RESEARCH ON LEARNING

Teaching Evolution to Students with Compromised Backgrounds & Lack of Confidence about Evolution – Is It Possible?

ALEXANDRIA SCHAUER,
SEHOYA COTNER, RANDY MOORE

Abstract

Students regard evolutionary theory differently than science in general. Students' reported confidence in their ability to understand science in general (e.g., posing scientific questions, interpreting tables and graphs, and understanding the content of their biology course) significantly outweighed their confidence in understanding evolution. We also show that those students with little incoming confidence in their understanding of evolution demonstrated more confidence and the most improved performance by the end of the semester. Collectively, our data indicate that regardless of prior experiences with evolution education, and in spite of myriad social challenges to teaching evolution, students can learn evolution.

Key Words: *Evolution education; science confidence.*

Most biologists agree that evolutionary theory is the foundation for modern biology (Chinsamy & Plagányi, 2008; Hermann, 2008; Moore & Cotner, 2009b; Rutledge & Sadler, 2011). However, the U.S. public disagrees; according to a recent Gallup poll (Newport, 2012), only half of Americans agree that humans have evolved. This crucial tenet of biology is often regarded as controversial (Chinsamy & Plagányi, 2007; Hildebrand et al., 2008; Cotner et al., 2010) and, thus, different from other components of biology, such as cell theory, germ theory, and molecular genetics (Rutledge & Sadler, 2011). Many Americans who reject evolutionary theory do so in favor of religious or supernatural alternatives as an explanation for the diversity of life on Earth (National Center for Science Education, 2010), a preference expressed by many college students. According to Moore and Cotner (2009a), even 1 in 10 undergraduate *biology majors* agree with the statement "Evolution is not a scientifically valid theory." Incoming undergraduate students in introductory biology courses enter with a broad spectrum of backgrounds and experiences regarding evolution education. Although 62% of biology majors report having been taught only evolution in their high school biology courses, 22% report having been taught both evolution and creationism, and 13% of students report having been taught neither evolution nor creationism (Moore & Cotner, 2009a).

Students are not a "blank slate" with respect to evolution when they enter college biology classrooms.

Students are not a "blank slate" with respect to evolution when they enter college biology classrooms. According to self reports, students derive their knowledge of evolution primarily from high school, religion, family, and the media (Moore et al., 2011). Prior misconceptions and beliefs may impede the construction of knowledge and the correction of misunderstandings of evolution in the biology classroom (e.g., Sinatra et al., 2008).

Because students enter introductory biology classes with a wide variety of backgrounds and experiences regarding evolution, incoming students' confidence about evolution varies. The alleged controversy behind evolutionary theory may prompt many students to regard this topic differently than other aspects of biology, resulting in greater confidence in science knowledge and ability *in general*, and less confidence in evolution knowledge *specifically*. However, even those students who are confident about their grasp of evolution are not necessarily knowledgeable. Students often are confident of their knowledge of a topic, despite the fact that they know little about it (Lundeberg et al., 1994). Students who are confident about their knowledge of evolution may score well on a quiz covering basic aspects of evolution, yet may reject the occurrence of evolution. Furthermore, low confidence about evolution could compromise a student's ability to learn about evolution.

The present study addresses several questions regarding the relationship between students' confidence and general knowledge of evolution. Namely, do students who misunderstand the tenets of evolution – for example, that mutation is random but selection is not, and that natural selection acts on individuals – realize they are wrong? Do students regard evolution differently than general science when evaluating their confidence in ability and knowledge? And does self-confidence about evolution comprehension play a role in students' ability to improve their knowledge? Several studies have addressed the complexities of teaching evolution in college and

The American Biology Teacher, Vol. 76, No. 2, pages 93–98. ISSN 0002-7685, electronic ISSN 1938-4211.
DOI: 10.1525/abt.2014.76.2.5

universities (e.g., Hildebrand et al., 2008; Moore & Cotner, 2009b; Moore et al., 2011; Rutledge & Sadler, 2011), as well as the relationship between confidence in knowledge and actual knowledge (e.g., Schunk, 1991; Lundeberg et al., 1994; Martin, 2011). However, none has examined the relationship between students' confidence about their understanding of evolution and their actual comprehension and capacity to learn about evolution. Our results may clarify to what extent students with compromised backgrounds in evolution, or those not confident in their understanding of evolution, can learn about this fundamental topic. Specifically, we sought to characterize how – if at all – confidence affects students' incoming knowledge and ability to learn evolution.

○ Methods

We used a previously validated survey instrument to collect data from two different introductory biology courses for nonmajors at the University of Minnesota–Twin Cities. Identical surveys were administered at the beginning and at the end of the semester; precourse and postcourse responses were matched by student name and identification numbers. The survey instrument is described in Cotner et al. (2011) and includes a wide range of questions pertaining to perception, knowledge, and confidence in students' ability in science and evolution.

A portion of the survey modified from early versions of the SENCER-SALG (Student Assessment of Learning Gains) instrument, available at http://www.sencer.net/Assessment/assessmenttools.cfm, was designed to measure levels of students' confidence in their ability to comprehend, analyze, and communicate scientific methods, concepts, and findings. Confidence levels were measured using a five-point Likert scale: 1 = not confident, 2 = a little confident, 3 = somewhat confident, 4 = highly confident, and 5 = extremely confident. We measured students' confidence in understanding scientific processes behind important scientific issues, making scientific arguments, posing scientific questions, thinking critically about findings, interpreting data from tables and graphs, determining the validity of scientific evidence, and, lastly, understanding the content of their current introductory biology course. In addition, students were asked to evaluate their confidence in their understanding of evolution, specifically.

We gathered additional information on students' sources of information about evolution (options included their high school courses, church or religion, family, or the media). Furthermore, the survey asked about students' previous experiences in biology courses, namely which of the following were invoked to explain the diversity of life existing on Earth today: (1) only evolution, (2) only creationism, (3) both evolution and creationism, or (4) neither evolution nor creationism. The survey included a previously validated metric as described in Moore et al. (2009), the Knowledge of Evolution Exam (KEE; Appendix), which assesses student comprehension of general aspects of evolutionary theory.

Students who responded to both precourse and postcourse surveys are the focus of the present study. By pairwise analysis of precourse and postcourse items, we gauged an individual's learning about evolution, and changes in their confidence about evolution. Further analyses included one-way analyses of variance on evolution quiz scores compared with reported levels of confidence about evolution, pairwise analysis of precourse and postcourse KEE scores, and matched-pairs analyses of reported levels of confidence about science compared with levels of confidence about evolution. All analyses were performed using JMP, version 9, statistical analysis software. The University of Minnesota's Internal Review board approved the survey instrument and procedure for the study, as well as the subsequent analysis. Students were assured of confidentiality and could opt out of any or all items in the survey.

○ Results

Background and prior experiences with evolution education. The reported evolution-related content of students' high school biology courses and the primary sources of students' knowledge of evolution are listed in Table 1. In general, data are similar to those reported in previous studies (e.g., Moore et al., 2011, and references therein). Namely, few students (2%) recall having been taught *only* creationism in their high school biology class, while a substantial number (nearly 1 in 5, or 17%) do not remember learning about evolution or creationism. Lastly, 66% of students remember having been taught only evolution in their high school biology class.

Confidence about science ability and evolution understanding. Students' confidence about science, in general, was significantly higher than their confidence about their understanding of evolution. For example, the average confidence level for thinking critically about scientific findings in the media was 3.12, whereas the average confidence level for ability to understand evolution was 2.64 (between "a little confident" and "somewhat confident"). These matched-pairs analyses report data from only those students who responded to *both* confidence metrics; thus, the sample size for each comparison varies. Table 2 illustrates this difference in means of reported confidence in general scientific ability (e.g., making scientific arguments, posing scientific questions, interpreting tables and graphs, and understanding course content) and confidence in the ability to understand evolution, specifically.

Table 3 shows frequency data of various levels of reported confidence with regard to the prompt "I am ____ in my understanding of evolution" before and after the course. Over the course of the

Table 1. Students' prior experiences with evolution (sample size: n = 361 for high school biology course information, n = 308 for sources of evolution knowledge).

Group of Students	Percentage of Students
All students	100
My high school biology course included	
Neither evolution nor creationism	17
Creationism only	2
Both evolution and creationism	15
Evolution only	66
I have primarily derived my views on evolution from	
My high school biology class	50
Family	27
The media	7
Church or religion	16

Table 2. Difference of means for matched-pairs responses. All reported confidence levels are averages of student responses using a five-point Likert scale (see text).

Items (I am confident in my ability to…)	General Science Confidence	Evolution Confidence	Difference of Means
Think critically about scientific findings I read about in the media	3.13	2.64	0.48*
Determine what is – and what is not – valid scientific evidence	3.04	2.64	0.40*
Make an argument using scientific evidence	2.94	2.64	0.28*
Pose questions that can be addressed by collecting and evaluating scientific evidence	3.19	2.64	0.55*
Interpret tables and graphs	3.68	2.64	1.04*
Understand scientific processes behind important scientific issues in the media	2.99	2.64	0.34*
Understand the science content of this course	3.26	2.64	0.61*

Notes: All differences of means are statistically significant (*) at P < 0.001. Sample sizes for each matched pair are between 213 and 215. For difference of means, all metrics are compared with students' confidence in their ability to understand evolution, which averaged between 2.64 and 2.66 for each matched pair. For example, in the first row, 3.13 – 2.65 = 0.48, which is significantly different in a matched-pairs analysis.

Table 3. Frequency distribution of students reporting varying levels of incoming and outgoing confidence with regard to their comprehension of evolutionary theory.

Level of Confidence	Incoming Distribution (n = 217)	Outgoing Distribution (n = 221)
Not confident (1)	27 (13%)	2 (<1%)
A little confident (2)	62 (29%)	9 (4%)
Somewhat confident (3)	86 (40%)	84 (38%)
Highly confident (4)	40 (19%)	113 (52%)
Extremely confident (5)	2 (<1%)	13 (6%)

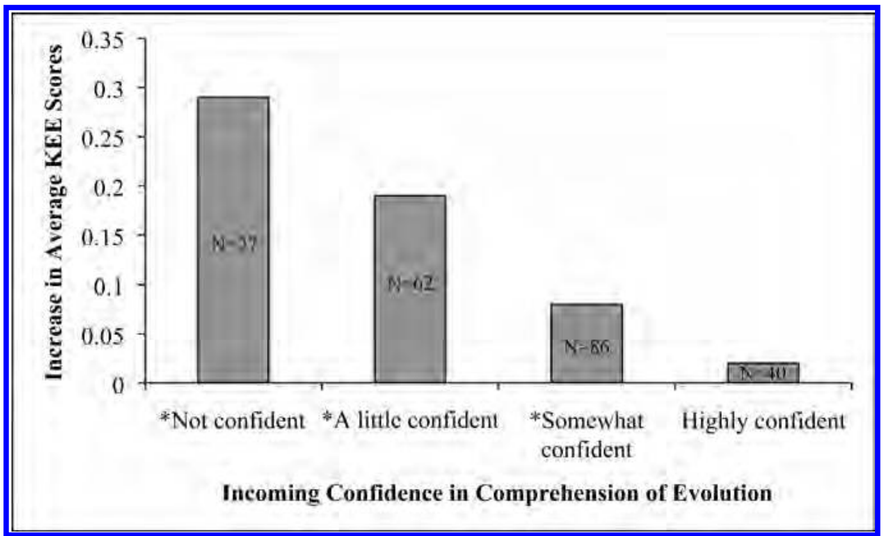

Figure 1. Increase in average Knowledge of Evolution Exam (KEE) scores by incoming confidence level. Differences of means between precourse and postcourse scores categorized by incoming reported level of confidence about evolution are significantly different at P < 0.01.

semester, students became increasingly self-confident about evolution; the frequency of students having low confidence in their grasp of evolutionary theory decreased significantly. For example, the percentage of respondents who initially were highly confident in their understanding of evolutionary theory was 19%; after the course, more than half (52%) of the students were highly confident in their grasp of evolution.

Comprehension of evolution with regard to incoming confidence. Prior to participating in the introductory biology courses, students, on average, performed poorly on the KEE, with a mean score of 45%. However, students who exhibited higher incoming confidence generally performed better, as illustrated by the precourse KEE scores of 29%, 39%, 52%, and 58% for students who reported confidence levels of 1, 2, 3, and 4, respectively. Data for incoming students who were extremely confident (5) about evolution were omitted because only two students selected this option. The postcourse survey showed a significant increase in KEE scores of 13 points, raising the mean score to 58%. Thus, students significantly improved their knowledge and understanding of evolution over the course of the semester.

Interestingly, incoming students who were not confident showed the largest improvement in their KEE scores: a 29-point increase for the 27 students who responded to both precourse and postcourse surveys (see Figure 1). Furthermore, incoming students who were highly confident showed no statistically significant improvement in their KEE score after the course. This trend, whereby students who were initially less confident improved their KEE scores more than those who were most confident, was true for all levels of incoming confidence about evolution. This trend might be anticipated, considering that incoming students who were highly confident about evolution may have less room to improve, but this was not the case – the average precourse KEE score was only 58% (with substantial room for improvement) for highly confident incoming students.

○ Discussion

Evolutionary theory is undoubtedly a controversial topic, for non-scientists as well as students in scientific disciplines. Even though it is foundational to understanding biology, the public's perceptions of evolution range from acceptance, to skepticism, to outright rejection. With this in mind, we sought to answer two questions.

(1) Do college students who enter introductory biology courses regard evolution differently than general science?

By addressing this question, we can appropriately assess whether students feel less confident in their understanding of evolution than they do in their ability to think critically about scientific findings from other disciplines. By comparing students' confidence in understanding various aspects of general science with their confidence in understanding evolution, we conclude that students regard evolutionary theory differently than science in general. Students' reported confidence in their ability to understand science in general (e.g., posing scientific questions, interpreting tables and graphs, and understanding the content of their biology course) significantly outweighed their confidence in understanding evolution (Table 2). In other words, there really is something special about evolution.

Not only are introductory biology students not a blank slate with regard to evolution education, but their past experiences have left some students feeling less than competent. This discrepancy between evolution and other scientific topics may be due, in part, to the influence of family and religion on students' understanding of evolution, as reported by the students themselves. We did not ask specific questions about other scientific theories, but we assume that family and religious influences are minor in generating an individual's understanding of, for example, cell theory, or the central dogma of molecular biology. Previous work has demonstrated that, outside of the high school classroom, treatment of evolution is likely to have a biased, unscientific spin (Moore et al., 2011). However, even high school biology courses often include a treatment of evolution that is taught alongside creationism, or not presented at all. Indeed, only two in three students report being taught evolution as the primary scientific explanation for the diversity of life on Earth (Table 1). In many cases, teachers devote only a single unit to evolution, rather than intertwining it into the discipline of biology, as it is perceived and practiced by most biologists. Therefore, we must realize that students enter the college-level introductory biology classroom with a wide range of backgrounds and beliefs regarding the theory of evolution. Although it is beyond the scope of the present study, it may be that students approach other politically charged scientific topics (e.g., climate change or population control) with similarly low confidence. However, this is not the only study to demonstrate that evolutionary theory is regarded differently than other scientific theories; for example, Rutledge and Sadler (2011) illustrated that students perceive evolution differently than other theories in the field (e.g., cell theory, atomic theory, and germ theory).

(2) Does confidence reflect evolution comprehension or a student's ability to learn evolution?

Students with more incoming confidence in their understanding of evolution scored higher on the precourse KEE, whereas students who were less confident scored much worse. However, students who were highly confident had an average score of 58% on the KEE, indicating that even the highest-scoring and most confident students had room to improve. Given that the KEE is focused on misconceptions about the central tenets of evolutionary theory, we are confident that improvement on the KEE implies tangible correction of prior misconceptions. These results are consistent with other findings (e.g., Lundeberg et al., 1994), in that students can feel confident in their knowledge in some area despite the fact that they actually know little about it. Therefore, regardless of their background in evolution, most students have plenty of room to improve their knowledge and understanding, and the potential to rid themselves of prior misconceptions.

We also assessed students' improvement on the KEE, through a comparison of precourse and postcourse scores for students in different incoming-confidence brackets. We anticipated that students who were initially more confident would improve more than their less confident peers. However, students who were least confident improved by the largest amount, whereas students who were highly confident improved the least (Table 3). One might expect this result if students who were highly confident were already high scoring, but they still had ample room to improve. These results indicate that less confidence does not imperil students' ability to improve their knowledge about evolution, and that the students are certainly teachable. In fact, those students with little incoming confidence in their understanding of evolution demonstrated more confidence and the most improved performance by the end of the semester.

○ Conclusions

Our results clarify to what extent students with compromised backgrounds in evolution or little confidence in their comprehension of evolution are teachable. In fact, low confidence in understanding evolution and poor understanding of the tenets of the theory do not impair students' ability to improve over the course of the semester. Although students who were not confident in their understanding initially scored very low on the KEE, students who were highly confident in their understanding initially scored higher but still were failing on a standard grading scale. Yet by the end of the semester, students who felt less than competent improved drastically, whereas very confident students improved, but by a much smaller amount. Collectively, these data indicate that regardless of prior experiences with evolution education, and in spite of myriad social challenges to teaching evolution, students can learn evolution.

References

Chinsamy, A. & Plagányi, É. (2008). Accepting evolution. *Evolution, 62,* 248–254.

Cotner, S., Ballen, C., Brooks, D.C. & Moore, R. (2011). Instructor gender and student confidence in the sciences: a need for more role models? *Journal of College Science Teaching, 40*(5), 96–101.

Cotner, S., Brooks, D.C. & Moore, R. (2010). Is the age of the Earth one of our "sorest troubles?" Students' perceptions about deep time affect their acceptance of evolutionary theory. *Evolution, 64,* 858–864.

Fenollar, P., Román, S. & Cuestas, P.J. (2007). University students' academic performance: an integrative conceptual framework and empirical analysis. *British Journal of Educational Psychology, 77,* 873–891.

Hermann, R.S. (2008). Evolution as a controversial issue: a review of instructional approaches. *Science & Education, 17,* 1011–1032.

Hildebrand, D., Bilica, K. & Capps, J. (2008). Addressing controversies in science education: a pragmatic approach to evolution education. *Science & Education, 17,* 1033–1052.

Lundeberg, M.A., Fox, P.W. & Punćcohaŕ, J. (1994). Highly confident but wrong: gender differences and similarities in confidence judgments. *Journal of Educational Psychology, 86,* 114–121.

Martin, A.J. (2011). Courage in the classroom: exploring a new framework predicting academic performance and engagement. *School Psychology Quarterly, 26,* 145–160.

Moore, R., Brooks, D.C. & Cotner, S. (2011). The relation of high school biology courses & students' religious beliefs to college students' knowledge of evolution. *American Biology Teacher, 73,* 222–226.

Moore, R. & Cotner, S. (2009a). Rejecting Darwin: the occurrence & impact of creationism in high school biology classrooms. *American Biology Teacher, 71,* 1–4.

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

National Center for Science Education. (2010). Polls and surveys. Available online at http://ncse.com/creationism/polls-surveys.

Newport, F. (2012). In U.S., 46% hold creationist view of human origins. Gallup Politics. [Online.] Available at http://www.gallup.com/poll/155003/Hold-Creationist-View-Human-Origins.aspx.

Pew Forum on Religion and Public Life. (2005). Public divided on origins of life. [Online.] Available at http://pewforum.org/Politics-and-Elections/Public-Divided-on-Origins-of-Life.aspx#3.

Rutledge, M.L. & Sadler, K.C. (2011). University students' acceptance of biological theories – is evolution really different? *Journal of College Science Teaching, 41* (2), 38–43.

Schunk, D.H. (1991). Self-efficacy and academic motivation. *Educational Psychologist, 26,* 207–231.

Sinatra, G.M., Brem, S.K. & Evans, E.M. (2008). Changing minds? Implications of conceptual change for teaching and learning about biological evolution. *Evolution: Education and Outreach, 1,* 189–195.

ALEXANDRIA SCHAUER is a D.V.M. candidate in the College of Veterinary Medicine, University of Minnesota; e-mail: schau140@umn.edu. SEHOYA COTNER is Associate Professor of Biology at the University of Minnesota; e-mail: harri054@umn.edu. RANDY MOORE is Professor of Biology at the University of Minnesota; e-mail: rmoore@umn.edu.

Appendix. Knowledge of Evolution Exam.

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 increased 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.