doi:10.1111/j.1558-5646.2009.00911.x

IS THE AGE OF THE EARTH ONE OF OUR "SOREST TROUBLES?" STUDENTS' PERCEPTIONS ABOUT DEEP TIME AFFECT THEIR ACCEPTANCE OF EVOLUTIONARY THEORY

Sehoya Cotner,[1,2] D. Christopher Brooks,[3] and Randy Moore[1]

[1] *Biology Program, University of Minnesota, Minneapolis, Minnesota 55455*

[2] *E-mail: harri054@umn.edu*

[3] *Office of Information Technology, University of Minnesota, Minneapolis, Minnesota 55455*

Received July 20, 2009
Accepted November 10, 2009

KEY WORDS: **Age of the Earth, evolution education, science education.**

When Charles Darwin was developing his ideas for *On the Origin of Species*, the most widely accepted estimates of Earth's age were those of William Thomson (later Lord Kelvin). Kelvin used calculations involving thermodynamics to argue that Earth is only 20–100 million years old—an age far too brief to accommodate evolution by natural selection. Darwin referred to Thomson's claim as one of his "sorest troubles," for Darwin understood that the history of life on Earth ultimately relies on geology. Darwin suspected that Earth was much older than Thomson claimed, but Thomson's enormous stature as a scientist obliged Darwin to reconcile his claims with Kelvin's data. To accommodate Kelvin's timeline, Darwin proposed pangenesis as an explanation of inheritance (i.e., every sperm and egg contained "gemmules thrown off from each different unit throughout the body"). Darwin's explanation sped evolution while avoiding Lamarck's quasi-spiritual sources of acquired traits. However, Darwin's explanation of inheritance was wrong (see discussion in Moore et al. 2009a).

The age of Earth remains a divisive topic in the modern evolution–creationism controversy. Whereas mainstream science has long acknowledged that Earth is approximately 4.5 billion years old, a vocal group of citizens and religious activists continue to insist that Earth is less than 10,000 years old. Although most geocentrists and flat-Earth advocates have capitulated to scientific evidence, young-Earth creationists continue to reject scientific evidence in favor of religious dictum to claim that Earth is less than 10,000 years old. These antiscience claims have been surprisingly popular with the public. For example, a Gallup Poll in early 2009 reported that "On Darwin's [200th] Birthday, Only 4 in 10 Believe in Evolution" (Newport 2009), and Berkman et al. (2008) noted that "16% [of biology teachers] believed that human beings were created by God in their present form at one time within the last 10,000 years." In another study, 12.5% of students were young-Earth creationists (Rutledge and Warden 2000), as are 10%–14% of biology majors (Moore and Cotner 2009). Answers in Genesis' (AiG) Creation Museum, along with the $27 million in donations required to build it, attest to the appeal of young-Earth creationism. Indeed, AiG's income for 2005 exceeded $13 million, and that of the Institute for Creation Research (ICR, another religious organization based on young-Earth creationism) exceeded $7 million. For comparison, the 2005 income of National Center for Science Education—the nation's leading organization that defends the teaching of evolution in public schools—was

$1.2 million (Moore et al. 2009a). Clearly, Earth's age remains one of the "sorest troubles" for many people today, just as it did for Darwin.

In this study, we examined how college students' self-described religious and political views influence their beliefs about Earth's age and how this may affect their knowledge and acceptance of evolution. To our knowledge, this is the first study to examine these factors in college students.

Methods

POPULATION AND SURVEY INSTRUMENT

In 2009, we electronically surveyed 400 students enrolled in several sections of a nonmajors introductory biology course at the University of Minnesota. Because the course is one of a few options required of all undergraduates at the University, we assumed the survey population is representative of all students (politically, religiously, and demographically), except for those enrolled in the College of Biological Sciences. The optional survey, which was completed before the start of classes, consisted of the 20-item Measure of Acceptance of the Theory of Evolution (MATE) developed and validated by Rutledge and Sadler (2007), our own 10-item Knowledge of Evolution Exam (KEE; Moore et al. 2009a), and several items intended to gauge students' religious and political preferences. The MATE consists of statements such as "the age of the Earth is less than 20,000 years" and "humans are the product of evolutionary processes," to which students noted their level of agreement on a five-point Likert scale (from "strongly agree" to "strongly disagree"). The KEE questions were modified from an internal exam database, were authentic to the nonmajors' test experience, and were designed to evaluate students' understanding of basic tenets of evolutionary theory—for example, how fitness is measured, natural selection as a mechanism for evolutionary change, etc. (Appendix I). None of the KEE items specifically addresses the age of the Earth or evolutionary time. We also asked students whether they were politically liberal, conservative, or middle-of-the-road, and whether they were not religious (atheist or agnostic), or, if religious, were they progressive/liberal, orthodox, or middle-of-the-road. Students could ignore questions, and their responses had no impact on students' grades. Response rate varied by survey item, with as many as 195 students (almost 50% of the targeted group) completing the KEE, and as few as 124 responding to some of the MATE items. The survey and subsequent data collection were approved by the University of Minnesota's Institutional Review Board.

DATA ANALYSIS

We extracted six variables from the survey to explore the factors that contribute to holding young-Earth and old-Earth beliefs about the origins of the world, on the one hand, and the relation of those beliefs to students' knowledge of evolution and their presidential vote.

The first two variables are self-reported measures of religious and political beliefs. The variable measuring students' religious views (MYRELVIEW) is based on the question, "In general, I would describe my religious views as conservative, middle-of-the-road, liberal/progressive, or none of the above/I'm not religious." Responses were coded on a four-point scale from conservative (1) to not religious (4). Similarly, students' political views (MYPOLVIEW) were determined by the question, "In general, I would describe my political views as conservative, middle-of-the-road, or liberal." MYPOLVIEW consists of a three-point scale ranging from conservative (1) to liberal (3).

We constructed the young-Earth and old-Earth variables from MATE items that represent perspectives aligning with those beliefs. For the young-Earth variable (YOUNGEARTH), we averaged responses to the following two items: "The age of the Earth is less than 20,000 years," and "The theory of evolution cannot be correct because it disagrees with the Biblical account of creation." The old-Earth variable (OLDEARTH) was constructed by averaging responses to how much students agreed or disagreed with the statements that "Organisms existing today are the result of evolutionary processes that have occurred over millions of years," and "The age of the earth is at least 4 billion years." Scales for YOUNGEARTH and OLDEARTH range from 1 (Strongly Disagree) to 4 (Strongly Agree). Factor analysis confirms that each pair of items load onto a single dimension representing young-Earth creationist and old-Earth evolutionist beliefs with rotated factor loadings of 0.6979 and 0.7787, respectively.

Students' recollections of their high school biology courses (HSBIO) were captured in responses to an item asking them to identify whether or not evolution or creationism was taught in their courses. For the purposes of our analysis, HSBIO is coded according the following scheme: included neither evolution nor creationism = 1; included creationism, but not evolution = 2; included both evolution and creationism = 3; and included evolution, but not creationism = 4.

The variable measuring students' level of evolutionary biology knowledge (EVOGRADE) is a summative index of the number of questions answered correctly about various facets of evolutionary theory. EVOGRADE ranges in value from zero to 10 with each increment representing a correctly answered question. The 2008 presidential candidate supported by each student was collected via the self-reported, retrospective response to the statement, "In the past presidential election, I voted/would have voted for John McCain or Barack Obama." For analytical purposes, we constructed the dichotomous variable VOTE in which support for John McCain = 0 and support for Barack Obama = 1. Students who voted for other candidates constituted a small minority and were excluded from analysis.

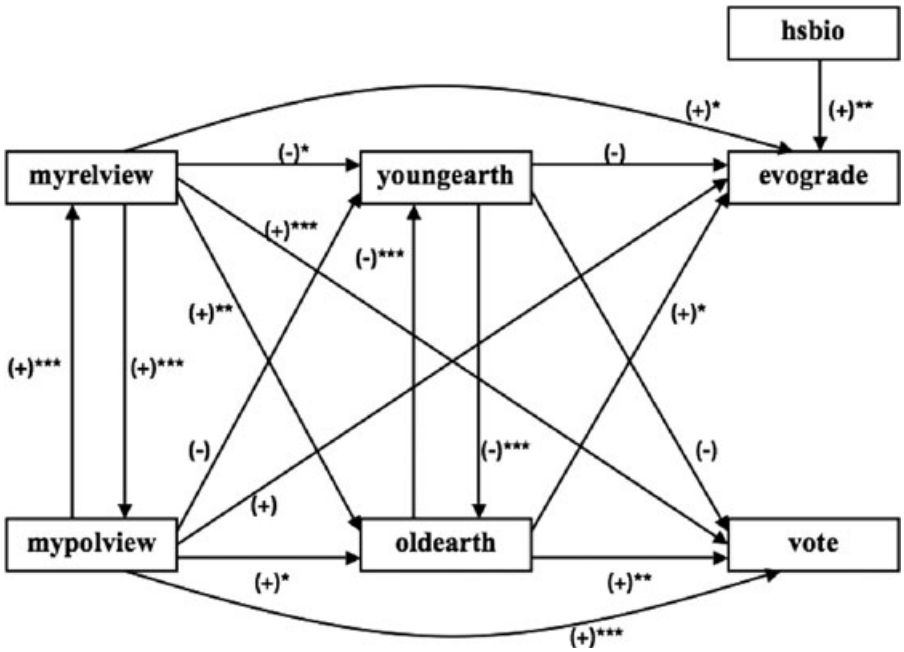

Figure 1. Structural equation model demonstrating the nature of the relationships among the variables identified in Table 1. Note that "+" and "−" refer to positive and negative relationships, respectively, and asterisks follow the code $*P < 0.05$, $**P < 0.01$, $***P < 0.001$.

Although our initial goals included the construction of a structural equation model (SEM) that employed simultaneous equations, the nature of the data is prohibitive (none of our variables is either linear or continuous). Therefore, we employed several individual models, each of which is best suited to the particular dependent variable under consideration. We then developed a structural model that demonstrates the nature of the relationships between and among our variables (Fig. 1). With the exception of models with VOTE as the dependent variable, all models are ordered logistical regression. We employed logistic regression models when the dichotomous VOTE variable was dependent. A Monte Carlo simulation was used to transform the ordered logistical regression results into predicted probabilities.

Summary statistics for the variables under consideration are reported in Table 1.

Table 1. Summary statistics.

Variable	N	Mean	Std. Dev.	Min.	Max.
Myrelview	180	2.8111	0.9501	1	4
Mypolview	173	2.3468	0.7361	1	3
Youngearth	124	1.4839	0.6806	1	4
Oldearth	132	3.3674	0.6958	1	4
Hsbio	194	3.3402	1.0270	1	4
Evograde	195	5.3026	2.2328	0	10
Vote	174	0.7816	0.4143	0	1

Results

The first set of relationships includes the exogenous variables related to students' religious and political views. These variables mutually reinforce one another at statistically significant levels ($P < 0.001$). That is, the more liberal one's political views, the more likely one is to be liberal, agnostic, or atheistic in their religious views and vice versa.

Students' religious views also served as significant predictors of their beliefs about the origins of the world, their knowledge of evolutionary theory, and for whom they cast their presidential votes. Specifically, the more conservative a student's religious views, the greater the likelihood of endorsing young-Earth beliefs ($P < 0.05$) and the less likely they are to endorse old-Earth evolutionist beliefs ($P < 0.01$). Additionally, more liberal, agnostic, or atheistic religious students were significantly more likely ($P < 0.05$) to correctly answer knowledge-based questions about theories and facts related to evolution. Finally, students holding less conservative religious views were considerably more likely to have voted for or supported Barack Obama in the 2008 presidential election ($P < 0.001$).

The political views held by students contribute significantly to their disposition toward evolutionary theory and to their choice of presidential candidate. Here, the more liberal a student's political views, the more likely they are to hold old-Earth beliefs about the origins of the world ($P < 0.05$) and to have cast their vote for Obama ($P < 0.001$). However, although more liberal political views are negatively related to acceptance of young-Earth views

and positively related to knowledge of evolutionary theory, political views fail to predict significantly either of those variables.

Turning to the intermediate variables measuring the impact of beliefs about the origins of life on Earth, we find mutually reinforced inverse relationships between young-Earth and old-Earth views that are highly significant ($P < 0.001$). Specifically, those who hold young-Earth views are significantly less likely to accept an old-Earth rooted in evolutionary theory and vice versa.

We also find that holding old-Earth beliefs contributes significantly to the ability of students to comprehend complex theoretical and factual tenets of evolutionary theory ($P < 0.05$). Furthermore, acceptance of old-Earth beliefs also significantly increased the probability of voting for or supporting Obama.

Conversely, holding young-Earth beliefs appears to impact negatively, but not significantly, one's ability to grasp cognitively evolutionary theory. And while holding creationist beliefs did predict a greater likelihood of voting for John McCain, they did not do so in a statistically significant manner.

Finally, in keeping with previous findings (Moore and Cotner 2009), the content of students' high school biology courses was a significant predictor of their acceptance of evolutionary theory. The content of students' high school biology course affects knowledge of evolution as well: students whose high school biology course included only evolutionary theory had approximately a 70% chance of answering half of the questions or more correctly whereas those with courses teaching only creationism had an approximately 50% chance of doing so (for discussion, see Moore et al. 2009b); those with neither evolution nor creationism had a 42% chance of scoring 50% or above, suggesting that creationism-only education is comparable to no education at all with respect to evolutionary biology. In combination, students who recall being taught evolution only in high school, and who are religiously and politically liberal, were more likely to earn any score above 50% on the exam than were their counterparts with more conservative educational, religious, and political backgrounds.

Discussion

College students have a variety of religious and political views that have been shaped collectively by their families, their communities, and the institutions with which they have come into contact during the course of their lives. These deeply rooted views influence students' receptiveness to theories about life's origins. And because these beliefs about creationism and evolution are firmly grounded in, and are expressions of, their worldviews, as instructors we are naïve to assume that students in college biology courses are necessarily open to scientific inquiry.

Although student views of evolution are subject to multiple influences, our data indicate that their views about Earth's age are a strong predictor of several different factors. But is the age of Earth one of our "sorest troubles?" Our research and historical and contemporary literature suggest the following:

(1) Deep time is conceptually difficult to grasp, for the general public, science educators, and students throughout the educational spectrum.

Charles Darwin himself had a hard time grasping "deep time"—the geologic concept of time, requiring billions of years—but knew that it was essential for his proposed evolutionary mechanism. Darwin didn't publish any estimates of Earth's age, but in the first edition of *On the Origin of Species* he did estimate the time needed to erode the Weald (a region in south England stretching from Kent to Surrey), "say three hundred million years." He then explained: "I have made these few remarks because it is highly important for us to gain some notion, however, imperfect, of the lapse of years. During each of these years, over the whole world, the land and the water has been peopled by hosts of living forms. What infinite number of generations, which the mind cannot grasp, must have succeeded each other in the long roll of years" (Darwin 1859).

More recently, attention has focused on the inability of scientists (Brush 2001), science educators (Petcovic and Ruhf 2008), college students (Catley and Novick 2009; Libarkin 2006; Truscott et al. 2006), and the general public (Hofstadter 1996) to comprehend time in billions of years. Our deficiencies involve concepts about both absolute time (time in years; Catley and Novick 2009) and relative time (events in an accurate sequence; Libarkin 2006).

(2) Students' inability to accept an old Earth is a barrier to evolution acceptance.

Not only is an appreciation of deep time foundational to our full understanding of life's origin and diversification (Catley and Novick 2009; Hillis 2007), it is a critical concept for understanding geology, physics, and astrophysics (see review in Trend 2002). Creationists themselves acknowledge that "An old age for the Earth is the heart of evolution" (Henry 2003), and have, in recent years, focused their argument to undermine an ancient Earth (Humphreys 1999; Baumgardner 2003; Humphreys et al. 2004; DeYoung et al. 2005). Investing energy in debunking an ancient Earth is only logical if in fact Earth's age is key to the Darwinian revolution, and is, in the words of Ernst Mayr (1972), "the snowball that started the whole avalanche."

Furthermore, evolution instruction is often independent of attempts to teach about deep time (Libarkin et al. 2005), a practice that enables students to learn about evolution without fully realizing its value as foundational to modern science. For example, Libarkin et al. (2005) describe students who can cite Earth's age correctly but fail to comprehend the span of time Earth was uninhabitable, or the types of primitive organisms that likely arose first. These disconnects may speak to a need to incorporate historical arguments (Jensen and Finley 1995) or, more generally, an

emphasis on the nature of science (Lombrozo et al. 2008) into a more multidisciplinary strategy for teaching about evolution and the age of Earth.

(3) Creationists' explanations for life's origin are easier to teach, learn and internalize than are scientific explanations that rely on an understanding of deep time.

For evidence of creationism's staying power, one can look to the recycled "argument for design" throughout history: In 45 BCE, Marcus Tullius Cicero invoked a sundial to claim evidence of a creator; in 1691, Anglican clergyman John Ray upgraded to a clock; and in 1802, William Paley's treatise "Natural Theology" invoked a watch and its associated watchmaker ("every indication of contrivance, every manifestation of design, which existed in the watch, exists in the works of nature . . ."). Technology–and the scientific advancements required to progress from sundials to watches—has changed, but the basic argument—evidence of design—remains unchanged (Moore et al. 2009a).

Public-opinion polls provide more contemporary evidence of the power of creationists' claims. In 1982, Philip Abelson wrote that scientific creationists "have no substantial body of experimental data to back their prejudices. Truth is not on their side. In the end, their activities must bring only harm to their cause." At that time, 44% of the American public believed that living organisms were created in their present form within the last 10,000 years (Gallup 1982). After more than two decades of science education reform, that percentage remains unchanged.

Whether we are constrained by teleology or intentionality (Sinatra et al. 2008), humans tend to believe in a universe designed for a purpose (Kelemen 2004; Evans 2001). This tendency lends a natural authority to supernatural explanations, which, in combination with a more intuitive model of Earth's age (thousands, rather than billions, of years; see DeYoung et al. 2005), severely jeopardizes a realization of deep time. In asking our students to forsake the young, the intended, and the concrete for the old, the accidental, and the abstract, we may be fighting our own evolutionary history.

(4) Teaching about time requires teaching for conceptual change.

Learning about deep time is a conceptual change for most students, whereby instructors must realize the real barrier that Earth's age presents to student understanding of evolution. In addition, and in accordance with studies of teaching for conceptual change (e.g., Sinatra et al. 2008), teachers may need to guide students to a realization that their understandings of Earth's age, both absolute and relative, are faulty and in need of revision. Although several authors have suggested strategies for addressing relative time (e.g., James and Clark's "ticking toilet paper roll" [2006]), input on conquering the absolute-time barrier is scarce.

(5) Failure to accept an ancient Earth has real-world implications.

We do not doubt that adherence to creationist explanations for natural phenomena has far-reaching significance. However, in this study, we specifically explored available information on voting activity in November 2008, and demonstrate a significant link between presidential candidate choice and Earth's-age dimensions. This association is likely bolstered by contemporary partisan politics; for example, Republican party platforms in several states support some form of teaching creationism (as "Creation Science," "Intelligent Design," etc.) as a viable alternative theory to evolution by natural selection (e.g., Governor Sarah Palin's Alaska: "We support giving Creation Science equal representation with other theories of the origin of life. If evolution is taught, it should be presented as only a theory").

The political motivation for embracing creationism is clear: Recent Gallup polls highlight the different levels of acceptance of evolution among Republicans, Democrats, and Independents (Newport 2008, 2009). In one poll, 60% of Republicans claim that humans were created in their present form by God within the last 10,000 years, a belief shared by 40% of Independents and 38% of Democrats (Gallup 2008). Of those polled agreeing that humans evolved and God had no part, 4% are Republicans, 19% are Independents, and 17% are Democrats. These data are consistent with findings that Republicans are more likely to attend church regularly, and Americans who attend church weekly are highly likely to believe in creationist explanations for human origins (Newport 2006, 2008). For example, of those who attend church weekly, 70% believe that God created humans in their present form (a central tenet of young-Earth creationists, or YEC); of those who seldom or never attend church, 24% are YEC (Newport 2008).

These data suggest that religiosity correlates with one's tendency to vote Republican and one's likelihood to doubt evolutionary interpretations of origins, specifically, as highlighted herein, an Earth that is 4–5 billion years old. We do not intend to claim that ignorance of science is restricted to Republicans, nor that there are no creationist Democrats; rather, Republicans frequently embrace creationism more explicitly than do their counterparts and have benefited in recent years by making creationism a campaign issue.

Implications

Our research suggests that students who are liberal, agnostic, or atheistic in their religious views, are politically liberal, were taught evolution in high school, and accept the science behind evolutionary theory are more likely to understand the theoretical concepts and empirical findings related to evolution than those who are more conservative politically and religiously, received either no evolution or a diluted form of evolution instruction in high school, and who do not accept an old Earth. However, our findings also reveal a possible exception to this latter formulation: holding young-Earth views may not significantly impede a

student's ability to learn facts about evolutionary theory. Thus, although it is not the role of biology instructors to engage in political or religious proselytizing, there remains the possibility of changing what students know about evolution via academic instruction.

A student's vote is likely a proxy for religious views, and therefore the association between their voting and their acceptance of evolution appears robust and bears further investigation. Given that adherence to young-Earth beliefs requires a refutation not only of modern biology, but also geology, paleontology, and physics, such convictions may serve as a proxy for scientific ignorance in general. Consequently, a commitment to comprehensive conceptual-change instruction in Earth's age, the scientific method, and evolutionary theory could have practical, real-world implications that include nothing less than who we elect for political office.

LITERATURE CITED

Abelson, P. H. 1982. Creationism and the age of the earth. Science 215:119.

Baumgardner, J. R. 2003. Catastrophic plate tectonics: the physics behind the genesis flood. Pp. 1–10 *in* In Proceedings of the Fifth International Conference on Creationism, Pittsbugh, PA. Creation Science Fellowship, Inc. Pittsburgh, PA.

Berkman, M. B., J. S. Pacheco, and E. Plutzer. 2008. Evolution and creationism in america's classrooms: a national portrait. Plos Biol. 6:e124.

Brush, S. G. 2001. Is the earth too old? The impact of geochronology on cosmology, 1929–1952. Geol. Soc. Lond. Spec. Publ. 190:157–175.

Catley, K. M., and L. R. Novick. 2009. Digging deep: exploring college students' knowledge of macroevolutionary time. J. Res. Sci. Teach. 46:311–332.

Darwin, C. 1859. The origin of species. John Murray Publishers, London.

DeYoung, D. B., J. Baumgardner, D. R. Humphreys, A. Snelling, S. A. Austin, E. F. Chaffin, S. W. Boyd, and L. Vardiman. 2005. Thousands, not billions: challenging an icon of evolution: questioning the age of the Earth. New Leaf Publishing Group, Green Forest, AR.

Evans, E. M. 2001. Cognitive and contextual factors in the emergence of diverse belief systems: creation versus evolution. Cogn. Psychol. 42:217–266.

Gallup, Poll 1982. Evolution, Creationism, Intelligent Design. Available at: http://www.gallup.com/poll/21814/Evolution-Creationism-Intelligent-Design.aspx. Accessed December 7, 2009.

Henry, J. 2003. An old age for the earth is the heart of evolution. Creation Res. Soc. Q. 40:164–172.

Hillis, D. M. 2007. Making evolution relevant and exciting to biology students. Evolution 61:1261–1264.

Hofstadter, D. R. 1996. Metamagical themas: questing for the essence of mind and pattern. illustrated ed. Basic Books. Web, New York.

Humphreys, D. R. 1999. Evidence for a young world. Creation Matters 4:1–4.

Humphreys, D. R., S. A. Austin, J. R. Baumgardner, and A. A. Snelling. 2004. Helium diffusion age of 6,000 years supports accelerated nuclear decay. Creation Res. Soc. Q. 41:1–16.

James, P., and I. Clark. 2006. Overcoming geological misconceptions. Planet 17:10–13.

Jensen, M. S., and F. N. Finley. 1995. Teaching evolution using historical arguments in a conceptual change strategy. Sci. Educ. 79:147–167.

Kelemen, D. 2004. Are children "intuitive theists"? Reasoning about purpose and design in nature. Psychol. Sci. 15:295–301.

Libarkin, J. C. 2006. College student conceptions of geological phenomena and their importance in classroom instruction. Planet 17:6–9.

Libarkin, J. C., S. W. Anderson, J. Dahl, M. Beilfuss, W. Boone, and J. P. Kurdziel. 2005. Qualitative analysis of college students' ideas about the earth: interviews and open-ended questionnaires. J. Geosci. Educ. 53:17–26.

Lombrozo, T., A. Thanukos, and M. Weisberg. 2008. The importance of understanding the nature of science for accepting evolution. Evol. Educ. Outreach 1:290–298.

Mayr, E. 1972. The nature of the Darwinian revolution. Science 176:981–989.

Moore, R., and S. Cotner. 2009. The creationist down the hall: does it matter when teachers teach creationism? BioScience 59:429–435.

Moore, R., S. Cotner, and A. Bates. 2009a. The influence of religion and high school biology courses on students' knowledge of evolution when they enter college. J. Excellent Teach. (Special Issue on Evolution Education), 9:3–11.

Moore, R., M. D. Decker, and S. Cotner. 2009b. No prospect of an end: a chronology of the evolution-creationism controversy. Greenwood Press, Westport, CT.

Newport, F. 2006. Almost half of Americans believe humans did not evolve. Available at: http://www.gallup.com/poll/23200/Almost-Half-Americans-Believe-Humans-Did-Evolve.aspx. Accessed December 7, 2009.

———. 2008. Republicans, democrats differ on creationism. Available at: http://www.gallup.com/poll/108226/Republicans-Democrats-Differ-Creationism.aspx. Accessed December 7, 2009.

———. 2009. On Darwin's birthday, only 4 in 10 believe in evolution. Retrieved May 3, 2009, from http://www.gallup.com/poll/114544/Darwin_Believe-Evolution.aspx

Petcovic, H. L., and R. J. Ruhf. 2008. Geoscience conceptual knowledge of preservice elementary teachers: results from the geoscience concept inventory. J. Geosci. Educ. 56:251–260.

Rutledge, M. L., and M. A. Warden. 2000. Evolutionary theory, the nature of science and high school biology teachers: critical relationships. Am. Biol. Teacher 62:23–31.

Rutledge, M. L., and K. C. Sadler. 2007. Reliability of the Measure of Acceptance of the Theory of Evolution (MATE) instrument with university students. Am. Biol. Teacher 69:332–335.

Sinatra, G. M., S. K. Brem, and E. M. Evans. 2008. Changing minds? Implications of conceptual change for teaching and learning about biological evolution. Evol. Educ. Outreach 1:189–195.

Trend, R. D. 2002. Developing the concept of deep time. Pp. 187–201 *in* V. J. Mayer, ed. Global science literacy. Springer, New York.

Truscott, J. B., A. Boyle, S. Burkill, J. Libarkin, and J. Lonsdale. 2006. The concept of time: can it be fully realised and taught? Planet 17:21–23.

Associate Editor: T. Meagher

Appendix I

KNOWLEDGE OF EVOLUTION EXAM (KEE)

(1) Which of the following support the theory of evolution?

A. artificial selection (also known as selective breeding), an analogue of natural selection
B. comparative biochemistry, where similarities and differences of DNA among species can be quantified
C. vestigial structures that serve no apparent purpose
D. comparative embryology, where the evolutionary history of similar structures can often be traced

E. all of the above provide evidence to support the theory of evolution

(2) Resistance to a wide variety of insecticides has recently evolved in many species of insects. Why?

A. mutations are on the rise
B. humans are altering the environments of these organisms, and the organisms are evolving by natural selection
C. no new species are evolving, just resistant strains or varieties. This is not evolution by natural selection
D. humans have better health practices, so these organisms are trying to keep up
E. insects are smarter than humans

(3) Which of the following is the most fit in an evolutionary sense?

A. a lion who is successful at capturing prey but has no cubs
B. a lion who has many cubs, eight of which live to adulthood
C. a lion who overcomes a disease and lives to have three cubs
D. a lion who cares for his cubs, two of whom live to adulthood
E. a lion who has a harem of many lionesses and one cub

(4) How might a biologist explain why a species of birds has evolved a larger beak size?

A. large beak size occurred as a result of mutation in each member of the population
B. the ancestors of this bird species encountered a tree with larger than average sized seeds. They needed to develop larger beaks to eat the larger seeds, and over time, they adapted to meet this need
C. some members of the ancestral population had larger beaks than others. If larger beak size was advantageous, they would be more likely to survive and reproduce. As such, large beaked birds increased in frequency relative to small beaked birds
D. the ancestors of this bird species encountered a tree with larger than average sized seeds. They discovered that by stretching their beaks, the beaks would get longer, and this increase was passed on to their offspring. Over time, the bird beaks became larger
E. none of the above

(5) Which of the following statements about natural selection is true?

A. natural selection causes variation to arise within a population
B. natural selection leads to increase likelihood of survival for certain individuals based on variation. The variation comes from outside the population
C. all individuals within a population have an equal chance of survival and reproduction. Survival is based on choice
D. natural selection results in those individuals within a population who are best-adapted surviving and producing more offspring
E. natural selection leads to extinction

(6) All organisms share the same genetic code. This commonality is evidence that

A. evolution is occurring now
B. convergent evolution has occurred
C. evolution occurs gradually
D. all organisms are descended from a common ancestor
E. life began millions of years ago

(7) Which of the following statements regarding evolution by natural selection is FALSE?

A. natural selection acts on individuals
B. natural selection is a random process
C. very small selective advantages can produce large effects through time
D. natural selection can result in the elimination of certain alleles from a population's gene pool
E. mutations are important as the ultimate source of genetic variability upon which natural selection can act

(8) A change in the genetic makeup of a population of organisms through time is

A. adaptive radiation
B. biological evolution
C. LaMarckian evolution
D. natural selection
E. genetic recombination

(9) Which of the following is the ultimate source of new variation in natural populations?

A. recombination
B. mutation
C. hybridization
D. gene flow
E. natural selection

(10) Which of the following best describes the relationship between evolution and natural selection?

A. natural selection is one mechanism that can result in the process of evolution
B. natural selection produces small-scale changes in populations, whereas evolution produces large-scale ones
C. natural selection is a random process whereas evolution proceeds toward a specific goal
D. natural selection is differential survival of populations or groups, resulting in the evolution of individual organisms
E. they are equivalent terms describing the same process