Teaching evolution: challenging religious preconceptions

Eric C. Lovely[1,*] and Linda C. Kondrick[†]

[*]Department of Biology and [†]Department of Physical Science, Arkansas Tech University, Russellville, AR 72801, USA

Synopsis Teaching college students about the nature of science should not be a controversial exercise. College students are expected to distinguish between astronomy and astrology, chemistry and alchemy, evolution and creationism. In practice, however, the conflict between creationism and the nature of science may create controversy in the classroom, even walkouts, when the subject of evolution is raised. The authors have grappled with the meaning of such behaviors. They surveyed 538 students in a public, liberal arts college. Pre/post course surveys were analyzed to track changes in student responses to questions that were either consistent or inconsistent with the Theory of Evolution after a semester of instruction in a college biology or zoology course in which evolution was taught. Many students who were initially undecided about issues regarding evolution had shifted in their viewpoints by the end of the course. It was found that more education about the evidence for and the mechanics of evolutionary processes did not necessarily move students toward a scientific viewpoint. The authors also discovered a ''wedge'' effect among students who were undecided about questions pertaining to human ancestry at the beginning of the course. About half of these students shifted to a scientific viewpoint at the end of the course; the other half shifted toward agreement with statements consistent with creationism.

Introduction

Modern biology is a rigorous academic discipline informed by what is now accepted as certain settled principles. Perhaps, the first among these principles is the theory of evolution and common descent. However, a significant number of students and other segments of the public object to this theory because they believe it to be contradictory to their religious beliefs. Changing minds is not a simple task (Nisbet and Mooney 2007). Scott (2004) presents a thorough review of the perceived conflicts between science and the religious beliefs of creationists.

This conflict is found across a broad base of Americans. The Harris Poll (2005) reported that 64% of Americans believe that human beings were created directly by God. And 54% did not believe that humans developed from earlier species. Their results show differences by educational level regarding acceptance of evolutionary explanations. In the category of some college, the poll found that 49% accepted the theory of evolution regarding plants and nonhuman animals, while only 22% agreed that humans evolved from earlier species. The college students surveyed in this study exhibited trends consistent with that survey. In the same poll, it was found that 47% do not believe that humans and apes have a common ancestry. According to Padian (2008), roughly a quarter of Americans accept evolutionary explanations, and another quarter holds fundamentalists views that are not likely to change with only an explanation of evidence.

Science is a body of knowledge and a methodology. It attempts to explain the material universe without supernatural causation. The scientific process is an inductive process in which observations and experiments are used to develop and test hypotheses. Some hypotheses, the ones with tremendous evidence and support, stand the test of time and become tried and true principles. These are scientific theories. A scientific theory is not ''just a theory'' but a founding principle that has extraordinary, explanatory, and predictive power. It is an idea that can explain why the world is the way it is. Religion, in contrast, is primarily a deductive process that starts with revealed truth that is assumed to be absolutely true. It then uses these truths to explain how the world works. College students are expected to distinguish between astronomy and astrology, chemistry and alchemy, medicine and mystic healing. Likewise, they are expected to understand evolution and common descent as established scientific principles, and creationism as a religious belief. In practice, however, the conflict between creationism and the nature of science may create controversy in the

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[1]E-mail: elovely@atu.edu
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classroom when the subject of evolution is discussed. It was out of such conflicts that this study was born.

In this study, the authors were concerned with the conceptual changes that students undergo with respect to their understanding about evolution within the context of a one semester course in which evolution is a common theme. The authors reviewed the relatively small body of literature in education journals that deals with the changes learners go through as they develop internal science-related constructs. Posner et al. (1992) studied changes in the conceptual ecology, or intrapersonal cognitive landscape students traverse when they encounter new and unusual experiences. They posited that learners can assimilate new experiences by making sense of them in terms of familiar internal paradigms. However, when the current paradigm is not sufficient to assimilate the new experience, cognitive dissonance occurs. Accommodation occurs when the learner's internal paradigm changes in order to make sense of the new experience. According to Posner et al. (1982), this model of cognitive change is mirrored by the scientific community. Normal science assimilates new information into existing scientific views, models, and theories. However, scientific revolution occurs when those discoveries require a change in the status quo.

Cross cultural conflict is another area of study that bears upon the peculiar conflict that students experience when trying to reconcile issues of faith and reason. Mills and Simpson (1986) explored many aspects of the problems learners encounter when they carry cultural baggage. When that baggage interferes with their ability to accommodate new constructs, a cultural victim mentality may arise. Hashweh (2003) stated, ''knowledge is constructed in search of meaning, and . . . the resolving of cognitive conflict, dissonance, inconsistencies or confusions is both the end and means of learning'' (p. 422).

The authors do not intend to imply that faith is unreasonable cultural baggage. Nor do we intend to imply that all preconceptions are misinformed, or erroneous. However, certain religious viewpoints are unreasonable by the standards of the science of evolution. For instance, according to evidence from geological, archeological, and other historical records, one cannot reasonably induce that the earth is only 6000-years-old. Yet, this is a religious teaching among some communities of faith (Scott 2004). Neither is it only the religious that may be misinformed about facts regarding evolution. A person does not have to be religious to be to be misinformed. Many students enter college classes with the preconception that dinosaurs and people inhabited the earth at the same time. Contrary to the purported evidence of Fred and Wilma Flintstone, this is an erroneous preconception that some students have. In the context of this study, the authors were interested specifically in finding if students, when presented with scientific evidence supporting evolutionary theory, shifted from agreement with statements consistent with literal creationism, and young earth paradigms toward viewpoints consistent with the theory of evolution.

The reason the authors were particularly concerned with the paradigm shifts of students expressing creationist views is that we have observed in the classroom that these views tend to obstruct learning in biology and zoology. When students do not approach introductory courses rooted in evolutionary theory with an open mind, they may struggle to see the relevance and importance of phylogenetic information throughout the semester. For example, in zoology classes the characteristics of taxonomic groups are learned within a phylogenetic context. If a student rejects common ancestry, the majority of the semesters' work placed in an evolutionary context becomes irrelevant and incorrect. Biology and zoology are taught within an evolutionary context. Evolution is the backbone, the beautiful and efficient explanation for why organisms today are different from organisms in the past and why there is such an amazing diversity of fascinating biological organisms with an awe inspiring lifestyles and body plans.

Methods

This study was constructed according to action research methodology. Actions studies are conducted by practitioners for the purpose of improving their own practice. The plan of this study was informed by the Zubber-Skerritt (1992) model of action research. It was designed to serve two purposes:

(1) To improve the practice of the instructors involved in the study, and

(2) To advance knowledge in college level science teaching by generating a grounded theory of the ways in which student paradigms regarding evolution develop over a semester course in which evolution is taught.

Zubber-Skerritt (1992) outlined a systematic, cyclic process of action research consisting of four phases: planning, acting, observing, and reflecting. In this study, the plan was to address the problem of student protests over the teaching of evolution.

The problem arose when a group of students taught by the primary author of this study staged a walk-out in one of his nonmajors biology classes.

It happened just as the instructor finished a discussion of antibiotic and insecticide resistance and had continued with a discussion of the fossil record. One by one, six students in a class of 50 or 60 got up, slammed shut their books and walked out of class. A smaller group of these students complained to administrators. The administration was completely supportive of teaching science in a science classroom, but the instructor was left with three questions:

(1) Was this just a vocal minority or do a majority of students have creationist views?

(2) How do students' religious views influence their comprehension of evolutionary constructs.

(3) How do students' understanding of the theory of evolution change over a semester of instruction in a college biology or zoology course in which evolution was taught.

In order to learn where the students were coming from, and thus ultimately to improve his practice the instructor devised a plan. This study represented the technical phase (Zubber-Skerritt 1992) of that action research plan: determining the ''effectiveness/efficiency of educational practice (p. 12).'' In order to learn where the students were coming from, and ultimately be able to devise actions to improve his practice the instructor constructed a research plan. He began surveying students and enlisted a colleague from the field of science education, the second author of this article, to assist him as an outside facilitator.

Pre–post test surveys were administered to 538 undergraduate students at a public, liberal arts university, before and after instruction in a college biology or zoology course in which evolution was taught. Data included in this study were from a total of 22 sections taught by five instructors over the course of eight semesters. There was no attempt to standardize the way in which the theory of evolution was presented in each of these classes. Neither were instructor effects taken into account in this study. The courses were primarily freshmen and sophomore level courses. About half were enrolled in the non-majors freshmen biology course and the remainders were enrolled in the sophomore level zoology course for majors.

Surveys were approved by the University Human Subjects Review Committee. Accordingly, students were assured verbally and in writing that their participation was entirely voluntary, and that the surveys would not in any way affect their grade in the course. They were also informed that the instructors would not be able to see either the pretest, or the posttest surveys before final grades for the course had been posted by the registrar. They were also given a contact person in the Human Subjects Review Office to contact if they had problems or concerns about participation in the study. No complaints were registered.

The pre–post test surveys consisted of 15 questions of two types: student beliefs and student understandings. Three questions were asked pertaining to the students beliefs about their own religiosity and about their ideas regarding conflicts between science and religion. The validity of these three questions was established in a pilot study by Kondrick and Lovely (2005).

The remaining 12 questions were relevant to student understanding of evolutionary theory. Response choices to all questions were agree, do not know, and disagree. In order to avoid issues of question construct bias, some statements were consistent with evolutionary theory while others were consistent with creationist viewpoints. The direction of the scale was also varied such that a response of ''Agrees'' was not always the scientifically correct answer. Statements were designed to reflect three levels of potential conflict with creationist views: uncontroversial, moderately controversial, and highly controversial. The questions were placed in random order in the survey to avoid effects bias either by question order or by category massing.

Uncontroversial statements focused on details of microevolution. The moderately controversial statements pertained to the age of the earth that were expected to conflict with the ''Young Earth Theory'' of some creationists. The statements expected to be most controversial among students were those pertaining to human origins. The selection of these categories was informed by the work of Scott (2004). The specific questions were selected from those used in a pilot study by Kondrick and Lovely (2005).

For student responses to each of the 12 questions cross-tabulation tables and a χ^2 test of independence were used to determine how student attitudes toward religion and understandings regarding evolution changed from the beginning to the end of course.

Conclusions of this study were informed by Assimilation/Accommodation Theory of cognitive dissonance (Posner et al. 1982, 1992) as outlines in the Introduction section earlier. Scott's (2004) definition and interpretations of creationist positions with regard to the theory of evolution were used in the construction of the survey instrument and the interpretation of the data analysis. In its simplest form Scott defines creationism as ''the Christian view that God created directly (p. 51).'' And finally,

for the purpose of this study, "correct responses" were defined as responses consistent with the principles of evolutionary biology. "Incorrect responses" were inconsistent with that scientific standard. In some cases, incorrect responses were also responses consistent with creationist positions as described by Scott (2004). Responses to the three questions regarding religious beliefs and ideas regarding conflicts between science and religion were not considered as either correct or incorrect. Changes in these responses were simply accepted at face value.

Results

Students ($N = 538$) were asked to respond to identical sets of questions regarding the theory of evolution before and at the end of a semester course. Since the data are categorical in nature, a nonparametric technique common to survey analysis was employed. A cross-tabulation table was constructed for responses to each of the 15 questions. In general, there is less probability of finding a difference or a relationship among variables with a nonparametric test than with a parametric test. However, in this study that was not a problem. The null hypothesis for the χ^2 test of independence for each pair of scores was rejected (Table 1). The alternative hypothesis was, therefore, accepted: there is a dependent relationship between the pre- and post-test responses for each of the 15 questions. Patterns of changes in pre/post responses were also examined. Analysis of trends in the data revealed three sets of response patterns depending upon the level of controversy evoked: uncontroversial statements, young-earth statements, and human origins statements.

Table 1 Test of independence for pre- and post-responses to each of the 15 statements in the order presented in the figures that follow

Statement	Degrees of freedom	χ^2	Probability	Decision
1	9	255.9	0.000	Reject
2	9	81.3	0.000	Reject
3	9	180.7	0.000	Reject
4	4	73.5	0.000	Reject
5	4	82.6	0.000	Reject
6	4	23.3	0.000	Reject
7	4	37.9	0.000	Reject
8	4	30.9	0.000	Reject
9	4	48.3	0.000	Reject
10	4	95.3	0.000	Reject
11	4	39.9	0.000	Reject
12	4	86.0	0.000	Reject
13	4	109.8	0.000	Reject
14	4	136.1	0.000	Reject
15	4	86.9	0.000	Reject

The order of the statements on the survey instrument was not congruent with the order presented in the results.

Students religiosity and perceived conflicts between science and religion

(1) Figure 1A shows student responses for the statement, "I consider myself a religious person." Before the course, 364 of the 538 students responded "describes me fairly well" or "describes me perfectly" to this statement while 44 responded "describes me not at all" (Fig. 1A). After the course, 15 students switched from "not at all" to "fairly well or perfectly" and 11 switched from "fairly well or perfectly" to "not at all" (Fig. 1B).

(2) Figure 2A shows student responses for the statement, "I believe there are some serious conflicts between scientific and religious beliefs on certain issues." Before the course, 359 of the 538 students responded "describes my opinion fairly well" or "describes my opinion perfectly" to this statement while 45 responded "describes my opinion not at all" (Fig. 2A). After the course, 24 students switched from "not at all" to "fairly well or perfectly" and 21 switched

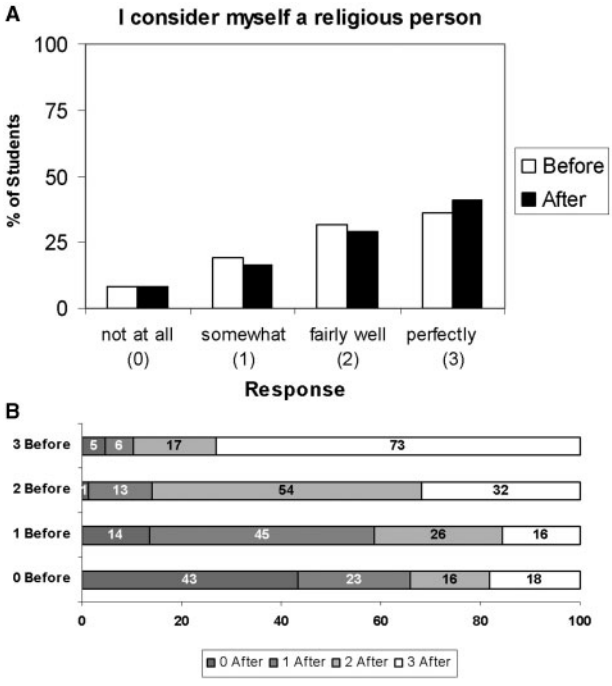

Fig. 1 (A) Student responses (at the start and end of the course) to the statement "I consider myself a religious person." **(B)** Cross tabulation results for the statement "I consider myself a religious person."

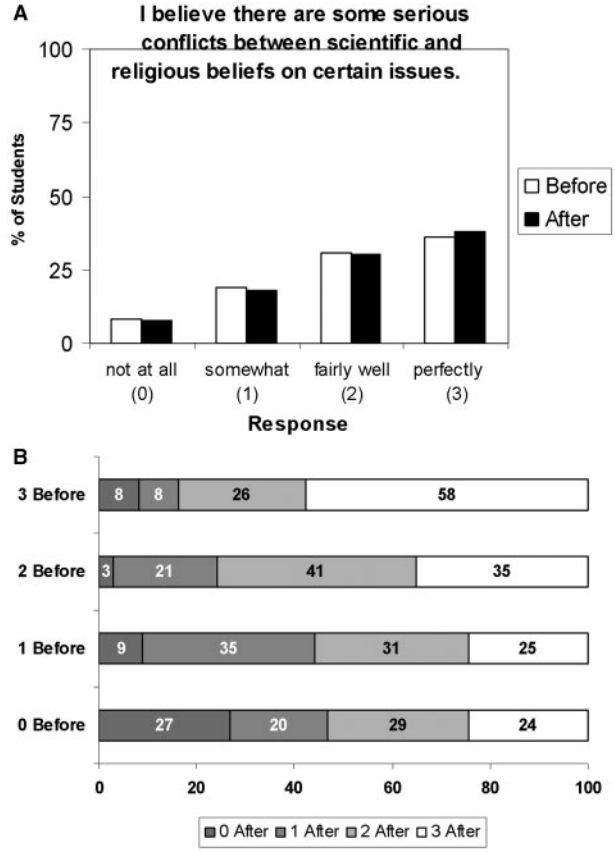

Fig. 2 **(A)** Student responses (at the start and end of the course) to the statement "I believe there are some serious conflicts between scientific and religious beliefs on certain issues." **(B)** Cross tabulation results for the statement "I believe there are some serious conflicts between scientific and religious beliefs on certain issues."

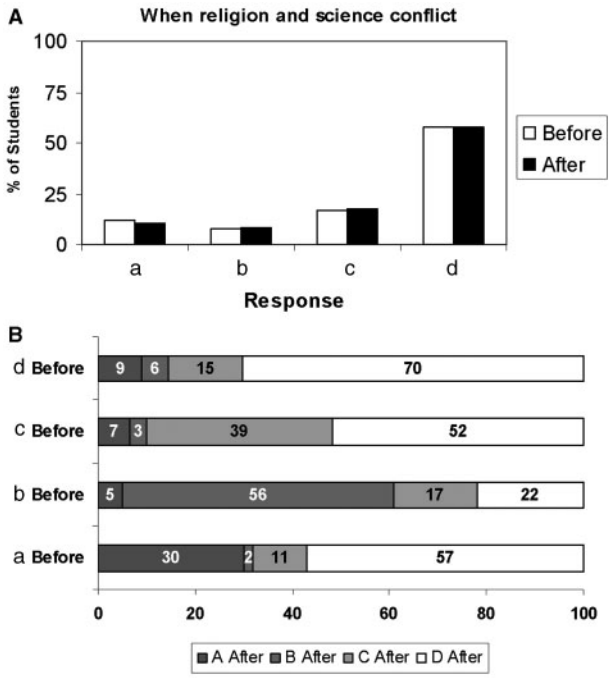

Fig. 3 **(A)** Student responses (at the start and end of the course) to the statement "When religion and science conflict; (a) only religion provides reliable knowledge, (b) only science provides reliable knowledge, (c) science and religion cannot conflict because each has its own domain of influence, or (d) science and religion inform from different perspectives. A complete picture of reality must integrate both areas." **(B)** Cross tabulation results for the statement "When religion and science conflict . . . ."

from "fairly well or perfectly" to "not at all" (Fig. 2B).

(3) Figure 3A shows student responses for the statement, "When religion and science conflict (a) only religion provides reliable knowledge, (b) only science provides reliable knowledge, (c) Science and religion cannot conflict because each has its own domain of influence, or (d) science and religion inform from different perspectives. A complete picture of reality must integrate both areas." Before the course, 63 of the 538 students responded "religion only," 41 responded "science only," and 402 responded with either a compartmentalized or holistic view (Fig. 3A). After the course, 36 students switched from "religion only" to a holistic view (Fig. 3B).

Uncontroversial statements

When asked about the nature of science or the process of evolution, student responses show the greatest shift in responses toward an understanding of the process of evolution. From beginning to end of coursework in biology and zoology among students who originally gave an incorrect response, the following patterns were observed. Shifted away means that they moved from the incorrect to either the correct answer, or to undecided.

(1) Figure 4A shows student responses for the statement, "The theory of evolution is supported by evidence." Before the course, 287 of the 538 students responded "agree" to this statement while 115 responded "disagree" (Fig. 4A). After the course, 24 students switched from "agree" to "disagree" and 49 switched from "disagree" to "agree" (Fig. 4B).

(2) Figure 5A shows student responses for the statement, "Science is a completed list of facts." Before the course, 153 of the 538 students responded "agree" to this statement while 291 responded "disagree" (Fig. 5A). After the course, 73 students switched from "agree" to "disagree" and 39 switched from "disagree" to "agree" (Fig. 5B).

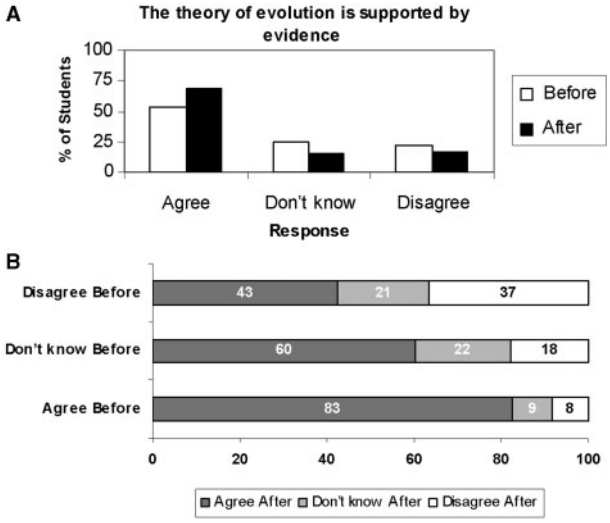

Fig. 4 (**A**) Student responses (at the start and end of the course) to the statement "The theory of evolution is supported by evidence." **(B)** Cross tabulation results for the statement "The theory of evolution is supported by evidence."

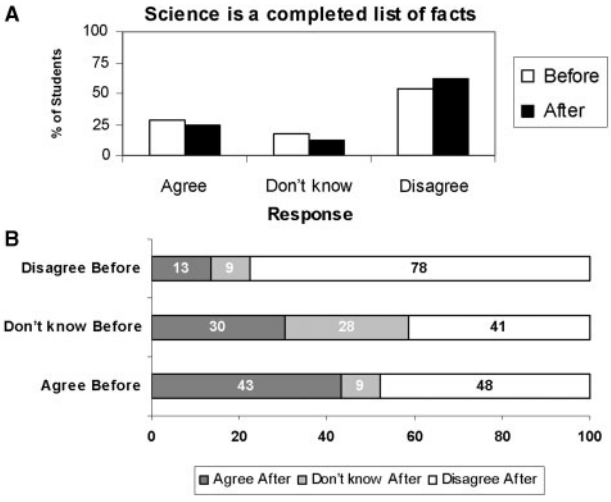

Fig. 5 **(A)** Student responses (at the start and end of the course) to the statement "Science is a completed list of facts." **(B)** Cross tabulation results for the statement "Science is a completed list of facts."

(3) Figure 6A shows student responses for the statement, "Evolution is a purposeful striving toward a higher form (a steady progress from microbes to man)." Before the course, 184 of the 538 students responded "agree" to this statement while 153 responded "disagree" (Fig. 6A). After the course, 40 students switched from "agree" to "disagree" and 51 switched from "disagree" to "agree" (Fig. 6B). Those that responded "don't know" before the course split between 78 changed to "agree" and 51 changed to "disagree" (Fig. 6B).

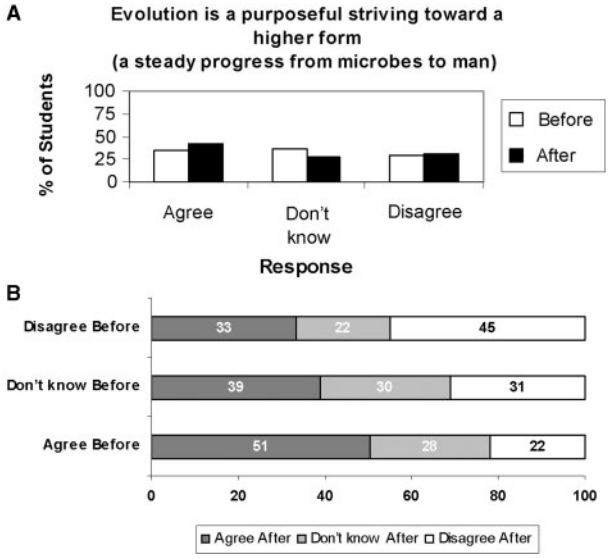

Fig. 6 **(A)** Student responses (at the start and end of the course) to the statement "Evolution is a purposeful striving toward a higher form (a steady progress from microbes to man)." **(B)** Cross tabulation results for the statement "Evolution is a purposeful striving toward a higher form (a steady progress from microbes to man)."

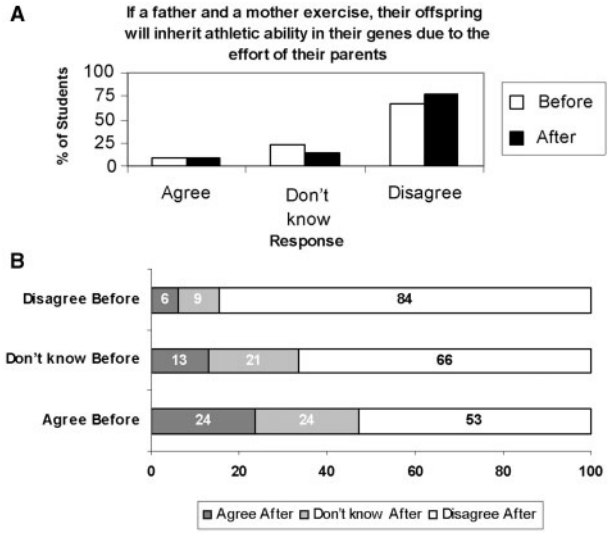

Fig. 7 **(A)** Student responses (at the start and end of the course) to the statement "If a father and a mother exercise, their offspring will inherit athletic ability in their genes due to the effort of their parents." **(B)** Cross tabulation results for the statement "If a father and a mother exercise, their offspring will inherit athletic ability in their genes due to the effort of their parents."

(4) Figure 7A shows student responses for the statement, "If a father and a mother exercise, their offspring will inherit athletic ability in their genes due to the effort of their parents." Before the course, 51 of the 538 students responded "agree" to this statement while 360 responded

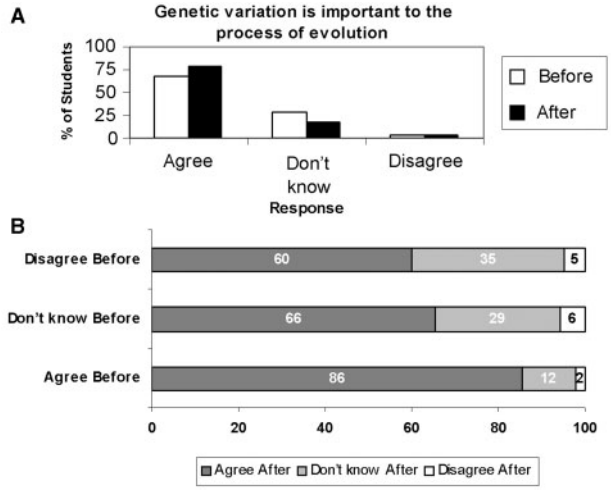

Fig. 8 (A) Student responses (at the start and end of the course) to the statement "Genetic variation is important to the process of evolution." **(B)** Cross tabulation results for the statement "Genetic variation is important to the process of evolution."

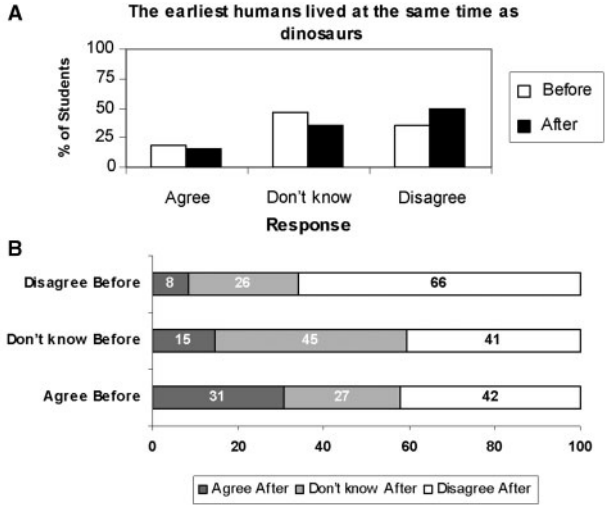

Fig. 9 (A) Student responses (at the start and end of the course) to the statement "The earliest humans lived at the same time as dinosaurs." **(B)** Cross tabulation results for the statement "The earliest humans lived at the same time as dinosaurs."

"disagree" (Fig. 7A). After the course, 27 students switched from "agree" to "disagree" and 22 switched from "disagree" to "agree" (Fig. 7B).

(5) Figure 8A shows student responses for the statement, "Genetic variation is important to the process of evolution." Before the course, 362 of the 538 students responded "agree" to this statement while 20 responded "disagree" (Fig. 8A). After the course, seven students switched from "agree" to "disagree" and 12 switched from "disagree" to "agree" (Fig. 8B).

Young-earth statements

When asked to respond to statements concerning a young-earth there is some shift toward a scientific view. Depending on the specific statement before the course $15 \pm 5\%$ of students expressed young-earth creationist views after the course creationist views increased to $16 \pm 5\%$ (average of next three questions $\pm$ one standard deviation). Among students who originally held a young-earth creationist viewpoint the following patterns were observed.

(1) Figure 9A shows student responses for the statement, "The earliest humans lived at the same time as dinosaurs." Before the course, 95 of the 538 students responded "agree" to this statement while 190 responded "disagree" (Fig. 9A). After the course, 40 students switched from "agree" to "disagree" and 16 switched from "disagree" to "agree" (Fig. 9B).

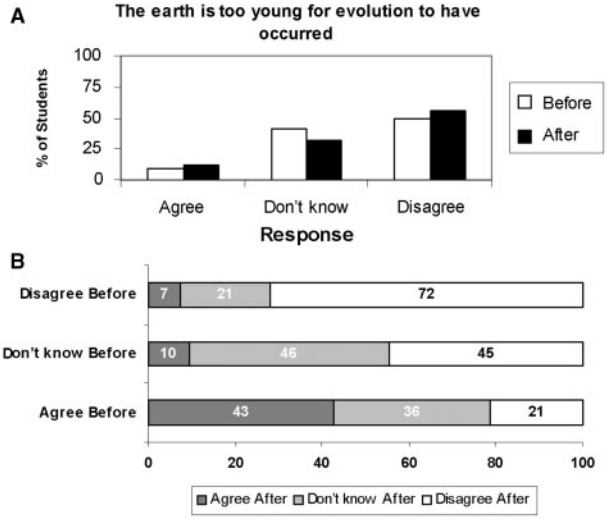

Fig. 10 (A) Student responses (at the start and end of the course) to the statement "The earth is too young for evolution to have occurred." **(B)** Cross tabulation results for the statement "The earth is too young for evolution to have occurred."

(2) Figure 10A shows student responses for the statement, "The earth is too young for evolution to have occurred." Before the course, 47 of the 538 students responded "agree" to this statement while 269 responded "disagree" (Fig. 10A). After the course, 10 students switched from "agree" to "disagree" and 20 switched from "disagree" to "agree" (Fig. 10B).

(3) Figure 11A shows student responses for the statement, "The theory of evolution explains the diversity of life on an about four or five billion

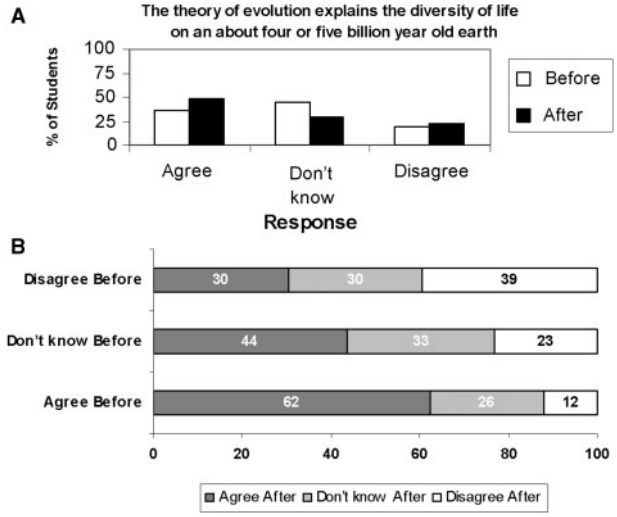

Fig. 11 **(A)** Student responses (at the start and end of the course) to the statement "The theory of evolution explains the diversity of life on an about four or five billion year old earth." **(B)** Cross tabulation results for the statement "The theory of evolution explains the diversity of life on an about four or five billion year old earth."

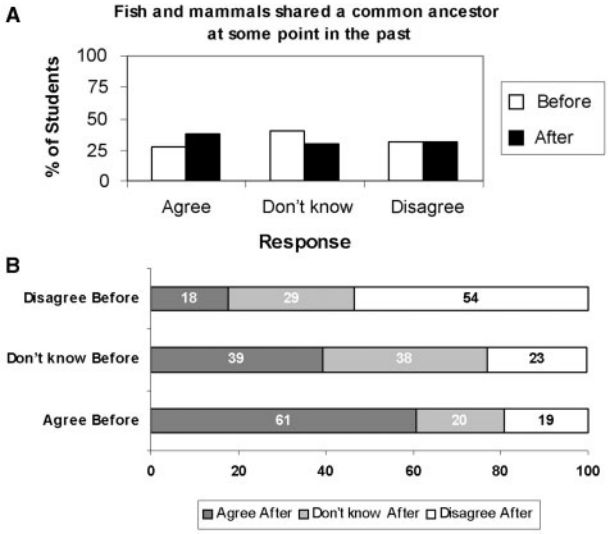

Fig. 12 **(A)** Student responses (at the start and end of the course) to the statement "Fish and mammals shared a common ancestor at some point in the past." **(B)** Cross tabulation results for the statement "Fish and mammals shared a common ancestor at some point in the past."

year old earth." Before the course, 193 of the 538 students responded "agree" to this statement while 99 responded "disagree" (Fig. 11A). After the course, 23 students switched from "agree" to "disagree" and 30 switched from "disagree" to "agree" (Fig. 11B).

Human origins statements

The most controversial statements, those dealing with human origins exhibit the most persistent creationist views. Some students that responded "don't know" at the beginning of the course changed toward a creationist view and others turned away from a creationist view.

(1) Figure 12A shows student responses for the statement, "Fish and mammals shared a common ancestor at some point in the past." Before the course, 150 of the 538 students responded "agree" to this statement while 170 responded "disagree" (Fig. 12A). After the course, 29 students switched from "agree" to "disagree" and 30 switched from "disagree" to "agree" (Fig. 12B). Students often had fewer problems with evolution of nonhumans. Only 32% of students expressed creationist views regarding fish and mammals, but depending on the specific statement before the course 51 ± 4% of students expressed creationist views regarding human origins after the course creationist views decreased

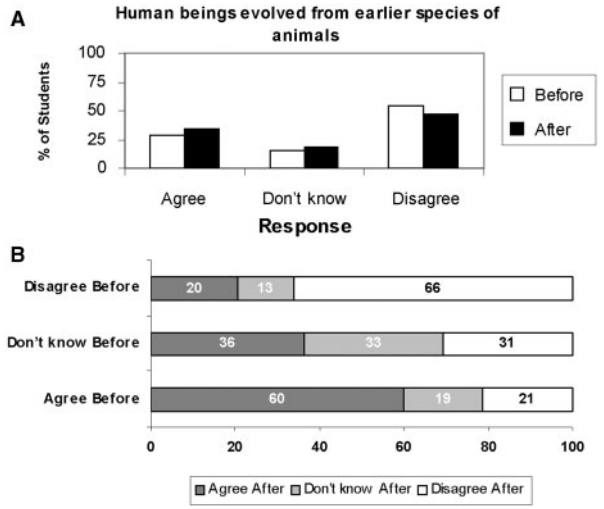

Fig. 13 **(A)** Student responses (at the start and end of the course) to the statement "Human beings evolved from earlier species of animals." **(B)** Cross tabulation results for the statement "Human beings evolved from earlier species of animals."

to 47 ± 1% (average of next three questions ± one standard deviation).

(2) Figure 13A shows student responses for the statement, "Human beings evolved from earlier species of animals." Before the course, 155 of the 538 students responded "agree" to this statement while 293 responded "disagree" (Fig. 13A). After the course, 33 students switched from "agree" to "disagree" and 60 switched from "disagree" to "agree" (Fig. 13B). Of the 88 students that

Fig. 14 **(A)** Student responses (at the start and end of the course) to the statement "Man, gorilla, and chimpanzee shared a common ancestor." **(B)** Cross tabulation results for the statement "Man, gorilla, and chimpanzee shared a common ancestor."

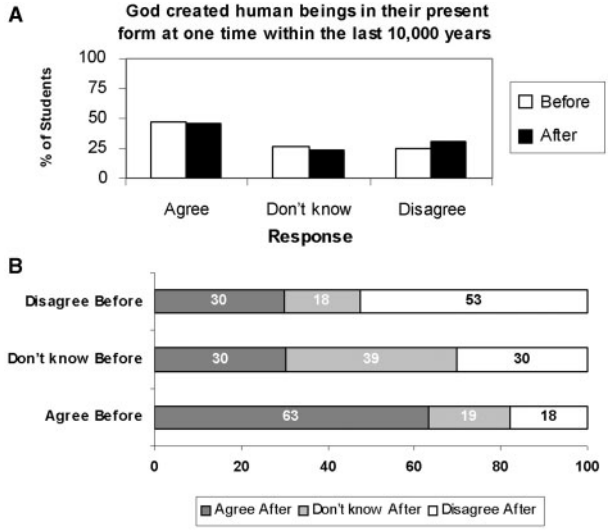

Fig. 15 **(A)** Student responses (at the start and end of the course) to the statement "God created human beings in their present form at one time within the last 10,000 years or so." **(B)** Cross tabulation results for the statement "God created human beings in their present form at one time within the last 10,000 years or so."

responded "don't know" before the course, 32 changed to "agree" and 27 switched to "disagree" (Fig. 13B).

(3) Figure 14A shows student responses for the statement, "Man, gorilla, and chimpanzee shared a common ancestor." Before the course, 113 of the 538 students responded "agree" to this statement while 275 responded "disagree" (Fig. 14A). After the course, 31 students switched from "agree" to "disagree" and 48 switched from "disagree" to "agree" (Fig. 14B). Of the 149 students that responded "don't know" before the course, 47 changed to "agree," and 35 switched to "disagree" (Fig. 14B).

(4) Figure 15A shows student responses for the statement, "God created human beings pretty much in their present form at one time within the last 10,000 years or so." Before the course, 256 of the 538 students responded "agree" to this statement while 137 responded "disagree" (Fig. 15A). After the course, 46 students switched from "agree" to "disagree" and 41 switched from "disagree" to "agree" (Fig. 15B). Of the 142 of students who originally stated "don't know" 56 were still undecided, the rest were evenly split at the end of the course: 43 shifted toward and 43 shifted away from a creationist viewpoint.

Discussion

It was not expected that students would shift in their perception of their own religiosity over the semester. Nor was there any overt or hidden agenda to influence students' religious identity *per se*. It was assumed that this variable would remain rather static. It most clearly did not. The "not at all religious percentage remained static" while the "fits somewhat" and the "fits fairly well" decreased. The only increase was in the percentage that considered themselves "perfectly" religious at the end of the course. Among groups, one-fourth of the "perfectly" religious became less religious; while more than one-half of the "not at all" religious became more religious at the end of the semester. The in between groups shifted more than two to one toward a more rather than a less religious stance.

It was assumed by the researchers that students who held scientific views (responded correctly to questions regarding the understanding of evolutionary theory) at the beginning of the course, would assimilate the course material and retain those views at the end of the course (Posner et al. 1982, 1992). However, depending upon which of the four most controversial statements, from 31% to 48% actually changed from a correct response to an undecided or even an incorrect response. In regard to the question of man, gorilla, and chimpanzee sharing a common ancestor, 31% moved away from the correct response. In regard to the creation of human beings in their present form within the last 10,000 years, 48% of those who originally responded correctly had shifted to an undecided or incorrect response.

It was hoped that the majority of students who were undecided about the facts of evolution would either assimilate or accommodate the new information on the theory of evolution, and give correct answers at the end of the course. Instead, the authors discovered a ''wedge effect'' among students undergoing conceptual change as they encountered information that required them to refine their schemas regarding the most controversial questions. Almost 40% remained on the fence. Of those who did not remain undecided, half shifted toward a scientifically correct response, while the other half shifted toward statements inconsistent with an understanding of the theory of evolution.

It was expected that some students who held creationist views at the beginning of the course would not be able to assimilate the new information, but would lean toward the undecided category as they tried to accommodate evidence throughout the course. Such was not entirely the case. Results indicated that these patterns were in evidence when the questions did not involve human ancestry. When humans were involved, there were often nearly as many students with correct scientific beliefs precourse who switched to incorrect or uncertain responses after the course as there were students with incorrect beliefs who switched to the correct answer or an uncertain response.

The greatest movement by far was among students who were uncertain about statements pertaining to human evolution prior to the course. Most (60%) of these students did not remain undecided, but they were equally likely to move toward incorrect as toward correct responses. This was not true. It was evident from these findings that over the course of the semester students when confronted with conflicts between scientific interpretations and religious beliefs do tend to move away from noncommittal and toward definite choices. However, those choices do not necessarily reflect the logic presented by the instructor in favor of the scientific viewpoint.

Further research into this wedge effect phenomenon is warranted in order to better understand the factors that influence these decision-making processes. The researchers recommend a qualitative follow-up to future surveys. Interviews with students may help to gain insight into the cognitive processes that they went through during the course. Both life science majors and nonscience majors responded to these surveys. It would also be interesting to determine if the wedge effect is observed for each of these subsets of students enrolled in the same courses. Survey instruments can be a useful tool for assessing changes in student attitudes, understanding views at the beginning and end of a semester course, and evaluating different teaching methods.

Concerns for further study

This was an action study rather than an experimental study. Actions studies are studies conducted by practitioners for the purpose of improving their own practice in a systematic way (Zubber-Skerritt 1992). These studies are conducted in authentic, rather than controlled classroom environments. The disadvantage of this approach is that there may have been confounding variables that were not controlled. The validity of the study, however, is enhanced in that the patterns and effects observed were found across a variety of random classroom settings.

In this action study, no attempt was made to standardize the way in which the theory of evolution was presented by the five different instructors. Neither were instructor effects were not taken into account in this study. Nonetheless, results were found to be remarkably similar to those found by Kondrick and Lovely (2005) in an earlier pilot study in which students were taught by only one instructor. In future studies, an analysis of instructor effects may give some clues as to which methods of instruction are most effective in teaching the theory of evolution within the context of foundational life science courses.

The 538 students surveyed represented a variety of cohorts among undergraduate students. Differences among responses in student patterns by class rank, gender, or major status were not separated in this study. Future studies might consider differences particularly among upper and lower classmen, differences by the number or type of biology classes taken, or differences between majors and nonmajors. Tracking majors over the course of their undergraduate program may be particularly useful in understanding the development of student constructs regarding the Theory of Evolution.

Another area of considerable interest is the observed shift in students' perception of their own religiosity. More study is needed to determine if this shift is typical of all college undergraduates, or if it is associated with studies that cause students to examine the assumptions of their religious beliefs critically. Also, the researchers would like to know how much students were influenced by outside sources who had a vested interest in influencing the perceptions of students in a course in which they would be taught evolution. It has been suggested to the authors that students in these courses may be actively recruited by members of the community who hold an antievolution bias. Such possibilities

should be investigated to better understand the shifts in pre–post test responses observed in the present study.

Conclusion

Student's conceptual frameworks did evolve during a semester course with evolutionary themes. Responses to statements regarding the nature of science or the process of evolution showed the most change toward agreement with scientifically correct statements. However, education in the principles of the theory of evolution did not necessarily insure that students will accommodate that theory in the schemas that they accept to be true. Response patterns indicated that students were more likely to agree with statements regarding evolution if human evolution from other life forms was not stated or implied. Students who were initially in a transitional stage of intellectual development (responded ''don't know'' at the beginning of the course) were the most likely to move away from agreement statements consistent with a creationist view, and toward those consistent evolution theory. Questions that involved human ancestry had a wedge effect among undecided students. In regards to statements involving human ancestry, roughly equal numbers of students who responded ''don't know'' at the beginning of the course changed toward a creationist view, while the other half moved toward an evolutionary view. The results revealed that students with uncertain opinions regarding human evolution are the most likely students to have a change in response after just one semester of a course in which evolution is a common theme. However, more education about the evidence for and the mechanics of evolutionary processes did not necessarily move student beliefs toward a scientific viewpoint. Students were equally likely to move toward agreement with statements congruent with a creationist position. The cause of this wedge effect is not yet understood.

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