowledge of relative geological time, ancient environments, extinction, and the nature of science. After participants examined the fossils, we asked questions that required them to draw inferences based on the fossil evidence, and to generate explanations for the pattern of evidence. Two project researchers independently coded the responses to this module for 25 percent of the interviews. Interrater reliability was 99 percent.

Cheetah microevolution. To assess visitors' understanding of intraspecies evolution, we asked participants this question: "According to many scientists, long ago the cheetah had an ancestor that was not able to run as fast as the modern cheetah. How would these experts explain the cheetah's running ability? Please explain this development as precisely as you can using the principles of biological evolution, regardless of whether you personally believe this explanation." We chose this scenario because it has been used in previous research on evolution understanding among college students and college-aged adults (Bishop and Anderson 1990, Demastes et al. 1995, Brem et al. 2003, Nehm and Reilly

2007). Participants' responses were coded in terms of explanatory, discrete frameworks, such as natural selection, transformative, amechanistic, static selection, teleologic, practice and learning, and others (table 1). For an answer to be coded as natural selection, the respondent had to include the following key microevolutionary concepts: intraspecies variation, survival advantage, genetic determination, reproductive advantage, and accumulated change. Interrater reliability was 95 percent.

Personal beliefs and geological time line. We probed participants' personal beliefs about evolution in two ways. After visitors gave their explanation of microevolution in the cheetah activity, we asked if they personally believed the explanation and, if not, how their beliefs differed. This approach has been used in previous research to elicit participants' personal beliefs about evolution (Brem et al. 2003). We also attempted to assess creationist beliefs by asking visitors to place seven major geological and biological events on a time line from 15 billion years ago to the present (figure 2), using cards labeled "Origin of the Universe," "Origin of Earth," "Life on Earth," "Fish," "Land plants," "Dinosaurs," and "Humans." We hypothesized that participants who were young-earth creationists (*sensu* Scott 2004) would place all of the cards at the bottom of the time line. We categorized responses to this latter exercise as either placing all items at one point in time (e.g., < 10,000 years ago) or spreading them out over the time line. Interrater reliability was 98 percent for personal beliefs and, on the basis of 25 percent of the interviews, 100 percent for the time line.

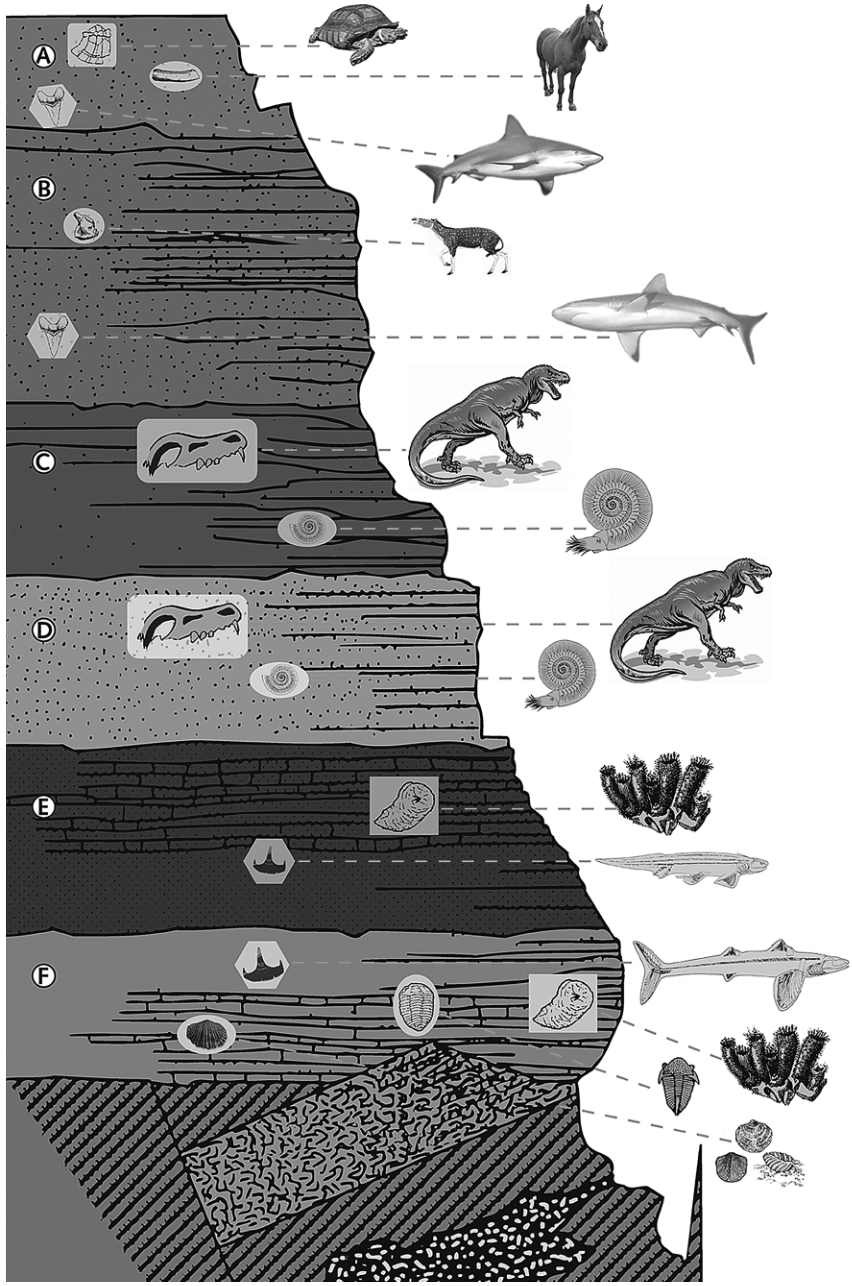

Figure 1. Geological strata, including fossils and reconstructed species (modified from Lawson 1999). During each survey, this graphic was supplemented by a collection of actual fossils or casts.

Interview results and interpretation

In the following three sections, we discuss results from interview questions about fossils and rock strata, cheetah microevolution, and personal beliefs and the geological time line.

Fossils and rock strata. Nearly all (95 percent) of the participants understood the concept of superposition (i.e., fossils in the bottom strata are older than those above). This understanding varied with age ($p < .05$, degrees of freedom [df] = 3, $\chi^2 = 7.72$) and education ($p < .039$, df = 2, $\chi^2 = 6.50$). Ninety-nine percent of middle-aged adults, compared with 90 percent of older adults, understood that the oldest fossils are found at the bottom of the rock column ($p < .047$, df = 1, $\chi^2 = 3.94$), as did 97 percent of those with a college degree, compared with 86 percent of participants with a high-school degree or less ($p < .039$, df = 1, $\chi^2 = 6.50$). All but two participants explained their correct response in terms of layers of sediment building up over time, or with knowledge of the times when the fossils would have lived (e.g., dinosaurs below horses indicated that the dinosaurs were older).

Likewise, nearly all (93 percent) of the participants interpreted the ancient environments from the fossils contained in the particular stratum—for example, sharks, corals, and

Table 1. Discrete explanatory framework categories used to code participants' responses during the "cheetah microevolution" component of the interview.

Framework	Verbatim sample answer
Natural selection	"Evolution through time...there would have been natural variation in the ancestral population of cheetahs and those who were better able to run faster would catch more prey and survived to reproduce and the others eventually became extinct. So the best adaptation for this environment for the cheetah was to be a fast runner. They survived to pass their genes on to future generations which led to the development of the modern cheetah."
Transformative	"You have a group of cheetahs that are all roughly the same speed except that you have a random mutation of genes that produces one little baby cheetah that is a little faster than the others...and that one tends to do better, get game better, and ends up having better success at breeding and its offspring carry that same propensity for speed and over multiple generations you end up with faster cheetahs."
	"The not-so-fast species mated with something that was faster than it and they made a new species of cheetah and it became a lot faster and their DNA changed."
Amechanistic	"Evolution. Things evolve. They start at one form that's different and then they keep developing so that they change...and so it could have started out slow and through evolution different things happened in their bodies as they went from generation to generation to they evolved into what they are today."
Static selection	"They explain that change by...I think selection. That the faster animals survived, the slower animals died off. Only those who could move fast enough to catch their prey were able to survive and the others starved to death."
Teleologic	"Probably then a long time ago it started to need to—like its prey was starting to get faster so then it had to adapt to that. And so then it started getting faster so it could eat. And then after a lot of years and generations they started to become faster so they could find food and eat it 'cause the antelope was getting to be faster and they needed to eat it."
Practice and learning	"Since the cheetah couldn't run very fast at the start...they eventually picked up pace by running, by trying to run faster every day. Eventually able to actually give birth to ones who could do that on their own instead of just exercise. Eventually it would come to cheetahs of today."
	"Maybe it just had to learn and evolved to be faster because the things it caught were really hard to catch. You needed to be fast and quick and you needed to be sneaky."
Other	"I feel that the reason is just basically... we are healthier than our forefathers were because we have a healthier diet. The climate, environment probably became more friendly to them. They had more food to eat and simply they started to have better children."

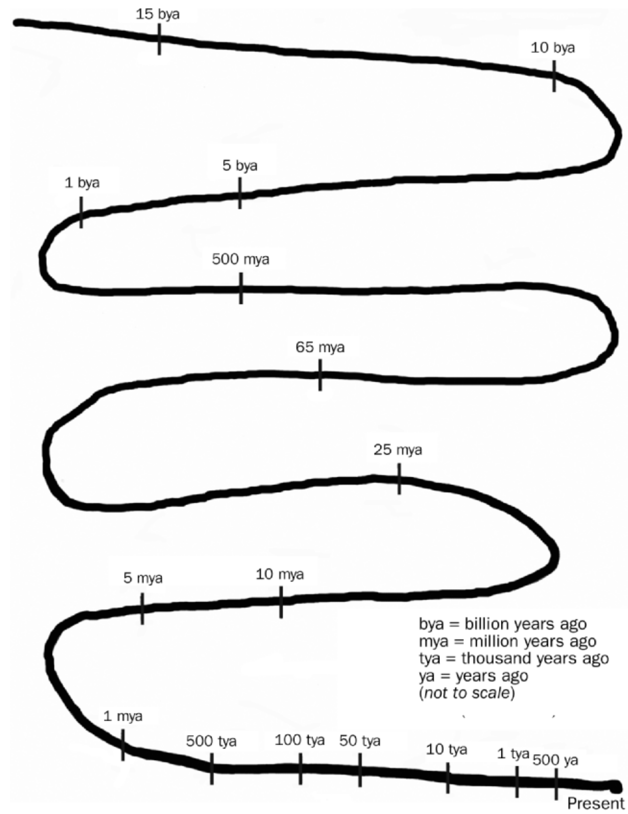

Figure 2. Time-line activity in which survey participants were asked to place major Earth and life events along this time line. Modified, with permission, from Pulling (2001).

shells (figure 1, stratum F) indicate an aquatic environment. Five percent of participants interpreted the environment as other than aquatic (e.g., "harsh" or "desert-like"). The majority (69 percent) of participants based their answers either on prior knowledge or on features in the graphic (figure 1).

When asked what it means when scientists find fossils in lower layers but not in upper ones, 74 percent of participants responded that the organism either lived long ago, died out, or evolved into something else. Similarly, when asked what it means to find fossils in upper layers but not lower ones, 74 percent said either that it was "newer" or that it had evolved. There is a significant difference in responses to this question with the participants' age ($p < .008$, df = 3, $\chi^2 = 11.90$). In this case, 89 percent of high-school students inferred the animal would be newer or would have evolved, while 76 percent of middle-aged adults, 66 percent of young adults, and 67 percent of older adults did so. High-school students differed significantly from both the young and older adults ($p < .002$, df = 1, $\chi^2 = 9.79$ and 9.70, respectively).

With regard to the nature of science, when asked about the implications of new fossil discoveries (e.g., fossils not previously found in a particular stratum but later found there during subsequent collecting), 94 percent of participants were able to draw a reasonable inference. Middle-aged adults were more likely than other age groups to discuss theory revision in light of new discoveries ($p < .038$, df = 3, $\chi^2 = 8.41$):

16 percent of middle-aged adults allowed that scientists would have to revise their theories, compared with 5 percent of high-school students, 8 percent of young adults, and 6 percent of older adults ($p < .05$, df = 3, χ^2 = 3.86, 4.74, and 4.37 respectively).

Cheetah microevolution. The participants' explanations for the cheetah's running ability varied by age ($p < .001$, df = 81, $\chi^2 = 46.16$; figure 3). High-school students were significantly less likely to offer natural selection explanations than young, middle-aged, or older adults ($p < .05$, df = 1, χ^2 = 19.99, 13.72, and 4.76, respectively). Older adults were less likely than either young or middle-aged adults to provide a natural selection explanation ($p < .05$, df = 1, χ^2 = 8.41 and 5.58, respectively). High-school students were more likely than other participants to offer amechanistic accounts for the cheetah's faster running ability—that is, they said the cheetah evolved, without specifying a process or mechanism ($p < .02$, df = 1, $\chi^2 = 7.61$ for young adults, $\chi^2 = 4.79$ for middle-aged adults, and $\chi^2 = 6.46$ for older adults). Middle-aged adults were less likely to offer teleological explanations than participants of other ages ($p < .02$, df = 1, $\chi^2 = 7.43$ for high-schoolers, $\chi^2 = 5.84$ for young adults, and $\chi^2 = 6.35$ for older adults). There were no age differences in the other types of explanation.

Explanation types also varied by level of education ($p < .001$, df = 18, $\chi^2 = 46.16$). Participants with a college degree were more likely than participants with less education to explain the cheetah's running ability in terms of natural selection (high-school versus college degree: $p < .001$, df = 1, $\chi^2 = 32.91$; some college versus college degree: $p < .002$, df = 1, $\chi^2 = 9.49$); and those with some college or technical training were more likely than those with a high-school degree or less to offer a natural selection account ($p < .02$, df = 1, $\chi^2 = 5.74$). Participants with a high-school degree or less were more likely to offer an amechanistic explanation than were those with a college degree ($p < .001$, df = 1, $\chi^2 = 23.99$). This latter difference may be a result of having had less opportunity to learn about natural selection during K–12 education than did those participants with a college education.

In the pooled sample from all museums, 30 percent of all respondents used natural selection as a framework to explain the faster running ability of the cheetah relative to its ancestors (figure 4). Although the percentage of respondents who cited natural selection as the reason for the cheetah's faster running ability was far higher than for any of the other explanatory frameworks, together those other frameworks represent more than two-thirds of the responses—responses that are essentially incorrect in terms of modern evolutionary theory.

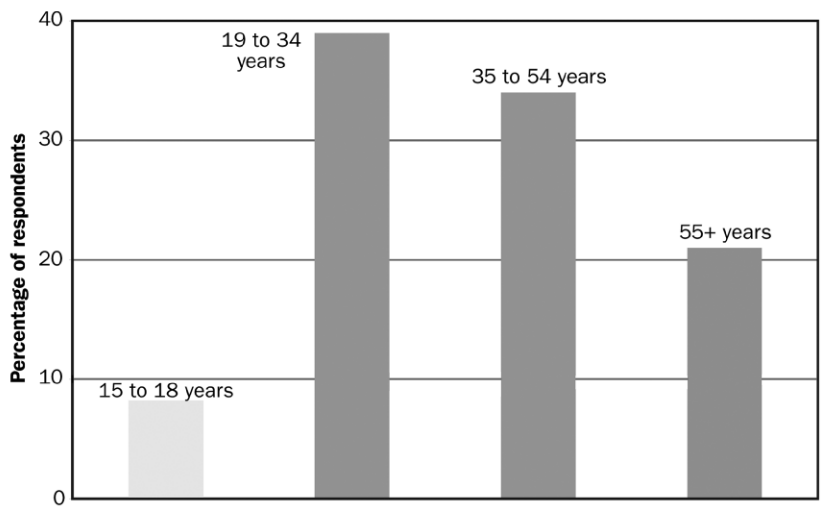

Figure 3. Percentage of respondents, by age, who used natural selection as an explanation for the faster-running cheetah.

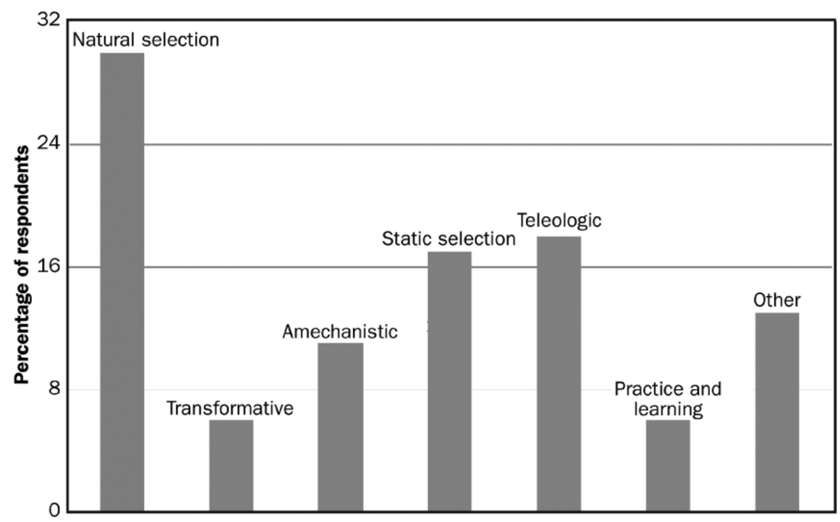

Figure 4. Percentage of responses, by explanatory framework for the faster-running cheetah, for the entire participant pool (see also table 1).

Personal beliefs and geological time line. Eighty-nine percent of study participants who were asked, or whose responses could be reliably coded ($n = 365$), accepted evolution. The remaining 11 percent either explicitly rejected evolution or expressed some skepticism, such as "God created animals as they exist today" and "Evolution is correct for some situations, but not others." With regard to the latter example, a participant may have accepted microevolution but not macroevolution, or he or she may have rejected the possibility that humans evolved from nonhuman primates.

When acceptance of evolution was tested on the time line, only 2 percent ($n = 9$) of participants placed all the events at the same time (< 10,000 years ago). This included 8 of the 22 study participants who believed God created animals on Earth as they are now, and one participant who accepted microevolution but not macroevolution. Six participants who believed God created animals in their current form declined to place the items on the time line at all. These respondents may be young-earth creationists, or perhaps they thought that all seven events occurred (or were created) at the same time. An interesting and unanticipated finding of the time-line activity was that although most (approximately 80 percent) respondents placed the cards in logical order, far fewer understand the magnitude of geological time corresponding to when these events actually occurred. Acceptance of evolution without reservation varied by age ($p < .004$, df = 3, $\chi^2 = 13.08$). Nearly all high-school students (96 percent) and young adults (95 percent) accepted evolution, compared with 84 percent of middle-aged adults and 83 percent of older adults. Thus, high-school students and younger adults were significantly more likely to accept evolution than either middle-aged adults ($p < .035$, df = 1, $\chi^2 = 4.45$; $p < .02$, df = 1, $\chi^2 = 5.39$) or older adults ($p < .031$, df = 1, $\chi^2 = 4.67$; $p < .019$, df = 1, $\chi^2 = 5.53$).

Rejection of evolution did not vary with level of education. Ten percent of participants with a high school degree or less rejected evolution, compared with 18 percent of those with some college or technical training and 13 percent with a college degree or more. Rejection of evolution, however, was inversely associated with understanding of evolution ($p < .013$, df = 1, $\chi^2 = 6.11$). Thus, 32 percent of those who accept evolution were able to provide a scientifically accurate account of the cheetah's running ability, compared with only 14 percent of those who reject evolution. Participants who either accept or reject evolution differed little in the alternative explanations they offered for the cheetah activity. However, differences between the two groups in the likelihood of offering a teleological explanation for the cheetah problem approached significance ($p < .053$, df =1, $\chi^2 = 3.72$). Only 17 percent of those who accept evolution offered a teleological account, compared with 29 percent of those who reject evolution.

One of the initial project goals was to determine whether there are geographic differences in understanding evolution among museum visitors. Indeed, differences among museum sites in acceptance of evolution approached significance ($p < .078$, df = 5, $\chi^2 = 9.92$). The lowest rates of acceptance were at KU, FLMNH, and NMNH, at 80 percent, 83 percent, and 83 percent, respectively. Acceptance rates at NHMLAC and Page were 94 percent and 88 percent, respectively. Our results indicate that at DMNS, 95 percent of participants accept evolution; however, 14 percent of the visitors approached to participate in the study at DMNS declined to do so because they held negative attitudes toward evolution. Thus, the rates of acceptance at DMNS are not strictly comparable with those at the other institutions. The interpretation of the geographic significance of these results is somewhat equivocal. Even though the study sites are located in different regions of the United States, the demographics of visitors, particularly at the large urban museums with a high percentage of out-of-town visitors, precludes conclusions about geographical differences. Visitors' prior exposure to evolution may have occurred not where the museum is located but where they live or were raised.

Recommendations and take-home messages

Several general patterns emerge from these data and from other studies of visitors to US natural history museums and science centers. When compared with respondents to recent general survey polls, high-school students and adults who visit natural history museums and other similar informal learning settings have a better understanding of evolution and are less likely to reject it (Spiegal et al. 2006, Storksdieck and Stein 2006). Nevertheless, there still is a need to improve the understanding of some key evolutionary concepts. For example, whereas the great majority of respondents understand the concept of relative geological time, fewer understand natural selection as a mechanism for microevolutionary change between successive generations.

Research studies like this one provide interesting and potentially useful results, but they also generate questions that cannot be answered within the limits of the current study design. Additional studies using major Earth and evolutionary events could perhaps elucidate misconceptions about the magnitude of geological time. Similarly, the significant geographic differences in rejection of evolution that are now merely speculative represent a potentially fruitful line of investigation.

Evolution is a major concept in the life and earth science standards for grades 9–12 (NRC 2001). Nonetheless, only 8 percent of the high-school-aged study participants gave accurate explanations for the change in running ability of the cheetah (figure 3). In contrast, almost 40 percent of the young adults provided an accurate explanation of natural selection. It is unclear why this age variation for the natural selection responses exists, nor can we account for the increase in understanding from high-school ages to young adulthood, and the subsequent reduction of understanding in middle-aged and older adults.

Previous research documents how difficult it is for high-school and college students to master the fundamental concepts of evolution. The findings presented here suggest that most adults beyond high-school or college age also struggle to understand the mechanisms of biological evolution. Research needs to go beyond documenting that evolution is difficult to grasp—it needs to examine the obstacles to evolution understanding. For example, recent research suggests that people who view knowledge as fixed and unchanging, and who are less open to new ideas and critical thought, have less understanding of evolution (Sinatra et al. 2003).

Another promising research direction focuses on intuitive theories that constrain human thinking about entities and events. These include essentialist beliefs (i.e., beliefs in the fixed, inherent nature of a thing), which prove problematic when thinking about common descent (Evans 2006), and teleological biases that make it difficult to reason about random and chance events (Kelemen 1999). Understanding how museum visitors consider evolution and identify evolutionary concepts has practical applications in the development of more effective museum exhibits. The various ways in which difficult concepts are presented can be examined to determine whether the science content of exhibits can be made more accessible. Moreover, the results of additional research on the knowledge and understanding of visitors to natural history museums could be compared with those of similar studies of evolution understanding in classrooms and among the general public.

The results and interpretations of this study yield some recommendations about how natural history museums and other institutions with evolutionary content can effectively convey evolution to their visitors. Several key concepts involved in communicating a holistic view of evolution are adaptation, homology, inheritance, population dynamics, selection, speciation, survival of the fittest, time, and variation, as well as the nature of science. The results of our study demonstrate that certain concepts, such as relative geological time (superposition), are well understood, whereas others, such as natural selection, are not. The latter concepts would therefore benefit from a stronger emphasis in exhibits and related public programs so that visitors have a more comprehensive understanding of evolution.

As a unifying theme within natural history museums, evolution content can be integrated into most biologically and geologically themed exhibits; it does not necessarily have to be set apart in a "hall of evolution," as has been done at some museums. Evolution can be communicated explicitly, or evolution content can be communicated through its key concepts. Summative evaluation of existing exhibits can elucidate the effectiveness of communication of the various concepts of evolution (e.g., Screven 1990, Frechtling 2002). Weaknesses or gaps in knowledge identified during evaluation can be remedied by redesigning particular exhibits or adding educational programs and activities specifically geared toward enhancing visitors' understanding of these difficult concepts.

The explicit inclusion of evolution in institutional mission statements precludes the continuing debate and uncertainty about whether this content should be the dominant scientific paradigm in relevant exhibits and public programs. Likewise, docents and floor-staff members who interact with museum visitors can benefit greatly from training sessions that articulate a consistent message about the museum's view on evolution, develop background about the key components and evidence for evolution, and provide additional resources for those who want it (Allmon 2006). Humans learn new concepts more readily when they build upon an existing knowledge base or when the concepts have direct relevance to daily life (Bransford et al. 2000). Thus, for macroevolution, the ever-popular dinosaurs facilitate an understanding of fossils and geological time. And microevolution has benefited from public awareness of rapidly evolving disease vectors that become resistant to antibiotics on the human timescale of months to years.

As the repository for evidence of evolution—the actual specimens, collections, and related objects—natural history museums have a societal responsibility to promote the understanding of evolution through exhibits and educational programs. It appears from our study that natural history museum visitors have a better understanding of evolution, and a lower rejection rate of it, than the general public. Nevertheless, there is room for improvement: gaps in knowledge need to be filled, and public acceptance of evolution could be much greater.

Acknowledgments

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