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Still More "Fancy" and "Myth" than "Fact" in Students' Conceptions of Evolution

Deborah L. Cunningham · Daniel J. Wescott

Abstract College students do not come to biological sciences classes, including biological anthropology, as "blank slates." Rather, these students have complex and strongly held scientific misconceptions that often interfere with their ability to understand accurate explanations that are presented in class. Research indicates that a scientific misconception cannot be corrected by simply presenting accurate information; the misconception must be made explicit, and the student must decide for him or herself that it is inaccurate. The first step in helping to facilitate such conceptual change among college students is to understand the nature of the scientific misconceptions. We surveyed 547 undergraduate students at the University of Missouri-Columbia on their understanding of the nature and language of science, the mechanisms of evolution, and their support for both Lamarckian inheritance and teleological evolution. We found few significant sex differences among the respondents and identified some common themes in the students' misconceptions. Our survey results show that student understanding of evolutionary processes is limited, even among students who accept the validity of biological evolution. We also found that confidence in one's knowledge of science is not related to actual understanding. We advise instructors in biological anthropology courses to survey their students in order to identify the class-specific scientific misconceptions, and we urge faculty members to incorporate active learning strategies in their courses in order to facilitate conceptual change among the students.

Keywords Misconceptions · Evolution · Biological anthropology · Conceptual change · Undergraduate education · Survey data · Pedagogy

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Just over 20 years ago, Alan J. Almquist and John E. Cronin (1988) published an article entitled "Fact, Fancy, and Myth on Human Evolution." In it, they presented results from a nationwide survey of college students conducted over ten years (1974–1983) that attempted to identify students' basic knowledge about the processes of evolution and their opinions on issues pertaining to science and religion. Almquist and Cronin (1988) concluded that students' understanding of biological evolution "is in considerable need of improvement, especially in the areas of the origins of life, the geographical setting of human evolution, the fossil groups identified as links in the chain of human evolution, the concepts underlying carbon-14 and potassium-argon dating, and the theory of natural selection... [and that] there may be limits to what a college education can hope to accomplish on its own" (p. 522).

Almquist and Cronin (1988) wrote that "it is obvious from the strength of creationism that the American public lacks both scientific knowledge and general understanding of evolutionary principles..." (p. 520). While it is arguable whether support for creationism is a result of a general lack of understanding of evolutionary theory, results based on nationwide polls (Newport 2004) and revitalized anti-evolution pressures (Berman 2003; Coyne 2005; Holden 2005; Matzke 2004; Scott and Branch 2003; Shipman

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2005) make us think that Almquist and Cronin's (1988) statements are still true today. In recent years, educators and scientists in the USA have witnessed a renewed impetus from anti-evolutionists, who now commonly operate under the label "Intelligent Design" (ID). The "wedge" approach employed by ID proponents seeks to further their objectives by deliberately introducing misconceptions or mistaken assumptions about evolution and the nature of science.

Numerous studies (e.g., Brumby 1984; Bishop and Anderson 1990; Wilson 2001; Wescott and Cunningham 2005) have demonstrated that students enter college-level biological anthropology and other biology courses with misconceptions regarding the nature of science and evolutionary theory that can interfere with their ability to understand scientific explanations presented in class. These misconceptions can be self-constructed or taught/learned and based on experience, vernacular terminology, or religion/myth (Alters and Nelson 2002). As a result, student misconceptions are often extremely complex and deeply rooted and not only stand in the way of student understanding in college science classes but also "are robust enough to have survived schooling" (Palmer 1999, p. 648). The particular misconceptions students have about evolution and the nature of science have been demonstrated to vary by religious background, sex, age, geographical region, and generation (Almquist and Cronin 1988; Palmer 1999; Losh et al. 2003; Morrison and Lederman 2003). In some cases, they can even be context specific. Palmer (1999), for example, found that students often apply one conception to mammals and another to plants.

In order to assess how students' opinions and understanding of evolutionary theory may have changed in the interim since the study by Almquist and Cronin (1988), we surveyed undergraduate students enrolled in Introduction to Biological Anthropology (IBA) at the University of Missouri-Columbia (UMC). The purpose was to identify the common misconceptions held by undergraduate students in the early twenty-first century and to attempt to explain the reasoning behind those misconceptions (e.g., support for Lamarckian ideas and/or teleological evolution). While we do not claim that the misconceptions of mid-Missouri college students represent those of the entire country, it is informative to evaluate what changes, if any, occurred in Midwestern college students' conceptions about the evolutionary processes between the 1970s–1980s and the early 2000s.

We present questionnaire results from a sample of college students enrolled in IBA at UMC and compare our results with those reported in previous studies. Then, we review the pedagogical literature and discuss some strategies that anthropology instructors can use to help students succeed in recognizing and overcoming their misconceptions about evolution and the nature of science. By understanding these misconceptions, making them explicit, and employing appropriate pedagogy, anthropologists can go a long way in helping students undergo conceptual change.

Method

Participants and Course

Participants included 547 undergraduate students (243 males and 304 females) enrolled in IBA at UMC during the Fall 2002, Fall 2003, and Winter 2003 semesters. Most (92%) of the students were under 23 years of age. Introduction to Biological Anthropology is a large (150–200 students per semester) sophomore-level course that fulfills UMC's Biological Sciences general education requirement. The course is required for all anthropology majors, but the majority of students enrolled in the course are nonscience majors (Table 1) who have limited educational background in science. Students are expected to gain a solid understanding about the forces of evolution early in the course, as evolutionary theory forms the cornerstone of later discussions about human evolution, variation, and adaptation.

Questionnaire

We developed an anonymous questionnaire to help discover student misconceptions and opinions about the nature of

Table 1 Student profile

Demographic variable	Variables	%
Age	≤22	92
	23–29	6
	30–39	1
	≥40	0.5
	Not available	0.5
Sex	Female	56
	Male	44
Class	Freshman	23
	Sophomore	37
	Junior	23
	Senior	15
	Graduate/other	2
Academic major area	Anthropology	8
	Other social science	13
	Humanities	26
	Science	21
	Other/undecided	32
Taught evolution in high school?	No	26
	Yes with creation	23
	Yes without creation	51

science and evolutionary theory. We administered the questionnaire on the first day of class to reduce any possible instructor influence and informed the students that their answers would have no influence on their final grade. Use of the questionnaire was approved by the UMC Internal Review Board.

The questionnaire had two sections. The first section requested demographic data (age, sex, academic standing, and major) and asked the students to indicate if they were taught about evolution in high school (public or private) and if they had taken a college-level biology, chemistry, or physics course. Following the methodology of Almquist and Cronin (1988), we examined sex differences in responses to the statements in the second section of the questionnaire but did not focus on trends in the other demographic data in this paper. In the second section of the questionnaire, we asked students to respond as to whether they strongly agree, somewhat agree, somewhat disagree, strongly disagree, or have no opinion ("undecided/never heard of it") on 24 statements. However, for the purpose of discussion, we grouped "strongly agree" and "somewhat agree" and combined "somewhat disagree" and "strongly disagree". We chose Likert-type items in the instrument to avoid many of the problems associated with multiple-choice and open-response questionnaires (Almquist and Cronin 1988; Wescott and Cunningham 2005). For example, Almquist and Cronin (1988) found that when students were given multiple-choice questions with answers that ranged from scientifically acceptable to teleological, students tended to choose the scientific explanation. Even so, these authors discovered that when students were presented with agree/disagree statements, students frequently agreed with statements based on misconceptions.

Bishop and Anderson (1986, 1990) and Wilson (2001) previously administered questionnaires that sought to uncover student misconceptions about science and evolution. We purposely adopted many of the same questions in order to compare results with these authors. However, we specifically constructed our questionnaire to reveal student misconceptions about the nature of science, the survival of new traits in a population, support of Lamarckian inheritance, appreciation of the importance of variation within a population, the process of natural selection, terminology that has different meanings in the vernacular and in science, and the idea of teleological evolution (evolution directed by an outside agent). These are major areas of misconception that have been pointed out by numerous researchers (e.g., Wandersee et al. 1989; Bishop and Anderson 1990; Greene 1990; Lawson et al. 2000; Wilson 2001) and affect students' understanding of biological anthropological theories on human variation and evolution in biological anthropology courses.

We recognize the existence of several extant methodological tools that measure acceptance and understanding of biological evolution (e.g., Measure of Acceptance of the Theory of Evolution (MATE) and Conceptual Inventory of Natural Selection (CINS); see "Discussion" section). We developed our own instrument because we were interested in questions more specific to biological anthropology, and since we were inspired by the studies listed above (e.g., Bishop and Anderson 1986, 1990; Almquist and Cronin 1988; Wilson 2001), we wanted to incorporate many of the same questions.

Statistics

The internal reliability of the questionnaire was investigated using Cronbach's alpha, which was obtained using the "alpha" option of PROC CORR in SAS (SAS Institute Inc. 2002). Cronbach's alpha quantifies how effectively a set of questions measures latent themes. The alpha coefficients ranges from 0 to 1, and values of 0.7 or above are accepted as reliable (Nunnaly 1978). We used the chi-square statistic to assess sex differences in responses and to determine the potential for interaction between selected variables. The chi-square statistic is a technique that assesses whether observed frequencies differ from theoretically predicted expected frequencies. In our case, we expect there to be no differences based on either sex of the student or on how a student responded to a statement.

Results

Table 1 presents the participant profile. The majority of the students were freshmen or sophomores (60%) under 23 years of age (92%). Fifty-six percent were females and 44% were male. Only 21% of the students reported being science majors, with the rest distributed fairly equally as social science majors (anthropology, political science, sociology, social work, or psychology), humanities majors (English, foreign language, philosophy, history, music, or journalism), and other/undecided. Just over a quarter of participants reported not being taught evolution in high school, and 23% were exposed to both evolution and creationism in high school. Only 51% of the UMC students in IBA had been taught evolutionary principles without creationism in high school science. Cronbach's alpha is 0.75, indicating that the internal reliability of the questionnaire is acceptable. Additionally, the reliability coefficient does not decrease by more than 0.01 if any item is deleted, indicating that removing any item would not greatly increase the questionnaire's reliability.

Sex Differences

Using chi-square statistics, we found statistically significant differences ($p \leq 0.05$) between males and females in their responses to four of the 24 statements on the questionnaire (Table 2). These statements are statement 10 ("A species evolves because individuals want to;" 6.9% males and 7.2% females agree, 84.6% males and 78.4% females disagree, 8.5% males and 14.4% females are undecided), statement 17 ("If two distinct populations within the same species begin to breed together this will influence the evolution of that species;" 85% males and 86.9% females agree, 10.3% males and 4.1% females disagree, 4.7% males and 9% females undecided), statement 20 ("You cannot prove evolution happened;" 30.7% males and 24.8% females agree, 59.1% males and 57.1% females disagree, 10.2% males and 18% females undecided), and statement 21 ("Evolution cannot work because one mutation cannot cause a complex structure [e.g., the eye];" 12.3% males and 8.1% females agree, 58.1% males and 53% females disagree, 29.6% males and 38.9% females undecided). Sex differences primarily reflect that males are more decisive than females in their responses to these four statements.

Since there are few significant differences between males and females, we pooled the results for the remainder of the discussion. Table 2 presents the UMC student responses to each of the 24 statements, while Table 3 shows results of the interaction between statements. We

Table 2 Percent response to each statement

#	Category	Statement	% Response					
			1	2	3	4	5	6
1	SF	There is lots of evidence against evolution.[a]	8	14	26	42	10	0
2	SF	Dinosaurs and humans lived at the same time in the past.[a]	3	9	16	60	12	0
3	SF	Humans and chimpanzees evolved separately from an ape-like ancestor.	22	38	11	12	17	0
4	LS	I have a clear understanding of the meaning of scientific study.[a]	29	49	11	4	7	0
5	ET	The theory of evolution correctly explains the development of life.[a]	17	38	16	12	17	0
6	LS	A scientific theory that explains a natural phenomenon can be defined as a "best guess".	12	28	22	23	15	0
7	PE	Small population size has little or no effect on the evolution of a species.	2	6	30	47	15	0
8	PE	If two light-skinned people moved to Hawaii and got very tan their children would be more tan than they (the parents) were originally.	5	11	19	54	11	0
9	PE	Variation among individuals within a species is important for evolution.	53	32	3	3	9	0
10	PE	A species evolves because individuals want to.*	2	6	27	52	13	0
11	ET	Humanity came to be through evolution, which was controlled by God.[a]	16	21	11	25	26	0
12	PE	A species evolves because individuals need to.[b]	31	35	12	10	12	0
13	PE	I have a clear understanding of the term "fitness" when it is used in a biological sense.[b]	20	33	17	10	20	0
14	PE	Two of the most important factors that determine the direction of evolution are survival and reproduction.[b]	53	36	3	2	6	0
15	PE	New traits within a population appear at random.[b]	10	30	33	12	15	0
16	PE	The environment determines which new traits will appear in a population.[b]	19	59	8	5	8	1
17	PE	If two distinct populations within the same species begin to breed together this will influence the evolution of that species.*	39	45	7	3	6	0
18	PE	All individuals in a population of ducks living on a pond have webbed feet. The pond completely dries up. Over time, the descendants of the ducks will evolve so that they do not have webbed feet.[b]	21	40	17	8	14	0
19	PE	"Survival of the fittest" means basically that "only the strong survive".[b]	33	31	19	14	3	0
20	ET	You cannot prove evolution happened.*	11	16	29	28	16	0
21	PE	Evolution cannot work because one mutation cannot cause a complex structure (e.g., the eye).*	4	9	27	27	33	0
22	PE	Evolution is always an improvement.	6	20	34	25	15	0
23	LS	A scientific theory is a set of hypotheses that have been tested repeatedly and have not been rejected.	39	39	8	6	8	0
24	PE	If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than individuals in their parents' generation.[b]	17	33	18	10	22	0

ET evolutionary theory, *SF* scientific facts, *PE* process of evolution, *LS* language of science, *1* strongly agree, *2* somewhat agree, *3* somewhat disagree, *4* strongly disagree, *5* undecided/never heard of it, *6* no response

*$p \leq 0.05$ (statistically significant sex difference)

[a] Statement from Wilson (2001)

[b] Statement modified from or inspired by Bishop and Anderson (1986, 1990)

Table 3 Interaction between responses to selected statements

Statement	Interaction statement	Agree with statement			Disagree with statement			Undecided about statement		
		%A	%D	%U	%A	%D	%U	%A	%D	%U
Evolutionary theory and scientific facts										
1	6	44.3	36.6	19.1	41.4	45.6	13.0	42.6	29.6	27.8
	10	14.6	69.2	16.2	5.2	87.3	7.6	3.7	63	33.3
	11	45.8	31.2	22.9	33.5	41.8	24.7	42.6	20.4	37.0
	12	57.7	24.6	17.7	69.5	22.2	8.3	63.0	14.8	22.2
	20	47.6	33.3	19.0	22.3	68.0	9.8	18.0	40.0	42.0
	21	25.4	30.2	44.4	5.8	66.1	28.1	4.0	32.0	64.0
5	6	45.1	44.2	10.7	39.9	39.9	20.2	35.7	39.8	24.5
	9	92.7	3.4	4.0	79.3	7.7	13.0	82.7	2.0	15.3
	10	4.9	87.4	7.7	10.2	76.1	13.8	8.2	69.4	22.5
	11	33.9	46.5	19.6	44.6	33.3	22.0	34.7	14.3	51.0
	12	71.8	20.9	7.4	55.0	30.2	14.8	67.4	12.2	20.4
Processes of evolution										
9	16	80.9	11.3	7.8	64.0	28.0	8.0	59.6	23.4	17.0
	24	47.5	31.7	20.8	43.5	21.7	34.8	40.4	12.8	46.8
12	8	14.3	75.3	10.4	10.7	82.4	6.9	1.2	63.8	26.1
	11	42.0	33.8	24.2	24.4	53.4	22.2	31.9	29.0	39.1
	18	69.4	20.4	10.2	48.8	36.8	14.4	54.4	16.2	29.4
13	14	93.4	4.2	2.4	91.5	4.2	4.3	81.0	5.8	13.2
	16	81.9	12.5	5.6	79.4	12.7	7.9	68.8	14.8	16.4
	19	61.2	36.7	2.1	67.9	32.1	0.0	72.9	20.5	6.6
Language of science										
4	6	44.7	42.3	13.0	32.6	47.8	19.6	35.0	27.5	37.5
	23	83.0	12.3	4.7	75.6	15.1	9.3	55.3	15.8	27.5

divided the results into three broad themes and present them as follows: (1) evolutionary theory and scientific facts, (2) processes of evolution, and (3) language of science. While there is some overlap between these themes, they are helpful in interpreting the data.

Evolutionary Theory and Scientific Facts

Statements 5, 11, and 20 deal with general opinions regarding the validity of evolutionary theory. Figure 1 illustrates the responses to each of these statements. Responses from statement 5 indicate that the majority (55%) of students agree that the theory of evolution correctly explains the development of life (Table 2). Students are fairly evenly split in their responses to statement 11 ("Humanity came to be through evolution, which was controlled by God"). Statement 20 states that evolution cannot be proven. A majority of UMC students (57%) disagree with this statement.

Several statements (1–3) on the questionnaire deal with scientific facts (Table 2; Fig. 1). The majority (68%) of students disagree with statement 1 ("There is lots of evidence against evolution;" Table 2). Students also realize the lack of temporal overlap of dinosaurs and humans (statement 2), with only 12% agreeing that they coexisted. The majority (60%) of students agree that humans and

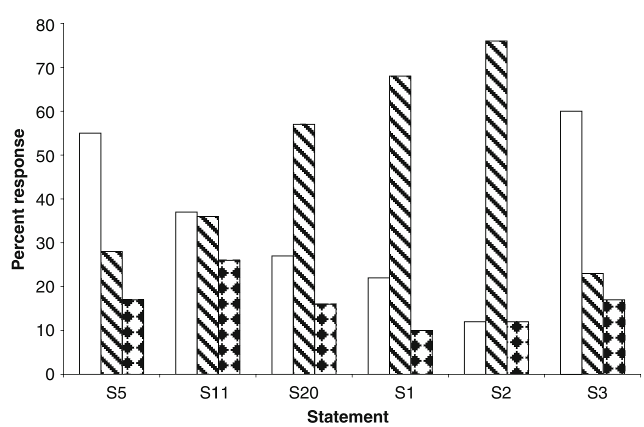

Fig. 1 Percent student response to statements about evolutionary theory and scientific facts. *Clear bar* = "strongly agree/somewhat agree"; *downward diagonal bar* = "somewhat disagree/strongly disagree"; *checked bar* = "undecided/never heard of it"

chimpanzees evolved separately from an ape-like ancestor (statement 3).

It is encouraging that 68% of UMC IBA students disagree that there is a lot of evidence against evolution (statement 1), but to explore their opinions more thoroughly, we examined the interaction between responses to statement 1 with those of statements 6, 10–12, and 20–21 (Table 3). Results show that the misconception that a scientific theory is a best guess (statement 6) is almost equally prevalent among those who agree that there is lots of evidence against evolution and those who disagree. However, the misconception that species evolve because individuals “want” to (statement 10) is more widespread among those who agree that there is much evidence against evolution. The majority of students who think that there is lots of evidence against evolution or those who are undecided tend to think that evolution is controlled by God (statement 11). Of those who agree that there is not much evidence against evolution, most do not think it is controlled by God, although the difference is not substantial. Responses to statement 12 indicate that the majority of students have the misconception that evolution is “need” driven, but it is more prevalent among those who think there is sufficient evidence in support of evolution and among those who are undecided about statement 1. The interaction between statements 1 and 20 shows that students who agree that there is a lack of evidence supporting evolution more often have the opinion that evolution cannot be proven, whereas 68% of the students who think that there is not much evidence against evolution think that evolution can be proven. Based on the interaction between statements 1 and 21, students who think that there is evidence against evolution are either more likely to agree that mutations cannot cause complex traits or are undecided on the issue. However, the overwhelming majority (66.1%) of students who disagreed with statement 1 also disagreed with statement 21. Of those who are undecided on statement 1, most are also undecided on statement 21 (Table 3).

To summarize, agreement or disagreement with statement 1 (“There is lots of evidence against evolution”) substantially affects answers to some statements but not others (Table 3). Notably, the misconception about the meaning of the term “scientific theory” is equally widespread among students regardless of how they responded to statement 1. Not surprisingly, students who think that there is lots of evidence against evolution also tend to believe in teleological evolution, that evolution cannot be proven, and that mutations cannot cause complex traits. It is surprising, however, that students who think that there is support for evolution more frequently have the misconception that species evolve because of “need.”

Of all the statements on the questionnaire, statement 5 (“The theory of evolution correctly explains the development of life”) is probably the one that most accurately measures whether or not students accept the validity of evolution. Because of this, we were interested in how agreement or disagreement with statement 5 affected responses to some other statements (specifically statements 6 and 9–12; Table 3). Just as the results from statement 1 indicate, students are fairly evenly split about the meaning of a scientific theory (statement 6). Misunderstanding of this term is not affected by one’s acceptance or denial of the theory of evolution, but it does seem that agreeing with statement 5 makes one more decisive in response to statement 6. The majority of students think that intraspecific variation is important for evolution (statement 9), and yet again, we see that those who agreed with statement 5 are more decisive in their responses to statement 9. Of course, those who disagreed with statement 5 might have answered negatively or undecided to statement 9 because they do not think that evolution occurred at all. Just as in the responses to statement 1, regardless of their position on statement 5, the vast majority disagreed that a species evolves because individuals want to (statement 10). Of the students who agreed that evolution correctly explains the development of life, 71.8% agreed that species evolve because of individual need (statement 12). Only 55% of students with the opinion that evolution does not explain the development of life have the misconception that evolution is need-driven (Table 3). Again, while the responses from those who disagreed with statement 5 may be due to the fact that they do not think evolution occurs at all, the responses by those who accept evolution reflect the common misconception of need-driven evolution, an inherently Lamarckian concept.

Finally, the interactions between statements 5 and 11 (“Humanity came to be through evolution, which was controlled by God”) are interesting. Almost 34% of students who agree with statement 5 agree with statement 11, while almost 20% are undecided about theistic evolution. Of those who claim that evolution does not correctly explain the development of life, 44.6% agree that evolution is controlled by God. Finally, those undecided about statement 5 are also overwhelmingly undecided about statement 11 (51% undecided). Theistic evolution is a popular idea among those who accept evolution and among those who do not accept it, although more students who accept evolution generally disagree that it is guided by God (Table 3).

In summary, we see many of the same patterns in the interaction of responses between groups that differed in their responses to statements 1 and 5 (Table 3). The misconception of the meaning of “scientific theory” is widespread, “need” driven evolution is more widely accepted than “want” driven evolution, and belief in theistic evolution is common.

Process of Evolution

The majority of the statements on our questionnaire dealt with the processes of evolution (Table 2; Fig. 2). Of these, we found that most UMC IBA students do not hold many of the common misconceptions that have been identified in the literature (e.g., Bishop and Anderson 1990; Wilson 2001; Losh et al. 2003; Vosniadou and Brewer 1992). Results from statements 7–10 show that a minority of students hold common misconceptions about the importance of population size and variation on species evolution, Lamarckian explanations for skin color, and the importance of "wanting" to evolve (Table 2). The vast majority of students recognize that survival and reproduction are crucial in evolution (statement 14); however, many fail to recognize that new traits in a population appear at random (55% disagree with statement 15). Most agree that evolution of a species can be affected by the interbreeding of two distinct populations within that species (84% agree with statement 17), and many disagree that a mutation cannot cause a complex structure (54% disagree with statement 21). Finally, the majority (59%) of students realize that evolution does not always result in an improvement (statement 22).

While the above results are encouraging, UMC IBA students do maintain many of the other common misconceptions about the processes of evolution. First of all, while students overwhelmingly (79%) disagree with the statement that "A species evolves because individuals want to" (statement 10), 66% of students think that "A species evolves because individuals need to" (statement 12; Table 2). Of these latter students, 69.4% agree that if a pond dried up, descendants of the current ducks living there will lose their webbed feet (interaction of statements 12 and 18; Table 3). This strongly suggests that students think that environmental factors control the "need" for certain traits in a population. In fact, 78% of UMC IBA students contend that it is the environment that determines which new traits will appear in a population (statement 16; Table 2). Additionally, of those who agree with statement 12, only 14.3% have the misconception that acquired traits are passed from parent to offspring (statement 8; Table 3). This suggests that while they think evolution is need-driven, they do not think acquired traits are specifically inherited—kind of a partial acceptance of Lamarckian inheritance. Of the students who agree with statement 12, 42% think evolution is controlled by God (statement 11). Of those who disagree with statement 12, only 24.4% think that evolution is controlled by God. This suggests that those who have the conception that species evolve out of necessity are more likely to think that evolution is directed by God.

Most students think they understand biological fitness (53% agree with statement 13; Table 2) and correctly agree that survival and reproduction are important factors in determining the direction of evolution (statement 14). However, when presented with statement 19 ("'Survival of the fittest' means 'only the strong survive'"), students overwhelmingly agree (64%). Clearly, confidence in one's ability to understand a scientific concept is not related to true understanding.

Of the students who agreed with statement 13 ("I have a clear understanding of the term 'fitness' when it is used in a biological sense"), 61.2% agreed with statement 19 ("'Survival of the fittest' means basically that 'only the strong survive';" Table 3). Of those who were undecided about statement 13, 73% agreed with the misconception in statement 19. Students have this misconception about fitness whether they think they understand it or not. Among students who claimed to understand fitness, 93.4% agree

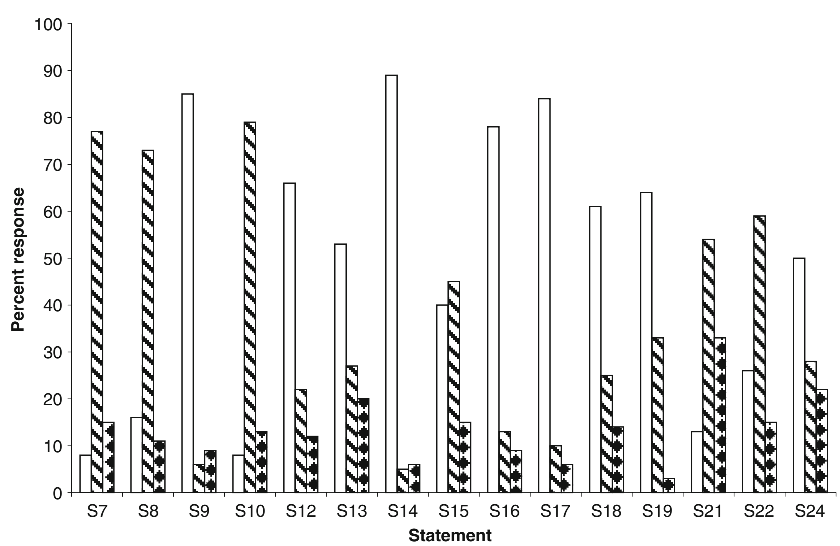

Fig. 2 Percent student response to statements about process of evolution. *Clear bar* = "strongly agree/somewhat agree"; *downward diagonal bar* = "somewhat disagree/strongly disagree"; *checked bar* = "undecided/never heard of it"

with the scientifically correct statement on fitness (statement 14). Of those who disagreed that they understood fitness, 91.5% agreed with statement 14. This shows that students, whether they think they understand fitness or not, can pick out the scientifically correct statement. Finally, of the students who agreed with statement 13, 81.9% think the environment directs which traits appear in a population (statement 16; Table 3). Students are of the opinion that they understand fitness and the mechanisms driving evolution, but obviously they do not.

Students also do not understand the basics of population variation or the two-step process that influences traits in a population (*origin* via mutation or sexual recombination and *survival* via natural selection). This is demonstrated in their agreement (61%; Table 2) with statement 18 ("All individuals in a population of ducks living on a pond have webbed feet. The pond completely dries up. Over time, the descendants of the ducks will evolve so that they do not have webbed feet") and with statement 24 ("If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than individuals in their parents' generation;" 50% agree). Students seem to know that intraspecific variation is important for evolution (statement 9), however, they are unclear about why it is important. Of those who think that variation is important, 47.5% agree with statement 24 (Table 3). Additionally, of those who agree with statement 9, 81% agree that the environment determines which new traits will appear (Statement 16). These results further support the idea that students know that variation is important but do not understand why this is so or that traits must already be present in a population for natural selection to act upon them.

Language of Science

Much of the controversy in the modern debate about the teaching of evolution has focused on the different meanings of the word "theory" when it is used in a scientific versus a vernacular sense (Bishop and Anderson 1990; Alters and Nelson 2002). We included two statements that addressed students' understanding of the differences. Statement 6 is "A scientific theory that explains a natural phenomenon can be defined as a 'best guess'." Forty percent agreed with this statement, 45% disagreed, and 15% were undecided (Table 2; Fig. 3). When the issue was phrased a little differently, as in statement 23 ("A scientific theory is a set of hypotheses that have been tested repeatedly and have not been rejected"), many more students agreed (78%).

Statement 4 asks if the student has a clear understanding of the meaning of scientific study. The majority (78%) of students think that they do (Table 2). When comparing the responses of those who agreed versus those who did not,

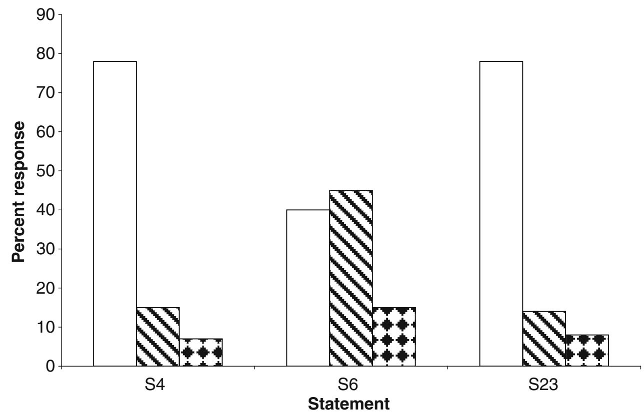

Fig. 3 Percent student response to statements about language of science. *Clear bar* = "strongly agree/somewhat agree;" *downward diagonal bar* = "somewhat disagree/strongly disagree;" *checked bar* = "undecided/never heard of it"

we see that students who think they understand science actually understand it less than those who do not think they understand it. Of those who agreed with statement 4, 44.7% of them agreed with statement 6 ("A scientific theory that explains a natural phenomenon can be defined as a 'best guess'"), while of those who disagreed with statement 4, only 32.6% of them agreed with statement 6. Statement 23 ("A scientific theory is a set of hypotheses that have been tested repeatedly and have not been rejected") rephrases the issue first raised in statement 6. When the concept of a scientific theory is phrased correctly, the majority of all three groups agree with statement 23. Results from statement 23 indicate that students recognize the correct statement about a scientific theory whether or not they think they understand science. As is typical, those undecided on the first statement were also more commonly undecided on the second.

Discussion

Studies have shown that student misconceptions about science can often differ significantly based on geographical region, religious background, and generation, as well as by sex and age (Almquist and Cronin 1988; Palmer 1999; Losh et al. 2003; Morrison and Lederman 2003). Five of our questions were taken directly from Wilson's (2001, p. 12; Table 2) questionnaire based on university and community college students from California. There is little difference between the UMC and California students in their previous exposure to evolutionary principles. Just over half (51%) of UMC students had been taught evolutionary principles in high school without creationism and only 23% were never exposed to evolutionary theory in high school (Table 1). Wilson (2001) found similar results among California college students. In his study, 46% of students were taught evolution but not creationism in high school, 30% had been exposed to both evolution and creationism, and 24% were not taught either. However, our results suggest that students from Missouri have a different configuration of misconceptions than do California students. Twenty-two percent of UMC IBA students agreed that there is lots of evidence against evolution (statement 1; Table 2), while Wilson (2001) found that 47% of his students agreed with the same statement. As for temporal overlap between dinosaurs and humans (statement 2), we found only 12% agreement, while Wilson (2001) found that 27% of students agreed. For statement 4 ("I have a clear understanding of the meaning of scientific study"), we found an overwhelming 78% of students agreed, while Wilson (2001) found that only half of his polled students agreed. When confronted with statement 5 ("The theory of evolution correctly explains the development of life"), 55% of UMC IBA students agreed, compared to only 39% of Wilson's (2001). Finally, the idea of theistic evolution as presented in statement 11 was accepted by 37% of UMC IBA students and by 62% of Wilson's (2001) students. While we do not think that agreeing with statement 11 represents a true scientific misconception (see below), clearly students in the Midwest (represented by mid-Missouri) have very different ideas and misconceptions about science than do the California university and community college students polled by Wilson (2001). The fact that the UMC IBA students are so favorably disposed toward evolutionary ideas is especially interesting. The IBA course is one course that fulfills a Biological Sciences general education requirement. Other courses that the students could have enrolled in include courses in the Department of Biological Sciences. Based on our personal experiences teaching IBA at MU, we have found that students enrolled in the course are generally averse to science and intimidated by the other "hard" science courses. Therefore, in some sense, IBA students may be self-selected to be unfavorably disposed to science in general.

While UMC students differ in their misconceptions compared to California students, they do hold many of the common misconceptions found among students nationwide. Several of our statements were either inspired by or modified from those of Bishop and Anderson (1990, 1986; Table 2) who examined misconceptions in college students from Michigan. These authors recognized that students frequently think that organisms develop novel traits because of "need." We found that the same misconception is overwhelmingly widespread among UMC students (66% agree with statement 12; Table 2) whether or not the students accept the validity of evolution (Table 3). Bishop and Anderson (1986, 1990) also found that students misunderstood the term "fitness" when it was used in a biological sense; our results (based on statements 13 and 19) concur (Table 2). While 53% of our students were confident that they understood this term (statement 13), 64% of them accepted the common misconception that "survival of the fittest" means that "only the strong survive" (statement 19). Bishop and Anderson (1986, 1990) also discovered that students failed to appreciate that two separate processes influence traits in a population. Rather, students think of a single process in which gradual changes in the trait, caused by the environment, occur over the entire species (Bishop and Anderson 1986, 1990; also see results from statement 24; Table 2). We found that when the basic tenets of natural selection are phrased correctly, 89% of UMC students agree (statement 14; Table 2). However, when confronted with the random appearance of new traits in a population (statement 15), students are much less likely to agree with the correct response. Like the findings of Bishop and Anderson (1986, 1990), UMC students think that environmental factors determine which new traits appear in the population (statements 16 and 18; Table 2).

We found little support for sex differences in responses to statements about evolution and the nature of science. There were significant differences between males and females in only four of the 24 statements in our study (Table 2). Furthermore, the major sex difference appears to be associated with the indecisiveness of females compared to males (i.e., more females tended to choose "undecided/never heard of it"). Almquist and Cronin (1988) found similar results in their survey.

Finally, results based on statement 20 ("You cannot prove evolution happened") may be problematic. When we initially formulated the questionnaire, we wanted agreement with this statement to represent a misconception, however, upon further review, we realized the semantic problem with the word "prove." Science attempts to disprove hypotheses, therefore, this statement is technically correct. Whether or not each student possessed a sophisticated understanding of the nature of the scientific method would affect how he or she would respond to the statement. In future surveys, this question will be rephrased. However, the question did not significantly affect the reliability of the questionnaire, as shown by Cronbach's alpha.

Our survey results show that student understanding of evolutionary processes is limited. Even the students who accept the validity of evolution do not understand how its mechanisms work. Students, for example, appear to partially accept the Lamarckian concept that morphology occurs out of "need," even though they understand that acquired traits cannot be inherited. Another unambiguous finding that we uncovered (also see Bishop and Anderson 1990; Wilson 2001) is that confidence in science is unrelated to competency. This, of course, can present difficulties for educators when trying to help their students overcome common misconceptions. The idea of theistic evolution is also widespread. Even so, it is inaccurate to call this a scientific misconception. It is a misconception to say that science can either support or refute such a worldview; we agree with Alters and Nelson (2002) that science by definition must be silent on this matter. In addition, the results of this study and others (e.g., Bishop and Anderson 1990; Sinatra et al. 2003) show that student acceptance of the validity of evolution does not impinge on their ability to learn and understand the processes involved in evolution.

We have identified the same trend in early twenty-first century students that Almquist and Cronin (1988) recognized in students from the 1970s and the 1980s: Students seem to be able to recognize the scientifically acceptable answer when the statement is phrased correctly (e.g., statement 23). However, when a statement is put forth that includes a common misconception, students tend to agree with the misconception (e.g., statement 6). This suggests to us that while our students may have heard the scientifically accurate definition of terms such as theory, fitness, and natural selection, they do not truly understand them. As a result, they retain their general misconceptions regarding these key concepts. The primary factor in students' failure to recognize and overcome their misconceptions is that some pedagogical approaches frequently used by instructors are not appropriate for helping students undergo conceptual change.

The Role of Misconceptions and the Anthropology Instructor's Task

Learning is a process of conceptual change that occurs through the proactive revision and reorganization of preexisting knowledge by the learner. If students do not recognize and reject their own scientific misconceptions in favor of scientifically accurate explanations, they will simply accommodate new knowledge obtained in the classroom within their existing framework rather than correcting their misconceptions. Even if students recognize their misconceptions during the semester, if they are not given the opportunity and motivation to reject or modify them, the students will usually revert to their misconceptions some time after completion of the science course (Greene 1990; Wandersee et al. 1989; Hellden and Solomon 2004; Mintzes et al. 2000).

Learning is ultimately the responsibility of the student, but as educators, we are obligated to provide our students the opportunities and tools necessary for them to recognize, revise, and reorganize their knowledge and undergo conceptual change. This can only be accomplished if we first understand the specific misconceptions our students bring to the classroom (for suggestions on how to do this, see Bishop and Anderson 1990; Wescott and Cunningham 2005; Anderson et al. 2002; Lederman et al. 2002) and then use appropriate pedagogy to allow our students to engage, explore, explain, elaborate, and evaluate their conceptions (Firenze 1997). An instructor-centered pedagogy (i.e., "lecture") does little to help most students recognize their misconceptions. This pedagogical approach promotes passive reception of knowledge and not the active learning necessary for students to see that their currently held concepts are erroneous. However, more than 70% of college professors use traditional lectures as their only pedagogical approach (Alters and Nelson 2002).

The first step in helping students recognize their own misconceptions is to identify them as well as the prevalence of any scientifically correct conceptions held by them. As has been suggested previously (Wescott and Cunningham 2005), we strongly advise that each science instructor use an assessment tool that evaluates his or her specific class. Once the misconceptions held by the instructor's class are identified, they can be used as a starting point for class discussion (Wilson 2001; Modell et al. 2005). In fact, Wilson (2001) reported great student interest when he used his students' survey results as a tool to identify and address misconceptions.

We realize that some instructors may not have the time to develop their own assessment tool. Besides the ones mentioned above and utilized herein, instructors may want to explore the Measure of Acceptance of the Theory of Evolution (MATE), which was developed to quantify biology teachers' acceptance, or lack of acceptance, of evolution (Rutledge and Warden 1999) and was demonstrated to be an effective measure of the same in university students (Rutledge and Sadler 2007). Other tools that could be used include a survey developed by Brian Alters and utilized by Ingram and Nelson (2006) that focuses solely on student attitudes toward creation and evolution, and the Conceptual Inventory of Natural Selection (CINS), which was developed to measure students' knowledge of natural selection (Anderson et al. 2002; but see Nehm and Schonfeld 2008 for a critique). It should be noted that the CINS is a multiple-choice tool, and research (herein and also in Almquist and Cronin 1988) indicates that students often are able to pick out the scientifically correct statement when faced with a multiple-choice assessment tool.

After results of the assessment tool are identified, however, it is not enough to point out the misconception and then attempt to rectify it with correct information (Committee on Undergraduate Science Education 1997; Modell et al. 2005). A more effective strategy involves the constructivist approach of conceptual change, which asks students to make each misconception explicit and then challenges them to solve a problem based on that misconception. This strategy provides the student with the opportunity to realize the inadequacy of the misconception.

Once this is accomplished, the student is presented with the scientifically accepted paradigm and asked to solve the problem under this model (Posner et al. 1982; Lawson 1994; Jensen and Finley 1996; Palmer 1999; Alters and Nelson 2002; Modell et al. 2005). This type of learning actively involves students in their own education and has been shown to be much more effective at combating misconceptions than the traditional lecture.

There are several different methods that can be used in lieu of the traditional lecture in order to achieve conceptual change (Alters and Nelson 2002). Biological anthropological instruction is especially amenable to the approach used with success by Jensen and Finley (1996). These authors used pre- and posttests to assess student understanding of evolution and found that the combination of an historically rich curriculum with paired problem-solving instruction was the most effective. Jensen and Finley (1996, p. 881) developed the historically rich curriculum specifically to

> (a) teach Darwin's theory of evolution by natural selection, (b) teach three non-Darwinian views of evolution, (c) present numerous evolution problems for students to solve using different theories of evolution, (d) enable students to identify strengths and weaknesses of the different theories, (e) convey to students that the history of evolutionary theory is a human endeavor influenced not only by the scientific community but also by social and political factors, and (f) communicate clearly the correct and incorrect meanings of key phrases used in describing evolutionary events. The use of the historically rich curriculum is based on the premise that its use meets the conditions required for conceptual change, as we have argued previously (Jensen and Finley 1995).

Paired problem-solving involves asking a student to solve a problem individually and then agree on a common solution to the problem with another student (Jensen and Finley 1996). An example of a problem that could be used in an introductory biological anthropology class in combination with the historically rich curriculum is to ask the students to individually write down an explanatory mechanism describing how the short-necked ancestors of today's giraffes evolved into the modern long-necked version. After the students have had a few minutes to contemplate this and make some notes, each student pairs with a neighbor and discusses results, arriving at a common explanation. Many students will present answers that are based on misconceptions, i.e., the giraffes "needed" to lengthen their necks because their food was high in the trees, and therefore, the necks eventually grew longer over time. The instructor can use this as a starting point for discussion and can ask the students to elaborate on the mechanisms behind this Lamarckian conception.

Another effective instrument to help achieve student conceptual change is the use of concept maps (Liu 2004; Mintzes et al. 2001; Trowbridge and Wandersee 1994). Concept maps show the student-accepted relationships between concepts within a domain of knowledge (Mintzes et al. 2001). These can be used as part of the assessment to identify misconceptions and provide a starting point for discussion and subsequent conceptual change.

All of these classroom strategies necessitate a reduction in course content. Obviously, if the instructor is taking class time for paired problem-solving discussions, concept mapping, and other active learning strategies, it may be impossible to cover the amount of material possible in a traditional lecture-based course. However, such active learning strategies have proved to be more effective in student learning than the traditional lecture (Alters and Nelson 2002; Udovic et al. 2002). Teaching does not equal learning; explaining that a misconception is wrong does not seem to be effective. Today, challenges to the teaching of evolution in public schools are rampant (see the National Center for Science Education's website www.ncseweb.org for up-to-date information). The college students in our introductory anthropology classes are future teachers, principals, school board members, and concerned parents. It is imperative that they understand the processes of scientific inquiry and the difference between evolution as "just a theory" and the scientific theory of evolution.

Finally, anthropology and other science instructors must be aware of and vigilant about reinforcing taught-and-learned and vernacular scientific misconceptions. We must be careful of the language we use when presenting material in class. It is very easy to unconsciously switch back and forth between the vernacular and scientific uses of words such as "theory", "adapt," and "fitness." Inconsistency in terminology can cause confusion among students. Unfortunately, the textbooks we choose to provide for our students often reinforce common misconceptions (Alters and Nelson 2002). Linhart (1997) surveyed 50 major textbooks on evolution (in evolution, general biology, ecology, genetics, paleontology, and systematics) and found that these textbooks frequently misrepresent evolutionary concepts. In fact, one of the most common textbooks used across the country in an introduction to biological anthropology class is guilty of just such a transgression: the textbook *Introduction to Physical Anthropology* by Jurmain et al. (2005) defines a theory as "a broad statement of scientific relationships or underlying principles that has been at least partially verified" (p. 16). The authors specifically state that "there is a popular misconception that theories are nothing more than hunches or unfounded beliefs. But in scientific terms, a theory is much more than mere speculation because it has been repeatedly tested and scientists have not been able to disprove it" (Jurmain et al. 2005, p. 16). However, in the very next chapter, they discuss Lamarck's "theory" of evolutionary change (Jurmain et al. 2005, p. 27). Lamarck's idea about the inheritance of acquired characteristics was a hypothesis that was falsified; hence, it did not achieve the status of a scientific theory. Jurmain and colleagues (2005) also state that "because Lamarck's explanation of species change was not genetically correct, his theories are frequently derided" (p. 28). Again, here they use the term "theory" to mean "ideas" or "hypotheses." It is no wonder that our students are confused between the scientific and vernacular uses of terms. As instructors, it is our role to carefully choose a textbook for our class and to identify any mistakes, especially those that reinforce common student misconceptions that may be present.

Conclusions

The questionnaire results based on University of Missouri students enrolled in Introduction to Biological Anthropology illustrate that student concepts about evolution and the nature of science are still more "fancy" and "myth" than "fact" in the twenty-first century. We agree with Almquist and Cronin's (1988) warning that a traditional college education may be unable to educate students about the tenets of evolution. This is primarily because traditional lecture pedagogy does little to help students undergo conceptual change. Research in education clearly demonstrates that if we want students in biological anthropology or other science classes to leave our institutions with an understanding of accurate scientific concepts, we must first identify their specific misconceptions and then employ appropriate pedagogical approaches to help them achieve conceptual change. We agree with Alberts (1997) that "research has taught us a great deal about effective teaching and learning in recent years, and scientists should be no more willing to fly blind in their teaching than they are in scientific research" (p. v). By using appropriate instruments to allow students to identify their misconceptions and give them an opportunity to reject them in favor of scientifically correct conceptions, we can make significant progress in improving our students' understanding of evolution.

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