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Does increasing biology teacher knowledge of evolution and the nature of science lead to greater advocacy for the teaching of evolution in schools?

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Does Increasing Biology Teacher Knowledge of Evolution and the Nature of Science Lead to Greater Preference for the Teaching of Evolution in Schools?

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Abstract This study investigated whether or not an increase in secondary science teacher knowledge about evolution and the nature of science gained from completing a graduate-level evolution course was associated with greater preference for the teaching of evolution in schools. Forty-four precertified secondary biology teachers participated in a 14-week intervention designed to address documented misconceptions identified by a precourse instrument. The course produced statistically significant gains in teacher knowledge of evolution and the nature of science and a significant decrease in misconceptions about evolution and natural selection. Nevertheless, teachers' postcourse preference positions remained unchanged; the majority of science teachers still preferred that antievolutionary ideas be taught in school.

Keywords Evolution · Evolution education · Biology education · Natural selection · Intelligent design · Creationism · Science teachers

Introduction

Despite the remarkable successes of evolutionary biology in the past century, and the fundamental role of evolution in new scientific disciplines with direct ties to

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everyday life (e.g., evolutionary medicine, pharmacogenomics, and genomic sciences), antievolutionism (creationism, creation "science", or intelligent design) remains pervasive and widespread in the United States. Antievolutionary views are commonly held by members of the general public (e.g., Brooks 2001; Newport 2006), high school students (e.g., Clough and Wood-Robinson 1985; Deadman and Kelly 1978; Demastes et al. 1995; Stallings 1996), undergraduate students (e.g., Bishop and Anderson 1990), undergraduate biology majors (e.g., Dagher and BouJaoude 1997; Grose and Simpson 1982), medical students (e.g., Brumby 1984), and science teachers (e.g., Affanato 1986; Nehm and Sheppard 2004; Osif 1997; Pankratius 1993; Tatina 1989; Zimmerman 1987). The problem of antievolutionism is one of the greatest challenges for biology education because biologists consider evolution to be the unifying concept of the discipline.

The maturing field of evolution education faces three core challenges: (a) to understand the interrelationships among cognitive, affective, epistemological, and religious variables that contribute to antievolutionary views in individuals of different ages and educational backgrounds; (b) to design, implement, and evaluate interventions that promote accurate cognitive models of evolution; and (c) to reduce overall levels of antievolutionary attitudes (Alters 1997; Pigliucci 2002; Scott 2004).

In recent years, there has been a growing body of knowledge outlining the diverse array of cognitive, affective, epistemological, religious and pedagogical factors that contribute to an antievolutionary worldview (e.g., Alters and Nelson 2002; Bishop and Anderson 1990; Lawson and Worsnop 1992; Southerland and Sinatra 2003; Southerland et al. 2001). Additional research has identified numerous misconceptions about the nature of science and its relationship to antievolutionism (National Academy of Sciences [NAS] 1998; Southerland and Sinatra 2003). This research has advanced our understanding of the complexity of the challenges that antievolutionism presents scientists and science educators. Unfortunately, these studies have not yet been directly translated into research-based clinical interventions.

Pedagogical and curricular strategies for addressing student and teacher antievolutionism continue to be developed. These include inquiry instruction (Alters and Nelson 2002; Demastes et al. 1995), paired-problem solving (Jensen and Finley 1997), small-group discussion (Scharmann 1993), concept mapping (Trowbridge and Wandersee 1994), historically rich curricula (Jensen and Finley 1995), modeling approaches (Passmore and Stewart 2002), explicit discussion of religious–scientific boundaries (Gould 1999; Nehm and Sheppard 2004), explorations of the nature of science (Dagher and BouJaoude 1997), technology-based visualization of abstract evolutionary processes, and emphasis on formal reasoning and critical-thinking skills (Lawson and Weser 1990; Lawson and Worsnop 1992).

Despite such innovations, the evolution education literature contains, remarkably, few empirical tests of these pedagogical interventions aimed at combating antievolutionism (e.g., Jensen and Finley 1995, 1997; Scharmann and Harris 1992). In general, those few interventions that have been evaluated have not produced significant or long-term learning gains or behavioral changes (e.g., increased emphasis on evolution in the curriculum). Additionally, nearly all intervention studies have investigated samples obtained from less scientifically sophisticated populations, primarily undergraduate nonscience majors (e.g., Bishop and Anderson 1990). Some groups, notably science teachers, are nearly absent from such work (see, however, the important work by Scharmann and Harris 1992). The effectiveness of the aforementioned pedagogical and curricular strategies on science teachers' understanding of evolution thus remains to be determined (Nehm and Reilly 2007).

The rare intervention studies that have demonstrated success in reducing antievolutionary ideas in science teachers have involved very small samples (< 20) and were of limited duration (compressed immersion programs or brief modules), thus limiting generalizability (e.g., Scharmann and Harris 1992). Most interventions to date have produced meager gains in many aspects of participant knowledge of evolution. Thus, the limited nature of existing studies precludes the resolution of many fundamental questions, including whether or not significant learning gains influence belief in—or acceptance of—evolution or the propensity to advocate for the teaching of evolution in schools (e.g., Bishop and Anderson 1990; Demastes et al. 1995; Jensen and Finley 1995, 1997; Scharmann and Harris 1992). In summary, evolution education research is in urgent need of intervention studies that employ sufficiently large teacher samples, offer treatments of reasonable duration, and achieve significant learning gains.

Science Teacher Education and Antievolutionism

Science teachers are an important "missing link" between scientists' understanding of evolution and the general public's ignorance of or resistance to the idea (Brooks 2001; Newport 2006). Science classrooms remain one of the few arenas in which learning about evolution has the potential to take place. Science teacher educator and scientist collaborations are, therefore, central to fostering the development of teacher understanding of evolution. One obvious approach to fostering this link between scientists and the public is to require, or at least offer, a college course in evolution as part of all science teacher certification programs in biology (and perhaps other sciences). Such a course could provide content knowledge on evolution and the nature of science, employ conceptual-change strategies, address well-documented misconceptions, and model pedagogical content knowledge necessary for the teaching and learning of evolution (Gess-Newsome and Lederman 1999). These goals would also be aligned with the National Science Education Standards (National Research Council 1995).

Those of us who have developed an evolution course as part of our biology teacher certification programs, and therein have attempted to employ effective pedagogical and curricular strategies to reduce antievolutionism in science teachers, have struggled to answer a fundamental question that inevitably arises during the development of such courses: What educational and social issues should such an evolution course target? Scientists and science teacher educators would undoubtedly agree that a fundamental goal of evolution instruction is to increase teachers' knowledge of evolution and the nature of science. But should that be the only goal? Should additional instructional goals of an evolution course that addresses the previously cited problems also include achieving biology teacher *acceptance* of (or belief in) evolution and teacher *preference* for the teaching of evolution in schools? If acceptance and preference are learning goals, how should they be implemented in the classroom? Surprisingly, the field of evolution education is only beginning to address the curricular, pedagogical, and ethical aspects of these theoretical questions. Therefore, the goals and methods of evolution courses for teachers are based upon a foundation of empirical and theoretical uncertainty.

Knowledge and belief underlie many fundamental research questions in science education (Southerland et al. 2001), but there is little agreement about whether or not both knowledge *and* belief are legitimate goals of evolution education or about how to practically and meaningfully differentiate such distinctions in classroom discourse. A burgeoning literature about knowledge and belief has thus far focused on the theoretical, philosophical, and epistemological meanings of these concepts and the justifications for advocating them as learning goals (e.g., Alters 1997; Chinn and Samarapungavan 2001; Coburn 1994, 2004; Cooper 2001; Davson-Galle 2004; Sinatra et al. 2003; Smith 1994; Smith and Siegel 2004; Southerland 2000; Southerland and Sinatra 2003; Southerland et al. 2001).

The purpose of this study is not to review the numerous theoretical arguments relating to knowledge and belief, but, rather, to contribute an empirical study of the relationships between knowledge and belief in science teachers in the context of their approach to teaching evolution. These theoretical issues must be resolved to determine the appropriate goals and methods of evolution courses designed specifically to meet the needs of science teachers. If the science education community cannot agree about the learning goals of evolution education for teachers, we must be prepared for continued confusion about this issue in teachers' minds and in their classrooms.

Prior research on the relation between knowledge and belief in undergraduates suggests that in some knowledge domains, such as photosynthesis and respiration, knowledge and belief tend to be correlated. This relation does not appear to hold, however, with regard to knowledge of and belief in evolution (Sinatra et al. 2003; Southerland and Sinatra 2003). However, the connection between knowledge and belief in the domain of evolution has yet to be studied in biology teachers. We might anticipate a stronger connection between these variables in this case.

In addition to knowledge and belief, preference for the teaching of evolution is another controversial issue in teacher education, but it too must be considered as a potential goal of an evolution course for teachers. The major science education organizations (e.g., the National Association of Biology Teachers 2004, and the National Science Teachers Association 1997) unequivocally support teacher understanding of evolution and also advocate for the teaching of evolution in schools. Would a logical consequence of such statements be that teacher education courses should foster science teacher preference for the teaching of evolution in schools? Surprisingly, this issue has not been addressed in the evolution education literature. As a first step in addressing this gap, the present study addresses these issues empirically.

Hypotheses

The overall goal of this study is to evaluate the impact of increasing science teachers' knowledge of evolution and the nature of science. Three specific hypotheses are tested:

1. Completion of a 14-week evolution course (designed to address teachers' initial misconceptions of evolution and the nature of science) is associated with significant increases in teacher knowledge of evolution and knowledge of the nature of science;
2. Significant increases in teacher knowledge of evolution and the nature of science are associated with increases in preference for the teaching of evolution in schools; and
3. Significant increases in teacher knowledge of evolution and the nature of science are associated with increased teacher preference that students believe in or accept evolution.

Sample Participants

This study included 44 students enrolled in a graduate science teacher certification program at a New York City college. Students were from a range of ethnic and racial backgrounds. While the majority was of White non-Hispanic origin, approximately 30% of the class was Latino or African Caribbean. The mean age of the sample was 27.4 years. All students were in-service (or practicing) teachers, and all were precertified (that is, they lacked permanent New York State teacher certification credentials). The mean teaching experience for the sample was 1.6 years. The vast majority (95%) of teachers was enrolled in the biology certification program, which requires previous college biology coursework prior to acceptance. Ninety-five percent of the student teachers had bachelor degrees or equivalent in the life sciences (BA, BS, or 30 credits of college biology). All of the participants completed the course intervention.

Data Collection, Variables, and Methods of Analysis

Teachers in the sample voluntarily enrolled in a 14-week graduate biology course that was part of their biology certification program. The course was not a program requirement, and participation in the study was voluntary. On the first day of the class, an instrument was administered to gather data on demographic variables (age, religiosity, spirituality), certification goal (e.g., biology, chemistry), the extent to which they were conflicted about the relationship between science and religion, whether they had taken an evolution course previously, how many biology courses they had completed, and whether or not they wanted students to be taught about "creationism" (defined broadly as biblical creation, intelligent design, or creation science) in schools and whether or not they personally preferred students to believe creationism.

Teacher knowledge and attitudes about evolution and the nature of science were assessed using a series of Likert-type items and essay questions. The Likert-type instrument contained both positively and negatively phrased statements that were ordered randomly. The modified essay questions about evolution were derived from Bishop and Anderson (1990, p. 418).

In the interest of conserving space, an overview of the course curriculum and pedagogy is provided in Table 1. The pretest knowledge results (Table 1, left column) were used to structure the scope and sequence of the evolution course (Table 1, middle column). Thus, the course attempted to engage teachers' prior knowledge of evolution and the nature of science. A variety of pedagogical approaches (Table 1, right column) was implemented.

To match pre-and postcourse instruments, teachers were asked to choose a term, phrase, number, or symbol that was not associated with their name or student identification number that they would remember. Teachers were asked to write this term on the precourse instrument and subsequently use it on their postcourse instruments. All 88 pre-and postcourse instruments were matched while maintaining participant confidentiality.

The reliability of responses was determined in two separate sections: the essay section and the Likert-type scale section. Participant response scores on a positively phrased Likert-type scale statement and on an equivalent negatively phrased Likert-type scale statement were not, statistically, significantly different. In addition, the two essay questions about natural selection (adapted from Bishop and Anderson 1990) using different taxa and selective contexts also produced numbers of misconceptions that were not significantly different. Thus, it appeared that teachers provided consistent answers to the survey questions. Eleven variables were extracted from the instrument for analysis. Details on the variables, their coding, reliability, validity, and methods of analysis are discussed below.

1. *Conflict*. Teachers were asked to self-report whether or not they were conflicted about their scientific and religious beliefs by determining which of the following statements best applied to them: (a) "Evolutionary ideas are at odds or in conflict with my religious beliefs," or (b) "Evolutionary ideas are NOT at odds or in conflict with my religious beliefs." The answers were coded as binary scores. The McNemar test in SPSS (Version 9.0) was used to determine if the distribution of Conflict scores changed significantly pre- and postcourse.
2. *Religiosity*. Teachers were asked to self-report their religiosity by identifying which of four statements about religion best applied to them: (a) "I am not religious at all," (b) "I am somewhat religious," (c) "Religion is an important part of my life," or (d) "Religion is a very important part of my life." The answers were coded as ranked ordinal scores (1–4). An isomorphic question about spirituality, scored in a similar manner, was positively and significantly correlated with the religiosity scores; and, therefore, only religiosity was analyzed. ENOS (see No. 8 below), ECK (see No. 9 below), teach (see No. 10 below), and belief (see No. 11 below), and were examined for significant correlations with religiosity using Spearman's rho in SPSS.

Table 1 Overview of How the Pretest Results Were Used to Structure Course Content and the Pedagogical Methods Used in Each Module

Selected pre-test knowledge results	Corresponding course topics and lessons	Pedagogical methods*
Evolution is weak because it is a theory	***The Nature of Science***	
Theories become facts when they are well-supported	(1) What is, and is not, science	ACE, CL, R
Evolution can't be observed so it is outside realm of science	(2) Scientific and common meanings of the terms theory, fact, law, and hypothesis	ACE, CL, R, V
Evolution can't be refuted by any observation	(3) The commonalities between evolution and other scientific theories	ACE, CL, R
Evolution can't be "proven"	(4) The role and significance of observation in the scientific process	ACE, CL
	Science and religion	
17% conflicted about science and religion	(1) Models of the relationship between science and religion	ACE, CL, R
Majority advocate teaching some antievolutionary ideas in school	(2) The positions of major religions on evolution	R
	Evolution content knowledge	
Lamarckian ideas prevalent	(1) The history of ideas in evolutionary biology	L, R, V
Chance cannot be a factor in origin of complex traits	(2) Sources of variation: mutation, recombination, sex	L, CL, CM, R
No fossil species found between humans and "apes"	(3) Natural selection; evolutionary patterns and processes	ACE, CL, M, R
Mutations are harmful and cannot give rise to new traits	(4) Molecular clocks and radiometric dating	L, R, V
Humans and dinosaurs coexisted	(5) Phylogenetic analysis using molecular and morphological data	L, CM
Fossil record lacks intermediates	(6) The fossil record	ACE, F, L, R

*ACE = Alternative Conception Exposure

CL = Collaborative learning

CM = Concept Mapping

F = Field Trip to a Natural History Museum

L = Lecture

M = Modeling

R = Readings

V = Video

3. *Biosemesters*. Teachers were asked to self-report how many semester-long or quarter-long college biology courses they had completed. Quarter-long course scores were converted to semester-long scores using the equation: 1 quarter = 2/3 semester. Spearman's rho in SPSS was used to determine if biosemesters was significantly correlated with ECK or ENOS (see Nos. 8 and 9 below) both pre-and postcourse.
4. *Evocourse*. Because the 44 participants had completed degrees or coursework in biology previously, it was possible that an evolution course was part of their

studies. To determine if prior completion of an evolution course was associated with patterns documented in this study, teachers were asked to answer the following questions: "Have you taken college courses that have discussed biological evolution (yes or no)?" and "Have you taken a college course primarily in biological evolution (yes or no)?" All of participants indicated that evolution had been discussed in their college courses and, therefore, this variable was dropped from the analysis. Approximately 20% of participants had completed an undergraduate-level evolution course. The Mann-Whitney U test in SPSS was used to determine if evocourse was associated with significantly different ENOS or ECK scores (see below) both pre- and postcourse.

5. *Key concepts* of natural selection. Seven key concepts relating to natural selection were identified (Anderson et al. 2002; Mayr 1982). The concepts included (a) the causes of phenotypic variation (e.g., mutation, recombination, sexual reproduction); (b) the heritability of phenotypic variation; (c) the reproductive potential of individuals; (d) limited resources, carrying capacity, or both; (e) competition or limited survival potential; (f) selective survival based on heritable traits; and (g) a change in the distribution of individuals with certain heritable traits. The presence or absence of these seven key concepts was noted in the teachers' essay responses to a slightly modified version (our modifications are contained in parentheses below) of Bishop and Anderson's (1990) extensively used essay question: "Cave salamanders (amphibian animals) are blind (they have eyes that are nonfunctional). How would a biologist explain how blind cave salamanders evolved from ancestors that had functional eyes and could see? Provide as detailed an answer as you can" (p. 418). A coding rubric was developed, and teacher responses were scored such that the use of a key concept in their explanation of evolutionary change in salamanders counted as 1 point. Thus, an essay response that employed all seven key concepts received 7 points. The essays were blindly recoded by another scientist using the same rubric to examine interrater reliability. Pearson correlation coefficients for key concepts between the two raters were statistically significant ($r = .89$, $p < .001$). The Wilcoxon signed-ranks test in SPSS was used to test for changes in the distribution of key concepts in pre- and postcourse essays.
6. *Concepts* of natural selection. In addition to the number of key concepts, biologically useful, accurate, but peripheral responses to the Bishop and Anderson question were also noted and coded as additional concepts. Examples of teacher responses that were scored as additional concepts included the use of phylogenetic analysis to determine salamander ancestry, the use of environmental change to explain selective forces, and the use of homeotic mutations to explain the loss of eye function. These additional concepts were deemed to be potentially useful for determining the teachers' degree of conceptual sophistication in answering questions about evolution and natural selection. A coding rubric was developed, and teacher responses were scored such that the use of any accurate concept (other than a key concept) in the explanation counted as 1 point. There was no limit to the

possible concepts that could be employed in the essays. The Wilcoxon signed-ranks test in SPSS was used to test for changes in the distribution of concepts in pre- and postcourse essays.

7. *Misconceptions* about natural selection. A coding rubric containing commonly documented misconceptions was developed (e.g., mutations are caused primarily by mutagenic substances; needs cause evolutionary changes to take place; the use or disuse of traits explains their appearance/disappearance; traits appear only when they are needed; all individuals in a population develop new traits simultaneously, and so forth [see Bishop and Anderson 1990]). Teacher responses were scored such that the use of an identifiable misconception in the evolutionary explanation counted as 1 point. There was no upper limit to the number of misconceptions that could be employed by teachers in the essays. The essays were blindly recoded by another scientist using the same rubric to examine interrater reliability. The Pearson correlation coefficient for the two raters' scores for key concepts was statistically significant ($r = 0.75$, $p = .008$). The Wilcoxon signed-ranks test in SPSS was used to test for significant changes in the number of misconceptions employed as explanations for evolutionary change pre- and postcourse.
8. *ENOS* is a composite variable that was used to measure teacher knowledge about the nature of science in relation to evolution (see Appendix). The reliability of ENOS was first assessed in a pilot study of 78 teachers in 2002. With 9 items, Cronbach's alpha was 0.62. The reliability of ENOS was also assessed using the 2004 sample of teachers. With the same 9 items, alpha was .61. These are acceptable reliability values, considering the homogeneity of the participants (Ary et al.2002, p. 261). The validity of ENOS was assessed by examining the correlation of ENOS scores with a separately administered essay that evaluated participant knowledge of the nature of science relating to evolution. This essay examined participants' abilities to (1) differentiate scientific falsification from confirmation and determine the relation of these ideas to the testing of evolutionary hypotheses (Popper 1959) and to (2) employ these concepts by providing examples of how evolutionary hypotheses could be tested. The allotted time was 30 minutes. Essays were coded, based on the (a) number of accurate concepts and (b) number of empirical examples. Coded essay scores for (a) and (b) were correlated with ENOS scores using Spearman's rho. ENOS scores were positively and significantly correlated with the nature of science essay scores: (a) Spearman's rho = .48, $p = .038$; (b) Spearman's rho = .61, $p = .005$. These results suggest that ENOS is a valid measure of participant knowledge about the nature of science in relation to evolution. ENOS was used to measure participant knowledge about the nature of science pre- and postcourse.
9. *ECK* is also a composite variable, but was used to measure evolution content knowledge (see Appendix). The reliability of ECK was first examined in a 2002 pilot study of 76 teachers. With 9 items, Cronbach's alpha for ECK was .72. The reliability of ECK was also assessed using the 2004 teacher sample. With the same 9 items, alpha was .77. As was found with ENOS, these are acceptable reliability values, considering the homogeneity of the participants

(Ary et al. 2002, p. 261). The validity of ECK was assessed by examining the correlation of ECK scores with a separately administered final exam essay that asked participants to explain the processes (mechanisms) that cause patterns of evolutionary change. Essay grades were converted to numerical scores and correlated with ECK scores using Spearman's rho in SPSS. ECK scores were positively and significantly correlated with the final exam essay scores (Spearman's rho = .48, $p = .033$). These results suggest that ENOS is a valid measure of participant knowledge about evolution. ECK was used to measure participant evolution content knowledge pre- and postcourse.

10. *Teach*. The instrument assessed teacher preference for what students should learn in school by using the following question: "Which of the following would you prefer students to learn about in school? (a) Creationism (e.g., biblical creation, intelligent design, and/or creation science); (b) Evolution; (c) Both creationism and evolution." Answers were coded as ordinal scores (1, 2, and 3). A Wilcoxon signed-ranks test was used to determine if the distribution of scores changed significantly pre- and postcourse using SPSS.
11. *Believe*. The instrument assessed teacher preference for student belief about evolution using the following question: "Which of the following would you personally prefer students to believe or accept? (a) Creationism (e.g., biblical creation, intelligent design, and/or creation science); (b) Evolution; (c) Both creationism and evolution." Answers were coded as ordinal scores (1, 2, and 3). A Wilcoxon signed-ranks test was used to determine if the distribution of scores changed significantly pre- and postcourse.

Results

Biology Teacher Misconceptions

The precourse instrument documented teacher misconceptions about evolution, natural selection, and the nature of science that have also been shown to occur in high school and college students (Table 2 and Figure 1). Commonly held misconceptions about the nature of science included the ideas that "theories" become "facts" when they are well supported, that evolution can't be "proven," and that evolution is a weak scientific idea because it is a "theory." Commonly held misconceptions about evolution included the ideas that transitional intermediates are missing from the fossil record, that mutations are harmful and could not have given rise to new traits, and that humans and dinosaurs coexisted. Teacher misconceptions regarding natural selection were numerous and included the ideas that the "use and disuse" of traits explains their appearance, that traits appear when they are needed, and that the environment causes evolutionary change.

Misconceptions about evolution and natural selection were frequently employed as explanations (Figure 1A). The majority of teacher answers to the Bishop and Anderson essay question, for example, contained misconceptions. Teachers in the sample often held the same misconceptions. Specifically, more than 25% of teachers employed "use and disuse: arguments or "need-based" explanations for evolution-

Table 2 Teacher Misconceptions Documented in This Study and Their Distribution in Other Populations

Biology teacher misconceptions:	**Also documented in samples of:**		
Nature of Science	Secondary students	College undergraduates	Teachers
Theories become facts when they are well-supported	Ryan and Aikenhead (1992)	Johnson and Peeples (1987), Sinclair et al. (1997)	Nehm and Sheppard (2004), Eve and Dunn (1990), Sharmann et al. (2003), Sharmann and Harris (1992)
Evolution can't be "proven"			
Evolution can't be refuted by any observation			
For evolution to be true it must be observed			
Evolution is weak because it is a theory			
Evolution			
Chance cannot be a factor in the origin of complex traits	Deadman and Kelly (1978), Lawson and Worsnop (1992)	Johnson and Peeples (1987), Sinclair et al. (1997)	Eve and Dunn (1990), Zuzovsky (1994), Nehm and Sheppard (2004)
No fossil species found between humans and "apes"			
Mutations are harmful and cannot give rise to new traits			
Humans and dinosaurs coexisted			
Fossil record lacks intermediates			
Natural selection			
Use and disuse explains the appearance/disappearance of traits	Deadman and Kelly (1978), Demastes et al. (1995), Hallden (1988), Settlage (1994).	Bishop and Anderson (1990), Brumby (1979 1984), Dagher and BouJaoude (1997), Jensen and Finley (1995 1997), Sinclair and Pendarvis (1997/1998), Sinclair et al. (1997), Nehm and Reilly (2007)	Jimenez (1992), Greene (1990), Zuzovsky (1994)

Table 2 continued

Biology teacher misconceptions:	**Also documented in samples of:**		
Nature of Science	Secondary students	College undergraduates	Teachers
Traits appear only when they are needed			
Populations develop new traits rather than individuals			
When sight is lost other senses evolve to be more sensitive			
Mutations are caused by mutagenic substances in environment			
Change is caused by the environment			

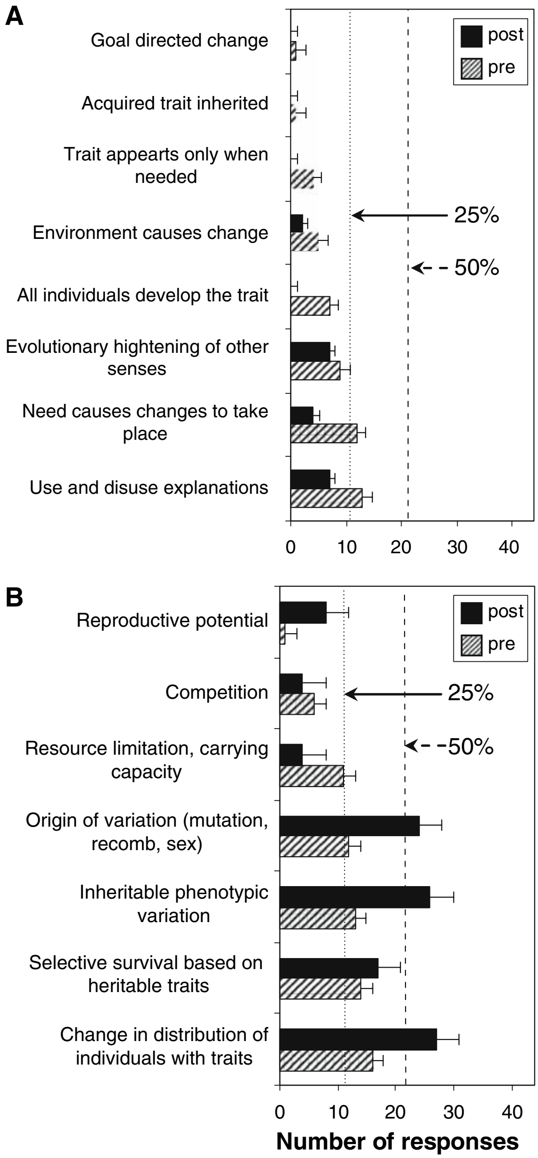
ary change (Figure 1A). A misconception that does not appear to have been reported in the literature was frequently voiced by teachers in this study: Almost 25% of teachers discussed the idea that the loss of salamander sight led directly to the heightening of other senses that were then passed to subsequent generations.

Figure 1A also illustrates significant decreases in the frequencies of specific misconceptions from precourse to postcourse. For example, “use and disuse” explanations, “need” as a cause of change, and simultaneous population change all decreased significantly postcourse. The total number of misconceptions employed in the teacher essays also decreased significantly postcourse (Wilcoxon signed-ranks test: $n = 44$, $z = -4.28$, $p < .001$). Specifically, 25 of 44 teachers used fewer misconceptions in their explanations postcourse. However, 19 of 44 teachers did not change (or, in two cases, teachers voiced one more misconception postcourse). In summary, although overall misconceptions decreased significantly after taking the course, they did not disappear, and many teachers continued to use the same misconceptions that they brought to the course.

Biology Teacher Knowledge of Natural Selection

Figure 1B illustrates the key concepts of natural selection and their distributions in pre- and postcourse teacher responses to the Bishop and Anderson question. Teachers employed the key concepts of natural selection in low frequencies in both the pre- and postcourse responses. Competition, limited resources, and overproduction of offspring, for example, were employed in less than 25% of the teachers’ explanations of evolutionary change both pre- and postcourse. Heritable phenotypic variation, selective survival, origin of variation, and changes in the distribution of individuals with certain traits were employed in less than 50% of all precourse responses. Teachers used some key concepts of natural selection markedly more often than other key concepts. As shown in Figure 1A, reproductive potential was invoked infrequently. By contrast, changes in the distribution of individuals with certain traits were invoked much more often. Overall, teachers employed the ideas of overproduction of offspring and competition in their explanations of evolution the least (< 15%). However, there were statistically significant increases in the use

Fig. 1 (A) Teacher misconception frequencies pre- and postcourse. (B) Teacher use of the components of natural selection in their explanations of an evolutionary event pre-and postcourse



of both individual key concepts (Figure 1B) and total key concepts postcourse (Wilcoxon signed-ranks test: $n = 44$, $z = -3.42$, $p = .001$).

Biology Teacher Knowledge of Evolution and the Nature of Science

In addition to the Bishop and Anderson essay question, ECK scores were used to measure changes in teacher knowledge of evolution. Pre- and postcourse comparisons of ECK scores indicated that statistically significant increases occurred

(Wilcoxon signed-ranks test: $n = 42$, $z = -4.01$, $p < .001$). Overall, 75% (31 of 42) of teachers increased their ECK scores. The evolution course was also associated with a positive and significant increase in teacher knowledge of the nature of science, as measured by ENOS scores (Wilcoxon signed-ranks test: $n = 40$, $z = -4.20$, $p < .001$). Overall, 83% (33 of 40) of teachers increased their ENOS scores postcourse.

Biology Teacher Preferences for Teaching Creationism

The precourse instrument revealed that 50% ($n = 21$) of biology teachers preferred that students be taught some amount of creationism in schools, and the other 50% of teachers preferred that students be taught evolution exclusively. A comparison of teacher attitudes pre- and postcourse indicated no significant change in teacher preferences for what students should be taught in schools (Wilcoxon signed-ranks test: $n = 44$, $z = -1.16$, $p = .25$). Thus, after completion of the 14-week evolution course, approximately half of the teachers continued to prefer that students be taught some amount of creationism in schools.

Biology Teacher Belief Preferences

The precourse instrument indicated that the majority (57%) of biology teachers preferred that students "believe and/or accept" some amount of creationism. Specifically, 9% of biology teachers preferred that students believe creationism exclusively, 43% preferred that students believe evolution exclusively, and 48% of biology teachers preferred that students believe both evolution and creationism.

A statistical comparison of teacher opinions pre- and postcourse indicated no significant change in belief preferences (Wilcoxon signed-ranks test: $n = 42$, $z = -0.49$, $p = .62$). However, 10 of 42 teachers did change their positions on what students should believe: There were 32 ties, 6 negative ranks (moved to evolution only), and 4 positive ranks (moved to both evolution and creationism). In summary, after course completion, the majority of teachers continued to prefer that students believe in creationism to some degree.

The Relationship of Knowledge Variables to Antievolutionary Teaching Preferences

Teachers were grouped into two categories based upon their preferences for teaching students antievolutionary ideas: Group 1 included those who preferred that students be taught exclusively evolution in school, and Group 2 included those who preferred that students be taught both creationism and evolution in school. No teachers in this sample preferred that students be taught only creationism in school. This analysis addressed the question: Do teachers who prefer that students be taught some amount of creationism in schools have significantly different ENOS and ECK scores than teachers who want students to learn only evolution in schools (Figure 2)?

A chi-square test indicated that Groups 1 and 2 (above) differed significantly in both their precourse ENOS scores (chi-square = 4.637, 1 *df*, $p = .031$) and precourse

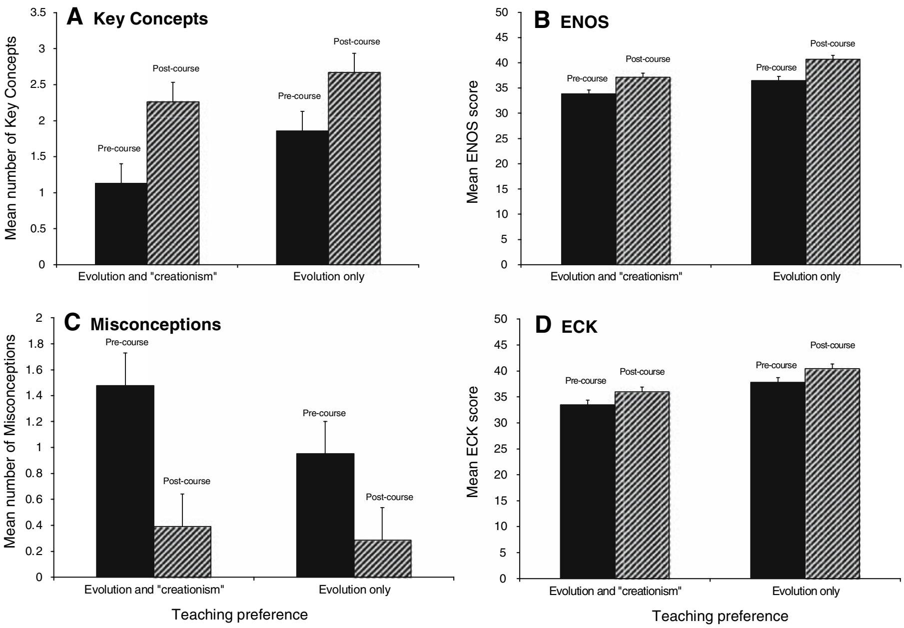


Fig. 2 Teacher knowledge variables pre-and postcourse reported by teaching preferences (both evolution and “creationism” or evolution only. N = 44. (A) Key Concepts of evolution scores. (B) Evolution in relation to the Nature of Science scores. (C) Misconception scores. (D) Evolution Content Knowledge scores. Error bars (1 standard error) are shown above each mean

ECK scores (chi-square = 10.35, 1 *df*, p = .001). Statistically significant results were also found for postcourse ENOS and ECK scores. Mean values for ENOS and ECK were greatest (i.e., most accurate) for the group of teachers who preferred that students be taught evolution only (Group 1, precourse ENOS mean rank = 25.53, Group 2 = 17.46; Group 1, postcourse ENOS mean rank = 28.60, Group 2 = 16.26). Similar results were also found for ECK scores (Group 1, precourse ECK mean rank = 28.58, Group 2 = 16.28; Group 1, postcourse ECK mean rank = 29.15, Group 2 = 15.78). Thus, teachers who preferred that students learn evolution only in schools had significantly higher ENOS and ECK scores in both pre- and postcourse analyses.

Different results were found for misconceptions and key concepts, however. A chi-square test indicated that Groups 1 and 2 (above) did not differ significantly in either their precourse misconceptions scores (chi-square = 2.90, 1 *df*, *p* = .09) or their precourse key concepts scores (chi-square = 3.6, 1 *df*, *p* = .06). No statistically significant differences were found in postcourse misconceptions scores by group (chi-square = 0.28, 1 *df*, *p* = .60) or key concepts scores by group (chi-square = 0.67, 1 *df*, *p* = .41).

Religiosity, Conflict, and Knowledge Variables

Analyses of the relationships between Religiosity and pre- and postcourse ENOS scores revealed statistically significant negative correlations in both cases

(Precourse: $n = 41$, Spearman's rho = $-.31$, $p = .045$; Postcourse: $n = 43$, $r = -0.34$, $p = .03$). Similar results were found in analyses of Religiosity and pre- and postcourse ECK scores (Precourse: $n = 43$, Spearman's rho = $-.29$, $p = .06$; Postcourse: $n = 43$, $r = -.39$, $p = .010$). Likewise, precourse misconception scores and key concepts scores were significantly associated with Religiosity scores ($n = 44$, Spearman's rho = .31, $p = .04$; $n = 43$, $r = -.35$, $p = .02$). Thus, unsurprisingly, religiosity appears to have had an influence on precourse and postcourse knowledge of evolution, natural selection, and the nature of science. Interestingly, the course appears to have reduced the magnitude of self-reported conflict between evolution and religion in participant teachers (McNemar test: $n = 44$, 2 tailed test, $p = .03$; see Table 3).

The Effects of Previous Coursework

The prior academic preparation of biology teachers did not appear to be associated with their knowledge of evolution, natural selection, or the nature of science as measured here. There were no significant differences in misconceptions (pre- or postcourse), key concepts (pre- or postcourse), ENOS (pre- or postcourse), or ECK scores (pre- or postcourse; Table 4) by Evoclass (prior completion of an undergraduate evolution class). Similarly, the number of college biology courses (biosemesters) completed was not significantly correlated with misconceptions (pre- or postcourse), key concepts (pre- or postcourse), ENOS (postcourse), or ECK scores (pre- or postcourse; Table 4). Remarkably, the only significant correlation between teachers' total number of biology courses and the measured knowledge variables was between biosemesters and precourse ENOS. Although difficult to explain, a plausible account is that students who have come through a long series of undergraduate biology courses often build up such a dense edifice of knowledge of biological facts that they lose perspective on the architecture of first principles (M. Cohen, personal communication, February 20, 2007).In summary, Religiosity was a better predictor of measured knowledge variables (largely negative in the case of

Table 3 Correlation of Religiosity With ENOS, ECK, Misconceptions, and Key Concepts of Natural Selection

	Religiosity		
	n	rho	*p*
Precourse ENOS	41	−0.31	0.05
Postcourse ENOS	43	−0.34	0.03
Precourse ECK	43	−0.29	0.06
Postcourse ECK	43	−0.39	0.01
Precourse Misconceptions	44	0.31	0.05
Postcourse Misconceptions	44	0.04	n.s.
Precourse Key Concepts	43	−0.35	0.02
Postcourse Key Concepts	44	−0.21	n.s.

Table 4 Pre- and Postcourse Knowledge Variables in Relation to Having Completed an Evolution Class (Evoclass) and Number of Undergraduate Biology Courses (Biosemesters)

	Pre-course				**Post-course**			
	Misconceptions	Key concepts	ENOS	ECK	Misconceptions	Key concepts	ENOS	ECK
Evoclass	0.935	2.632	0.008	0.434	0.075	0.606	0.221	0.52
Chi-square	df = 1	df = 1	df = 1	df = 1	df = 1	df = 1	df = 1	df = 1
	p = 0.333	p = 0.105	p = 0.931	p = 0.510	p = 0.785	p = 0.436	p = 0.638	p = 0.471
Biosemesters	−0.152	−0.064	−0.473	−0.249	−0.025	−0.108	−0.166	−0.145
Pearson	p = 0.338	p = 0.689	p = 0.002*	p = 0.116	p = 0.874	p = 0.494	p = 0.299	p = 0.367

* Significant result

knowledge and positive in the case of misconceptions) than previous undergraduate coursework in biology, evolution, or both.

Discussion

Significant core challenges for evolution education remain: (a) developing a better understanding of the relationship between knowledge and belief, (b) testing interventions designed to dissolve barriers to evolutionary understanding, and (c) reducing overall levels of antievolutionism (Alters 1997; Pigliucci 2002; Scott 2004). This study explored the first two challenges by evaluating the impact of knowledge induction in evolutionary biology on the teachers' attitudes toward the teaching of evolution. We demonstrated that one cannot assume that biology teachers with extensive backgrounds in biology have an accurate working knowledge of evolution, natural selection, or the nature of science. Considering the centrality of evolution to biology, an evolution course should be a required component of all biology teacher education programs. We investigated what effects such a course would have on our biology teachers' knowledge and beliefs in regard to evolution and the nature of science.

The biology teachers who participated in this study had extensive background in the biological sciences; 95% had bachelor's degrees in biology or the equivalent. Nevertheless, most teachers began the evolution course with diverse and abundant misconceptions about evolution, natural selection, and the nature of science that are also commonly held by high school students and college undergraduates. Only one novel misconception was uncovered that does not appear to have been documented previously.

The 14-week evolution course was associated with significant decreases in the frequencies of specific misconceptions, such as "use and disuse" explanations, "need" as a cause of change, and simultaneous population change. Additionally, the total number of misconceptions employed in the teacher essays also decreased significantly postcourse. There were statistically significant increases in the use of both individual key concepts of natural selection and total key concepts of natural selection postcourse. Pre- and postcourse comparisons of evolution content knowledge (ECK) scores indicated that statistically significant increases occurred. The evolution course was also associated with a positive and significant increase in teacher knowledge of the nature of science, as measured by Evolution in relation to the nature of science (ENOS) scores. Thus, overall, the evolution course was associated with statistically significant decreases in teacher misconceptions and significant increases in teacher knowledge of natural selection, evolution, and the nature of science.

Considerable research has focused on increasing science teacher understanding of both evolution and the nature of science and decreasing science teacher antievolutionism and resistance to teaching evolution in schools. Increasing teacher knowledge of evolution and the nature of science has often been difficult to achieve; thus, as a result, it has been difficult to determine the possible effects of increasing knowledge about evolution and the nature of science on teacher preference for teaching evolution. In summary, this study determined that statistically significant increases in teacher knowledge about evolution and the nature of science did not translate into greater preference for teaching evolution in schools. Indeed, we found that the majority of New York City science teachers who participated in the course still preferred after taking the course that (a) students be taught some amount of creationism and (b) students believe, to some degree, in creationism (broadly defined). Although 10 of 42 teachers did change their positions on what students should believe, the majority of teachers continued to prefer that students believe some amount of creationism.

One question that this study did not address is whether or not knowledge of evolution could have a threshold effect on preference for teaching evolution; that is, perhaps a certain level of understanding greater than what was achieved in this study is necessary before preference levels change. Indeed, the teachers who participated in the course began with low levels of scientific understanding (despite bachelor's degrees in biology). Despite significant learning gains (our mean pre-to-post effect size was .79), perhaps the threshold of understanding necessary to alter preference position was not reached. Further research should attempt to examine the effects of overall knowledge level on preference position.

In Knowledge Domains Other than Evolution, Do Knowledge Gains Produce Attitude Changes?

Research on the effect of knowledge on belief and attitude change has examined diverse targets. Some of these include individuals infected with HIV (Slusher and Anderson 1996), HIV prevention (Albarracin et al. 2003), the elderly (Angiullo et al. 1996; Carmel et al. 1992), nuclear power plants (Showers and Shrigley 1995), the death penalty (Wright et al. 1995), struggling learners (Nierstheimer et al. 2000), addiction (Erickson et al. 2003), income tax (Eriksen and Fallan 1996), obese individuals (Harris et al. 1991), and smoking (Koumi and Tsiantis 2001).

The results have been mixed but largely negative: A minority of studies suggests that knowledge induction leads to significant but modest attitude and belief change (e.g., Albarracin et al. 2003; Slusher and Anderson 1996). The meta-analysis conducted by Albarracin et al., for example, indicated that knowledge inductions about HIV transmission led to attitude change on some dimensions (e.g., the perceived threat) but not in actual condom use. A number of problems undermine Wright et al.'s (1995) finding that knowledge induction led to decreased acceptance of the death penalty: The instructor of a college course on the death penalty was also the chief investigator, raising the possibility of students changing their beliefs to please the instructor; the psychometric properties of the measures were not included; and data analyses were conducted on an item-by-item basis, rather than on the basis of coherent scales. Although Nierstheimer et al. (2000) concluded that increasing prospective teachers' knowledge of struggling learners produced positive attitude change, two problems call into question that conclusion: There was no control group, and the methods for collecting data on the participants' beliefs were not made clear.

In many studies, however, knowledge-oriented interventions have not changed long-term attitudes and beliefs (Angiullo et al. 1996; Carmel et al. 1992; Erickson et al. 2003; Harris et al. 1991; Koumi and Tsiantis 2001; Showers and Shrigley 1995). In a few studies, immediate postintervention attitude change occurred (e.g., Angiullo et al. 1996; Erickson et al. 2003; Koumi and Tsiantis 2001), but no significant attitude differences were found between experimental and control groups 3–6 months after the intervention concluded.

In one of the most interesting and carefully controlled studies of attitude change as a function of knowledge gain, Eriksen and Fallan (1996) compared a group consisting of college students enrolled in a marketing course and a group of college students enrolled in a tax law course. The two groups were equivalent in their initial knowledge of tax law and attitudes toward taxation. The instructors involved were not made aware of the purpose of the study. At the end of the semester, the learners of tax law showed significant improvement on one attitude, belief in the fairness of the progressive income tax system, concomitant to their gain in knowledge of tax law. However, with regard to other important tax-related attitudes, for example, attitudes toward one's own tax ethics, others' efforts at tax evasion, and other tax-related crimes, the two groups were indistinguishable at the semester's end.

The preponderance of these findings on knowledge gain and its relationship to attitude and belief change is consistent with our finding that knowledge induction in evolutionary biology did not induce attitude change toward the teaching of evolution in schools. Our results are also consistent with the results of Sinatra et al. (2003), who found no relation between knowledge of animal and human evolution and its acceptance. It is probably too much to expect knowledge gain alone to precipitate much change in beliefs and attitudes vis-à-vis the teaching of evolution.

The above studies that bear on knowledge domains other than evolution have a number of implications for future research on inducing in biology teachers more positive beliefs and attitudes toward the teaching of evolution. First, if possible, the college instructors recruited for such research should not be aware of the investigators' hypotheses. Second, investigators should assess a variety of aspects of attitudes and beliefs toward evolution, using richer psychometric instruments. Third, in addition to measuring beliefs and attitudes regarding evolution and its teaching, it is incumbent upon investigators to assess the actual occurrence of evolution instruction among participating teachers in their classrooms. Fourth, research on the induction of more positive beliefs and attitudes regarding evolution should include both immediate and delayed posttests to assess the durability of induced changes.

Is Belief Significantly Different from Acceptance?

The meanings of the terms belief and acceptance, at first glance, can be clearly delineated, thereby eliminating potential semantic confusion in discussions regarding the goals of evolution courses for science teachers. For example, acceptance may be considered the recognition of a theory's validity through rational and systematic evaluation of evidence, whereas belief may be considered the recognition of a theory's validity using personal conviction, opinion, and extrarational criteria (Southerland and Sinatra 2003; Smith 1994). Unfortunately, such solid distinctions dissolve in many research and classroom contexts because research participants may be (a) unaware of the differences in the meanings of these terms and (b) unlikely to recognize that their beliefs are irrational or not based on evidence, thus rendering the distinctions between belief and acceptance meaningless in self-reports. Indeed, it could be argued that few individuals are sufficiently metacognitive such that they are cognizant of the epistemological foundations of their beliefs. Is it possible for a researcher to rigorously determine how, in an epistemological sense, an individual has arrived at his or her conclusion?

Finally, the distinction outlined above between belief and acceptance is perhaps only useful within "scientistic," "prescriptive," or naïve epistemological worldviews. In other words, it may be likely that practicing scientists believe in, rather than accept, many scientific contexts. One could argue that belief is a central and common descriptive reality in all scientific endeavors; no scientist has the specialized knowledge and access to experimental apparatuses, data, or materials to rationally and systematically determine the validity of most (if not all) scientific ideas outside of his or her discipline. Therefore, it is likely that scientists believe, rather than accept, much of their scientific knowledge, even though they would undoubtedly prefer to view their scientific knowledge as acquired exclusively through the systematic and rational evaluation of evidence. This problem calls into question the utility of the tight distinctions made between acceptance and belief in many teaching documents (e.g., NAS 1998; University of California Museum of Paleontology 2004). Is the distinction between belief and acceptance relevant? (see also Alters 1997).

This study tested very simple hypotheses of association between two major variables (knowledge and level of preference), whereas we suspect that multiple variables, with multiple interactions, are involved. Considerable research in cognitive psychology and science education has indicated that the relationships among understanding, acceptance, belief, knowledge, and preference are complex, poorly understood, and controversial (Smith 1994; Southerland 2000). Indeed, many factors, including cognitive dispositions, levels of reasoning, and personal epistemologies, dispose the individual toward preference positions. It is likely that knowledge is a necessary—but not sufficient—factor in reducing antievolutionism in biology and other science teachers. Therefore, implementing evolution content courses for biology teachers should not necessarily be assumed to be sufficient to produce significant decreases in teacher belief in—or preference for—antievolutionary standpoints.

Now we return to the question that was raised at the beginning of this paper: What should be the goals of teacher evolution education courses? Are the goals of such courses to achieve teacher understanding of evolution, acceptance of evolution, belief in evolution, preference for teaching evolution, or some combination of these? In an age of standards and performance-based education, it is, in many contexts, mandatory to specify the goals of a course prior to instruction to assess the success and quality of teacher education programs (as required by many accreditation agencies, such as the National Council for the Accreditation of Teacher Education). What should teacher educators list as the goals of their education courses, and what are appropriate foundations or justifications for such goals? Scientists and science educators have much work to do, because the goals of evolution education remain only superficially clear. For example, do we conclude that the intervention executed in this study was "successful?" Teachers achieved statistically significant gains in their knowledge of evolution and the nature of science, but they continued to harbor antievolutionary worldviews. It will be difficult to determine how to judge our science teacher education courses until the goals of instruction are more explicitly delineated by the science teacher-education community. In the meantime, we must begin to recognize that knowledge alone may not be the primary solution to the problem of science teacher antievolutionary beliefs—if, of course, belief is considered to be the problem that we need to address.

Appendix

Selected Likert-scale survey questions	Variable
a. As evolution cannot be observed, it is outside the realm of science.	ENOS
b. After scientists determine that theories are well supported, they refer to theories as facts.	ENOS
c. Mutations are harmful and therefore cannot give rise to new characteristics.	ECK
d. Evolution is weaker than many other scientific concepts because it is only a theory.	ENOS
e. Fossil species have been found that are intermediate between humans and apes.	ECK
f. The survival of early humans was difficult because of predatory dinosaurs.	ECK
g. The organisms that cause malaria, gonorrhea, and tuberculosis have become resistant to antibiotics. The biological cause of this resistance is evolution.	ECK
h. Radiometric dating of rocks indicates that the Earth is billions of years old.	ECK
i. If evolution were true, "living fossils" like the horseshoe crab would not have stayed the same for millions of years.	ECK
j. Evolution is not a testable scientific hypothesis because it cannot be refuted by any observation.	ENOS
k. Chance cannot be a key factor in the origin of complex organisms.	ECK

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