

Recognizing Student Misconceptions about Science and Evolution

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Abstract

It is well documented that student misconceptions can create barriers to learning, especially in introductory biological science courses. In this paper, we examine some of the misconceptions that students enrolled in *Introduction to Biological Anthropology* at the University of Missouri-Columbia have about the nature of science and evolutionary processes, and compare them to published data. We then combine these results with a review of the educational literature to illustrate why it is important that instructors identify and fully comprehend the misconceptions of their own students as a first step in assisting their students achieve conceptual change.

Introduction

Most students enter introductory biological science courses with misconceptions about the nature of science and evolutionary theory that can impede their ability to understand the scientific explanations presented in class (Bishop & Anderson, 1990; Brumby, 1984; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou & Brewer, 1992; Wandersee, Mintzes, & Novak, 1994; Wilson, 2001). Although the students' misconceptions are often naïve, they frequently have strong explanatory power to the student (Bahar, 2003; Fisher & Lipson, 1986; Greene, 1990). Furthermore, these misconceptions are often deeply rooted, extremely complex, and reinforced by the popular media, instructors and textbooks attempting to simplify concepts, and other sources (Bishop & Anderson, 1990; Losh, Tavani, Njorge, Wilke & McAuley, 2003; Modell, Michael, & Wenderoth, 2005; Wandersee, Mintzes, & Novak, 1994). As a result, it is often difficult or impossible for students to recognize and prevail over these misconceptions in biological science courses. But, if the students fail to recognize and reject their misconceptions and fully comprehend the scientifically accurate explanation offered in class, they will commonly fall back on their former conceptions (Greene, 1990; Hellden & Solomon, 2004; Mintzes, Wandersee, & Novak, 2000; Wandersee, Mintzes & Arnaudin, 1989). Research suggests that even science graduate students continue to cling to misconceptions about evolution (Brumby, 1984; Mintzes, Wandersee & Novak, 2001).

Student misconceptions in science courses have been addressed by numerous authors (e.g., Bishop & Anderson, 1990; Greene, 1990; Wandersee, Mintzes, & Novak, 1994; Wilson, 2001), but we contend that it is vital for instructors to investigate the misconceptions of *their own* students as a first step in helping students recognize conceptual difficulties and undergo conceptual change. While students across the country have many similar misconceptions about science and evolution, these

misconceptions can vary by sex, age, geographical location, and student motivation or interest, between urban and rural areas, and can change over time (Almquist & Cronin, 1988; Losh, Tavani, Njoroge, Wilke & McAuley, 2003; Morrison & Lederman, 2003; Palmer, 2003). In this paper, we discuss questionnaire results of students entering *Introduction to Biological Anthropology* (IBA) at the University of Missouri-Columbia (UMC) and compare them to published results in order to identify common themes or discrepancies between the misconceptions of UMC students and those of college students in other parts of the country. We developed the questionnaire in order to reveal student misconceptions about the nature of science and evolutionary processes. We then intertwine these results with a review of the educational literature to illustrate why it is important for instructors to identify and fully comprehend their own students' misconceptions as a first step in helping their students achieve successful conceptual change.

Project Methodology

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. The majority (92%) of the students were under 22 years of age. *Introduction to Biological Anthropology* is a sophomore level course that fulfills the university's general education requirement for Biological Sciences. Normal enrollment for this course is 150 to 200 students per semester. The course is required for all anthropology majors, but the majority of students enrolled in the course are non-science majors who have limited educational background in science. During the course, students learn about a broad range of topics related to human evolution, variation, and adaptation. As a result, it is crucial that students gain a solid understanding of evolutionary principles early in the semester.

Questionnaire

An anonymous questionnaire was developed to help discover student misconceptions about the nature of science and evolutionary theory in the IBA class. The questionnaire was administered on the first day of class to reduce any possible instructor influence. The students were told that there were no correct answers and that their answers would not influence their final grade.

The questionnaire was divided into 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 have taken a college-level biology, chemistry, or physics course (Table 1). In the second section, students were asked to respond as to whether they strongly agree, agree, disagree, strongly disagree, or have no opinion on 25 statements (Table 2). The reasons for using this type of instrument are discussed in the Results and Discussion section below.

The statements on the survey were chosen to help reveal the students' conceptions regarding 1) the nature of science, 2) the survival of new traits in a population, 3) support of Lamarckian inheritance, 4) appreciation of the importance of variation within a population, 5) the process of natural selection, 6) terminology that has different meanings in the vernacular and in science, and 7) the idea of teleological evolution (evolution directed by an outside agent). These are major areas of misconceptions that have been pointed out by Bishop and Anderson (1990), Greene, 1990; Wandersee,

Mintzes, and Novak (1994), Wilson (2001) and others. We adopted many of the questions from Bishop and Anderson (1985, 1990) and Wilson (2001) so that we could compare our results with theirs.

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
	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

Table 1
Student Profile.

#	Statement	% Response 1					
		1	2	3	4	5	6
1	There is lots of evidence against evolution.	8	14	26	42	10	0
2	Dinosaurs and humans lived at the same time in the past.	3	9	16	60	12	0
3	Humans and chimpanzees evolved separately from an ape-like ancestor.	22	38	11	12	17	0
4	I have a clear understanding of the meaning of scientific study.	29	49	11	4	7	0
5	The theory of evolution correctly explains the development of life.	17	38	16	12	17	0
6	Humans evolved from monkeys/apes.	15	32	16	21	16	0
7	A scientific theory that explains a natural phenomenon can be defined as a "best guess."	12	28	22	23	15	0
8	Small population size has little or no effect on the evolution of a species.	2	6	30	47	15	0
9	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
10	Variation among individuals within a species is important for evolution.	53	32	3	3	9	0
11	A species evolves because individuals want to.	2	6	27	52	13	0
12	Humanity came to be through evolution, which was controlled by God.	16	21	11	25	26	0
13	A species evolves because individuals need to.	31	35	12	10	12	0
14	I have a clear understanding of the term "fitness" when it is used in a biological sense.	20	33	17	10	20	0
15	Two of the most important factors that determine the direction of evolution are survival and reproduction.	53	36	3	2	6	0
16	New traits within a population appear at random.	10	30	33	12	15	0
17	The environment determines which new traits will appear in a population.	19	59	8	5	8	1

18	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
19	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.	21	40	17	8	14	0
20	“Survival of the fittest” means basically that “only the strong survive.”	33	31	19	14	3	0
21	You cannot prove evolution happened.	11	16	29	28	16	0
22	Evolution cannot work because one mutation cannot cause a complex structure (e.g., the eye).	4	9	27	27	33	0
23	Evolution is always an improvement.	6	20	34	25	15	0
24	A scientific theory is a set of hypotheses that have been tested repeatedly and have not been rejected.	39	39	8	6	8	0
25	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.	17	33	18	10	22	0

Table 2

Percent response to each statement.

1 Response:

1 = strongly agree

2 = somewhat agree

3 = somewhat disagree

4 = strongly disagree

5 = undecided/never heard of it

6 = no response

Results and Discussion

Study Results and Comparison

The participant profile is presented in Table 1. 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 (Table 1). Only 51% of the UMC students in IBA had been taught evolutionary principles without creationism in high school science. Wilson (2001) found similar results among California college students. In his study, 46% of the 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.

The UMC student responses to each of the 25 questions are presented as percentages in Table 2. The UMC students have many of the misconceptions found by other researchers, but they differ in the pattern of misconceptions. Like the non-science majors studied by Bishop & Anderson (1990), UMC students fail to recognize that the origin and survival of traits in a population involves two distinct processes. Instead they conflate these two processes into a single process in which species gradually change over time due to environmental causes (Bishop & Anderson, 1990). Bishop and Anderson (1990) argue that students often find that the function of a trait is sufficient to explain how the trait evolved, and we found similar results among UMC students. For example, students were asked if they would agree or disagree with the following statement (Table 2: #19) about ducks in a pond: "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" (Bishop & Anderson, 1990). Sixty-one percent agreed with this statement, reflecting their belief in the use/disuse idea. However, most of the UMC students do not have the alternative conception that species evolve because individuals want to (Table 2: #11) or that acquired traits are inherited (Table 2: #9).

Variation within populations is an essential precursor for evolutionary change via natural selection. The survey of Michigan college students conducted by Bishop and Anderson (1990) found that students did not view variation as important in evolution. Our results, however, differ. We discovered that 83% UMC students tend to agree that variation matters (Table 2: #10). Only 6% of the respondents think that variation is not important. Even so, many UMC students do not fully understand the role of variation (Table 2: #25).

According to Darwin's theory of evolution via natural selection, new traits that improve an individual's fitness increase in frequency within populations as the proportion of individuals in the population with these traits proliferates with each succeeding generation. Bishop and Anderson (1990, p. 423) found that students, on the other hand, view evolutionary change as depending on "gradual changes in the traits themselves" over generations. Only half of the UMC students had this misconception (Table 2: #25). Twenty-eight percent of the UMC students did not have this conception and 22% were uncertain.

Bishop and Anderson (1990) argued that many of the students' misconceptions are reinforced by terms that have different meanings in the vernacular and in science. Our results generally support this finding. Like Bishop and Anderson (1990), we found that despite the fact that 53% of the students thought they had a clear understanding of the term "fitness" as used in biology (Table 2: #14), 64% agreed with the statement that survival of the fittest means that only the strong survive (Table 2: #20). This implies that students view fitness as health, strength, and intelligence instead of the capability of individuals to differentially survive long enough to produce surviving offspring or to produce a greater number of offspring. Likewise, biologists use the term "theory" to mean a set of hypotheses that have been tested repeatedly, have not been rejected, and explain current data and predict future observations. Students, on the other hand, often use the term to mean a "best guess," which perpetuates that idea that evolutionary theory is a best guess at explaining the development of life. Our survey indicates that 40% of UMC students in IBA do not differentiate between the vernacular and scientific use of the term (Table 2: #7). Interestingly though, when the statement was phrased differently, 78% of students correctly identified the meaning of a scientific theory (Table 2: #24).

Surveys indicate that “belief” in evolution has changed little in the United States over the past century (Bishop, 1999). However, Bishop and Anderson (1990) discovered that 49% to 55% of Michigan students accepted evolution as a theory that correctly explains the patterns of life on earth, but Wilson (2001) found that only 39% of California students “believed” in evolution. Of the UMC participants, 55% agreed that evolution correctly explains the development of life (Table 2: #5), only 22% thought there was lots of evidence against evolution (Table 2: #1), and only 27% agreed that evolution cannot be demonstrated scientifically (Table 2: #21). Similarly, Wilson (2001) found that 27% of California students thought humans and dinosaurs lived at the same time, but only 11% of UMC students had this misconception, and 12% were undecided (Table 2: #2). However, we did discover that 37% of UMC students believe in teleological evolution or that change is goal-directed by an outside agent (Table 2: #12). Students who operate under this perspective see an outside agent selecting individuals who are in need of helpful changes (Greene, 1990), which may explain why UMC students see evolution as a need driven process (Table 2: #13).

The results of this study suggest that UMC students in IBA do not follow the same patterns in their misconceptions as found by other researchers in the United States (e.g., Bishop & Anderson, 1990; Wilson, 2001). While many of the misconceptions held by UMC IBA students are the same as students in other regions, the UMC students seem to be better scientifically informed about some concepts. This was a surprising result since most of the students in IBA have taken few science courses, which suggests minimal interest in science and evolution, and had no more prior exposure to evolutionary principles than students in other studies. Palmer (2003) found a strong relationship between students’ conceptual change and interest in and motivation to learn the subject being presented, but the UMC IBA students are not likely to have a greater interest in science or evolution than students in other introductory biological science courses. Unfortunately, the reasons why UMC students differ from students in other regions cannot be clearly uncovered in this study, but probably reflect educational, religious, generational and possibly motivational differences between UMC students and those surveyed by Bishop & Anderson (1990) and Wilson (2001).

Why Investigate Student Misconceptions?

A review of the literature identifies two barriers to student learning: the worldview of the student and the student’s own misconceptions (Wandersee, Mintzes, & Novak, 1994). Assuming that simply exposing students to the overwhelming evidence for evolution will “convince” them of its accuracy assumes that they have a scientifically compatible worldview, which many do not. For these students, an evolutionary explanation is not acceptable, and presenting overwhelming evidence for evolution will not make a difference. In fact, Bishop and Anderson (1990) and Sinatra, Southerland, McConaughy, and Demastes (2003) found that a stated “belief” in evolution did not affect the students’ understanding of evolutionary processes. While we, as educators, cannot change the students’ worldviews, we can address the second barrier to student learning: scientific misconceptions. Because most students come to class with a preconceived explanation of how something (e.g., evolution) works, if they do not comprehend the scientifically accurate explanation that they are offered in class, they simply fallback on the process that has explanatory power to them.

Student misconceptions are deeply rooted, extremely complex, and frequently reinforced by a number of sources. Likewise, the misconceptions students have often vary by geographical region, religious background, sex, age, and generation (Almquist & Cronin, 1988; Losh, Travani, Njoroge, Wilke, & McAuley, 2003; Morrison & Lederman, 2003; Palmer, 1999). For example, Almquist and Cronin (1999) found that males tend to have a greater scientific bias in their responses than females. Similarly, Losh et al. (2003) showed that the effect of generational experience can be easily seen by looking at changes in the pseudoscientific belief in astrology in the 1980s. Research shows that belief in astrology dropped from over 40% to 15% in 1989 because of media coverage of Nancy Reagan's consultation with an astrologer (Losh et al., 2003). Additionally, the misconceptions employed by students may be context specific (Palmer, 1999). That is, they may apply one conception to mammals and another to plants. This suggests that it is vital for educators to discover the misconceptions relevant to the context of the class. Furthermore, instructors must take into consideration the worldview and demographic makeup of students at their university or college.

While it is well documented that students have misconceptions about science and evolution, they also often have many scientifically acceptable conceptions that may be used by instructors to provide a solid learning base that links the students' existing knowledge with the class content and assists them in conceptual change (Morrison & Lederman, 2003; Palmer, 1999). Therefore, it is important for instructors of introductory biology and biological anthropology courses to not only understand the *scientific misconceptions* their students have, but to also understand the students' *scientifically acceptable conceptions*. For example, many UMC students appear to understand that new traits appear in populations at random (Table 2: #16), that humans and chimpanzees are separate evolutionary lineages (Table 2: #3), and that genetic drift (Table 2: #8) and gene flow (Table 2: #18) are important processes in evolution.

The instructor's role in the students' education is to use instructional and motivational methods that gives each student an opportunity to become dissatisfied with their existing conception, achieve some understanding of the scientific conception, and recognize the utility of the scientific conception to explain a variety of situations (Jensen & Finley, 1996; Palmer, 2003). The first step in conceptual change instruction is to understand the students' naïve scientific conceptions so that they recognize and change them (Morrison & Lederman, 2003). We contend that developing and administering a questionnaire, conducting interviews, initiating discussion, or using some other technique that elicits students conceptions at the beginning of each semester (preferably even before the syllabus is handed out) is the only way instructors will have the knowledge necessary to help their students undergo conceptual change.

Developing an Instrument

We suggest that instructors develop an instrument that enables them to closely examine the misconceptions of their students that are relevant to the course. The type of instrument used will depend on class size, instructor's teaching and other workload responsibilities, and the number of areas that the instructor wishes to explore. Concept maps, individual interviews, small group discussions, journal writing, multiple choice quizzes, and questionnaires have all been suggested as techniques to help instructors reveal student misconceptions about evolution (Anderson, Fisher, & Norman, 2002; Bishop & Anderson, 1985, 1990; Morrison & Lederman, 2003; Wilson, 2001). Each instructor must decide which instrument is most effective and appropriate for his or her science course.

Several excellent and well-established diagnostic instruments have been developed to tease out student misconceptions about evolution, but these may not be appropriate for every biological science course. Anderson, Fisher and Norman (2002) developed a 20-question multiple choice instrument ("Conceptual Inventory for Natural Selection" or CINS) focusing on misconceptions regarding natural selection. Each question has four options to choose from with a scientifically correct answer and at least one common misconception used as a distraction. The advantage of their instrument is that it uses questions based on scientific studies and has been tested for validity, reliability, and readability. The disadvantage is that the CINS focuses only on natural selection and uses multiple choice questions. Almquist and Cronin (1988) found that when students were asked multiple choice questions that contained answers ranging from scientifically acceptable to theological, respondents generally chose the more scientifically acceptable answer. However, on the same survey, when participants were asked to answer how much they agreed or disagreed with statements involving misconceptions, the respondents frequently answered in strong agreement with the misconception. Bishop and Anderson (1985, 1990) developed an instrument with both open-response and multiple-choice questions that also reveals misconceptions about natural selection.

There are definite advantages to open-response questionnaire, but in a large class like IBA this type of question requires too large of a time commitment from the instructor to be practical. Open-response questions require the instructor to read all of the responses and develop a coding procedure to evaluate the answers. In addition, open-response questions can often be ambiguous because it may be unclear if students are using scientific or vernacular terminology (e.g., "theory"). Wilson (2001) developed a questionnaire with 33 statements that participants respond to in agreement or disagreement. However, his questionnaire was designed to evaluate students' beliefs about pseudoscience and therefore includes statements about conceptions regarding unidentified flying objects, Bigfoot, psychics, and the curse of the mummies.

We contend that educators will gain more insight into their students' misconceptions by developing their own instrument that address problems specific to their course, and should consult Lederman, Abd-El-Khalick, Bell, and Schwartz (1992), Mintzes, Wandersee, and Novak (2001), Morrison and Lederman (2003), the Field-Tested Learning Assessment Guide website (www.wcer.wisc.edu/nise/cl1/flag) and other sources for recommendations and guidelines.

Our questionnaire adopted many of the multiple-choice questions used by Bishop and Anderson (1985, 1990) but modified them to agree/disagree statements. We found that the use of agree/disagree type questionnaires has several advantages, especially when used in large classes. First, the questionnaire can be completed by the students with relative ease and results can be quickly obtained. We had the students answer the questions on scantron forms and had them read electronically at the campus testing center. The questionnaire results were available to us before the next class period. However, we have not conducted a study to determine if agree/disagree statements provide a better understanding of the respondents' conceptions than multiple-choice questions, and suggest that, if possible, this type of instrument should be combined with interviews, concept maps, two-tiered questions or other instruments to gain a full insight into student misconceptions (Morrison & Lederman, 2003). We have recently begun incorporating free response follow-up questions and questions regarding epistemological beliefs to help gain further insight into student misconceptions. We are also

administering posttests to measure student conceptual change following instruction, which will be used to evaluate teaching strategies.

Conclusions

Learning is a process of conceptual change where the learner proactively revises and reorganizes his or her preexisting knowledge (Bahar, 2003; Liu, 2004; Mintzes, Wandersee, & Novak, 2000; Posner, Strike, Hewson, & Gertzog, 1982). Only the learner has the ability to recognize and modify his or her misconceptions (Modell, Michael, & Wenderoth, 2005), but, as teachers, we are responsible for helping our students recognize that their misconceptions lead to erroneous conclusions and offer the students an opportunity and the motivation to reject or modify them. For many subjects, the learner's preexisting knowledge is helpful to promote conceptual change, but in science courses, the students' misconceptions often slow down or even prohibit conceptual change (Jensen & Finley, 1996). As a result, the understanding of student-held concepts regarding science and evolution is vital to effective teaching. In order for the instructor to assist students in undergoing permanent conceptual change, the instructor must first understand the misconceptions with which the student enters the classroom, make them explicit, and offer the student an opportunity to reject them in favor of scientifically accurate information (Modell et al., 2005; Morrison & Lederman, 2003).

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