The Journal of Effective Teaching

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Special Issue
Teaching Evolution in the Classroom

Volume 9/Issue 2/September 2009

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CONTENTS

CALL FOR PAPERS

The Journal of Effective Teaching is accepting submissions for review for the Spring 2010 issue. Manuscripts will be due October 31, 2009. The expected publication date will be February 28th. Articles will be accepted in any of the Content Areas supported by the journal.

INFORMATION FOR AUTHORS

The Journal of Effective Teaching is an electronic journal devoted to the exchange of ideas and information about undergraduate and graduate teaching. Articles are solicited for publications which address excellence in teaching at colleges and universities. We invite contributors to share their insights in pedagogy, innovations in teaching and learning, and classroom experiences in the form of a scholarly communication which will be reviewed by experts in teaching scholarship. Articles should appeal to a broad campus readership. Articles which draw upon specific-discipline based research or teaching practices should elaborate on how the teaching practice, research or findings relates across the disciplines. We are particularly interested in topics addressed in the particular Content Areas described at this site, including empirical research on pedagogy, innovations in teaching and learning, and classroom experiences.

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Manuscripts for publication should:

- Follow APA guidelines (5th Edition).
- Include an abstract and 3-5 keywords.
- Typeset in English using MS Word format and 12 pt Times New Roman
- Articles/essays on effective teaching should be 2000-5000.
- Research articles should be 3000-8000 words.
- Tables and figures should be placed appropriately in the text.

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Deadlines for Upcoming Issues

	Spring 2010	**Fall 2010**
Submissions Due	October 31, 2009	May 31, 2010
Notification of Acceptance	December 31, 2009	July 31, 2010
Final Manuscripts Due	January 31, 2010	August 31, 2010

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Letter from the Editor-in-Chief: Origins

Russell L. Herman[1]
The University of North Carolina Wilmington, Wilmington, NC

In the beginning -

$$\nabla\cdot\mathbf{E}=\frac{\rho}{\varepsilon_0}$$
$$\nabla\cdot\mathbf{B}=0$$
$$\nabla\times\mathbf{E}=-\frac{d\mathbf{B}}{dt}$$
$$\nabla\times\mathbf{B}=\mu_0\mathbf{J}+\mu_0\varepsilon_0\frac{d\mathbf{E}}{dt}\ \ldots$$

and there was light.

This set of equations, which makes little sense to some, has been displayed on many a physics major's T-shirt. These equations are referred to as Maxwell's equations, named after the famous physicist James Clerk Maxwell, who used what was known about electricity and magnetism in the 1860's and predicted the existence of electromagnetic waves. It wasn't until 1887 that a thirty year old Heinrich Hertz produced the first electromagnetic waves, leading to radio and television broadcasting. Not long after that Jagadish Chandra Bose discovered microwave radiation. Just a few years before Maxwell's predictions, in 1859, Charles Darwin published *On the Origin of Species*.

This year is the bicentennial of Darwin's birth (February 12, 1809) and the 150th anniversary of his publication, *On the Origin of Species* (November 24, 1859)[2]. Many groups have been celebrating these events and there has been much discussion in college and university classrooms about the impact of Darwin's work in the sciences and beyond. Considering the recent controversies in the public schools and the media, this topic has lead to questions as to how to effectively teach a diverse student population and the general public about the science, philosophy, and history of evolution and Darwinism in our society.

In this volume of *The Journal of Effective Teaching* you will find articles on teaching evolution in the classroom marking these anniversaries. We solicited articles on teaching evolution in the college classroom which also adhered to the mission of the journal, namely articles which highlighted effective teaching practices, or studies involving student learning, and not those solely about the content of evolution.

[1] Author's email: hermanr@uncw.edu
[2] It is interesting to note that there are other significant anniversaries ending in "9" such as those as shown in Table 1.

Table 1: Some Other Significant Dates Ending in "9"

Years Ago	Date	Event
400	25 August 1609	Galileo Galilei demonstrated his new telescope.[3]
300	1609	Johannes Kepler wrote the book *Astronomia nova*
280	1729	First English translation of Newton's *Principia* by Andrew Motte
200	12 February 1809	Charles Darwin and Abraham Lincoln were born.
150	24 November, 1859	*On the Origin of the Species*
130	March 14, 1879	Albert Einstein was born.
120	November 20, 1889	Edwin Hubble was born.
90	May 29, 1919	Sir Arthur Eddington solar eclipse expedition confirmed Einstein's theory of general relativity.
80	1929	Hubble discovered the Redshift Distance Law of galaxies, Hubble's law.
70	1939	Nuclear fission is discovered independently by Lise Meitner and Otto Hahn.
40	July 20, 1969	Neil Armstrong and Buzz Aldrin land on the Moon.
20	November 18, 1989	COBE launched http://lambda.gsfc.nasa.gov/product/cobe/
10	December 1, 1999	First Human Chromosome Completely Sequenced http://www.ornl.gov/sci/techresources/Human_Genome/project/chr22.shtml

Where did we come from? Why am I here? What is the fate of the universe?

Many people have contemplated such questions since their youth from points of view ranging from philosophical and religious to scientific. The question of origins was the subject of the recent September 2009 issue of Scientific American, which considered the origins of many fields including topics like the origins of the universe, life, and computing. It was also the theme of the 2009 Origins Symposium[4] held at the Arizona State University, which brought together 70 of the world's leading scientists and scholars to explore Origins issues.

Over the last one hundred and fifty years our collective view of the universe has changed more than it had the two thousand years after Aristotle. We found out we are not at the center of the universe, or even the solar system. We learned by the 1800's that we were

[3] Matson, J. (August 25, 2009). 400 years ago, Galileo's telescope was ready for prime time. In 60-Second Science Blog, Scientific American. http://www.scientificamerican.com/blog/60-second-science/

[4]The Origins initiative can be found at http://origins.asu.edu/. The symposium featured Nobel laureates and others giving lectures, or participating on panels, including people like Richard Dawkins, Ann Druyan, Steven Weinberg, Paul Davies, Craig Venter, Neil deGrasse Tyson, Steven Pinker, Brian Greene, Donald C. Johanson, Lawrence Krauss, and many others. Videos from the symposium are online at http://origins.asu.edu/symposium/video/.

part of the Milky Way Galaxy. In the 1920's we realized there were galaxies beyond our own. In fact, the Hubble telescope has uncovered over a hundred billion galaxies - each containing a hundred billion stars.

There were also surprises in store for us in the twentieth century on very small scales further challenging our thoughts about the fabric of the universe. The electron was discovered in 1897, the neutron in 1932 and hundreds of subatomic particles resulted in the atom smashers in the mid 1900's. The strange world of subatomic physics lead to practical applications that changed our modern world – transistors, lasers, computers and cell phones.

In 1905 Albert Einstein and others introduced us to new ways to view space, time, and determinism, upsetting the clockwork universe handed down to us by Newton. Such ideas found their way into all walks of life, appearing in the works of philosophers and artists Einstein's work on gravitation eventually lead Edwin Hubble to data for an expanding universe, Arno Penzias and Robert Wilson in 1965 to detect the signs of the beating heart of the early universe, only later to be confirmed to incredible accuracies by experiments like COBE (Cosmic Background Explorer) and WMAP (Wilkinson Microwave Anisotropy Probe) in the last decade. By looking at experimental evidence of the universe's past, we are now confident that the universe as we know it dates back 13.7 billion years to a hot soup of matter and radiation. The fabric of spacetime exploded, dragging with it the material universe as we have come to know it, along the way producing elements, stars, galaxies and more.

And, billions of years later the Earth was born and a few million years after that Charles Darwin introduced his famous work, *On the Origin of Species*. Ever since 1859, the theory of evolution has been challenged and tested by many. How do we bring this subject into the classroom? There are many ways one can do this. However, in this special issue of *The Journal of Effective Teaching* we are not as much interested in the deep details of how to present arguments for or against evolutionary ideas, but we want to see what preconceptions students have, or how to bring students into contact with the facts … like actually going to Galápagos, critically discussing the recent Dover case, or even to face preconceived notions of where the borders of science and religion might meet. We hope that you find these articles interesting and provoking, leading you to other discussions as to how we explore controversial topics in the classroom.

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The Influence of Religion and High School Biology Courses on Students' Knowledge of Evolution When They Enter College

Randy Moore[1], Sehoya Cotner, and Alex Bates
University of Minnesota, Minneapolis, MN 55455

Abstract

Students whose high school biology course included evolution but not creationism knew more about evolution when they entered college than did students whose courses included evolution plus creationism or whose courses included neither evolution nor creationism. Similarly, students who believed that their high school biology classes were the primary source of their views of evolution knew more about evolution than did students who claimed that religion was the primary source of their views about evolution. Students who described their religious views as conservative or middle-of-the-road knew less about evolution than did nonreligious students or those who described their religious views as liberal/progressive. To our knowledge, this is the first measure of how students' experiences in high school biology courses affect their knowledge of evolution when they enter college.

Keywords: Evolution, teaching, religion, high school biology.

For several decades, numerous surveys conducted throughout the United States have documented the surprisingly large percentage of biology teachers who are creationists (Moore & Cotner, 2009, and references therein). Indeed, 20-35% of biology teachers include creationism in their courses, and fully one-sixth of biology teachers are young-Earth creationists who reject many of the tenets of biology and other sciences (Berkman, Pacheco, & Plutzer, 2008). The popularity of creationism among biology teachers continues despite decades of science education reform, numerous statements by professional scientific organizations supporting evolution and rejecting creationism, state science-education standards requiring the teaching of evolution, and numerous court decisions declaring that the teaching of creationism (e.g., creation science, intelligent design) in public schools is unconstitutional. Some of these court decisions have involved biology teachers who have taught creationism (Moore, 2002). Other such teachers have also made headlines; for example, Ohio biology teacher John Freshwater taught creationism, prayed, and held "healing sessions" in his classes for more than a decade, but was fired only after he used an electrical device to brand a cross into a student's arm (Demartini, 2008). Although the studies cited above have often lamented the occurrence of creationism in high school biology courses, few have measured the impact of including creationism in the curriculum. Does it matter if biology teachers teach creationism in their high school courses?

[1] Corresponding author's email: RMoore@umn.edu

We have previously reported that students whose high school biology courses included evolution (but not creationism) are significantly more likely to accept evolution than are students whose high school biology courses did not include evolution (Moore & Cotner, 2009). Similarly, students whose high school biology courses included creationism (with or without evolution) are significantly more likely to accept creationism and reject evolution than are students whose high school biology classes included only evolution. These studies involved students' responses to the Measure of Acceptance of the Theory of Evolution (MATE) survey, which measures students' acceptance of broad statements about evolution (e.g., age of Earth, fixity of species; Rutledge & Sadler, 2007). Although the MATE survey is informative about the acceptance of evolution, it does not measure students' factual *knowledge of* evolution. Knowledge of evolution is not synonymous with acceptance of evolution; as Cavallo and McCall (2008) have noted, biology students have "little scientific understanding of evolutionary processes, but hold many beliefs about the theory" (p. 522).

In this study, we examined the relationship of students' high school biology courses to their knowledge of evolution. Although several studies have examined whether college biology courses alter students' views of evolution (Hoyakem & BouJaode, 2008; Cavallo & McCall, 2008), we wanted to know how students' high school biology courses are associated with students' knowledge of evolution. We wanted to answer several questions. For example,

- Do students whose high school biology courses included evolution (but not creationism) know more about evolution when they enter college than students whose high school biology courses included creationism?
- Do students whose high school biology courses included evolution or creationism know more about evolution than students whose biology classes included neither evolution nor creationism?
- From what source do students believe they got the most information about evolution and creationism? Their high school biology course? Their family? Their religion?
- Do students' evaluations of the evolution-related content of their high school biology courses reflect their actual knowledge of evolution?

Methods

Study population. During the week before classes, we surveyed students enrolled in several sections of an introductory biology course at the Twin Cities campus of the University of Minnesota. All of the students in this study had taken a biology course in a public high school. Students in this course had an average high school graduation-percentile of 84 $\pm$ 12% and an average ACT composite score of 25 $\pm$ 4.

The survey instrument. We designed our survey to assess students' background in, and knowledge of, the theory of evolution. First, we asked students to tell us whether their high school biology course included evolution but not creationism, creationism but not evolution, both evolution and creationism, or neither evolution nor creationism (Table 1).

Table 1. Students' descriptions of their high school biology course and their grades on the knowledge of evolution exam (KEE); *n =193*.

My high school biology course included	% of Students	KEE Score
Evolution only	62.2	57 $\pm$ 3.9
Creationism only	2.6	44 $\pm$ 4.5
Evolution and creationism	22.3	53 $\pm$ 4.5
Neither evolution nor creationism	12.9	41 $\pm$ 3.3

We then asked students to respond to several statements from the Measure of the Acceptance of the Theory of Evolution (MATE) instrument developed and validated by Rutledge and Sadler (2007). Students could answer "strongly agree," "agree," "unsure," "disagree," "strongly disagree," or not answer at all. We also included 10 basic, discriminating questions about evolutionary topics with which we and other biology instructors at our university assumed that entering students would be familiar (e.g., fitness, natural selection, evidence for evolution); these questions, which were developed and tested over a period of several years with students in introductory biology courses, are hereafter known as the Knowledge of Evolution Exam (KEE). Students could answer "strongly agree," "agree," "unsure," "disagree," "strongly disagree," or not answer at all. We also asked students to identify their and their classmates' primary source of their views of evolution, and whether their high school biology courses' treatment of evolution was adequate, less than adequate, or more than adequate. Finally, we also asked students to identify their religious beliefs as being conservative, liberal, middle-of-the-road, or nonexistent (i.e., not religious). Copies of the survey and students' responses are available from the authors.

The survey, which was voluntary, anonymous, and approved by the university's Institutional Review Board, was distributed electronically to students one week before classes started. To ensure that students' responses were not influenced by the instructor or course, we closed the survey on the morning that classes began (i.e., before the first meeting of the class). Students' responses were tabulated electronically and had no impact on students' grades. The survey was completed by 193 students.

Results

Students' descriptions of their high school biology course and their grades on the KEE are shown in Table 1. The population averaged 54.2% on the KEE questions. The highest score on a question was 68.7%, and the lowest was 33.9%. Students whose high school biology course included evolution but not creationism scored higher on every question than did students whose high school biology classes included neither evolution nor creationism. The average difference between the scores was 32.7%, with the largest difference (61.8%) occurring on the question about mutation as the ultimate source in variation in populations, and the smallest difference (12.5%) occurring on the question about resistance to insecticides as an adaptation.

A one-way ANOVA revealed a significant effect (F-stat = 3.58; $p < 0.02$) of high school biology on the KEE score. Students whose high school biology course included evolution but not creationism scored an average of 56.4 ± 2.0% (s.e.) on the KEE. As indicated with a post-hoc pair-wise *t*-test, this score was not significantly different from that of students whose high school biology course included both evolution and creationism (i.e., 50.0 ± 3.3%; $p = 0.10$) or creationism only (48 ± 9.8%; $p = 0.4$), but was significantly different from that of students whose high school biology course included neither evolution nor creationism (41.6 ± 4.4%; $p < 0.01$). The KEE scores of students whose high school biology course included both evolution and creationism were not significantly higher than those of students whose high school biology course included neither evolution nor creationism ($p = 0.12$).

Table 2 shows students' evaluations of the adequacy of the evolution coverage in their high school biology courses, as well as 1) the evolution content of their high school biology course, and 2) these students' scores on the KEE. Students who evaluated their high school biology course as "adequate" or "more than adequate" had similar high school biology courses; for example, 70-72% of the courses included evolution only, 25-28% included evolution plus creationism, and 0-5% included creationism only or neither evolution nor creationism. Thirty percent of students claimed that their high school biology course did a "less than adequate" job with evolution, despite the fact that 60% of these students' courses included evolution. The KEE scores of students' who evaluated their high school biology course as "adequate" and "more than adequate" were not significantly different. However, the KEE scores of both of these groups of students were significantly different ($p < 0.001$ per a Student's *t*-test) from those of students who evaluated their high school biology course's treatment of evolution as "less than adequate".

Table 3 shows students' claims of the primary sources of *their* views about evolution and these students' scores on the KEE. Students claimed that the top sources of their views of evolution were their high school biology course (55.1% of students), their family (26.9% of students), the media (14.7% of students), and their religion (3.2% of students). The KEE scores of students who claimed that their high school biology course was their primary source of information were significantly higher than those of students who claimed that their church/religion was the primary source of their views of evolution ($p < 0.04$). There were no significant differences between any of the other groups' scores.

Table 3. The relation of students' KEE scores to their primary sources of information about evolution. All numbers in the table are percentages.

Primary source of views About evolution	% of Students	KEE Score
Church/religion	3.1	32 ± 10.4
Family	26.9	53 ± 3.6
High school biology course	55.1	54 ± 2.5
Media	14.7	47 ± 4.8

Table 2. How students' evaluations of the evolution-related content of their high school biology courses are related to their KEE scores. All numbers in the table are percentages.

			Emphasis of Students' High School Biology Course			
Evaluation of Biology Course	% of Students	KEE Score	Evolution only	Creationism only	Evolution + Creationism	Neither evolution nor creationism
More than adequate	13.2*	56 ± 4	72	0	28	0
Adequate	56.6	58 ± 2.4	70	1	24	5
Less than adequate	30.2	42 ± 4.4	43	7	15	33

*For example, 13.2% of students evaluated their high school biology course's treatment of evolution as "more than adequate." These students scored 56% on the evolution questions. Seventy-two percent of these students had high school biology courses that included evolution only, 28% had courses that included evolution and creationism, and none had courses that included creationism only or that included neither evolution nor creationism.

The KEE scores of students having different self-described religious beliefs are shown in Table 4. Students who claimed to be middle-of-the-road scored significantly lower on the KEE than did students who described themselves as liberal/progressive ($p < 0.04$).

Table 4. The relationship of students' self-described religious views with their KEE scores. All numbers in the table are percentages.

Religious View	% of Students	KEE Score
Conservative	8.5	46 ± 5.4
Liberal/progressive	36.0	56 ± 2.8
Middle-of-the-road	25.0	47 ± 3.2
Not religious	30.4	55 ± 3.2

Discussion

Students' knowledge of evolution. Although evolution is a required part of the curriculum in most states' high school curriculum (including Minnesota), students averaged only 54% (i.e., a failing a grade) on the KEE. Students' scores on individual questions varied dramatically, but mean scores on all questions were surprisingly low, and even the highest score on an individual question (i.e., 68.7%) was in the D range. These results indicate that students entering college know relatively little about evolution, despite the fact that they took a high school biology course. Evolution may be the unifying theme in biology, but few high school students learn much about it in their high school biology courses, or at a minimum, few retain much of what they learn about evolution in high school.

***How students' high school biology courses are associated with students' knowledge of evolution*.** Students' KEE scores were strongly associated with the evolution-related content of their high school biology courses. Students who scored highest (i.e., 57%) on the KEE were those whose high school biology course included evolution but not creationism (i.e., as required by state educational standards). Students whose high school biology course included evolution and creationism scored lower (i.e., 53%), and students whose high school biology course included neither evolution nor creationism scored lower still (i.e., 41%). These results indicate that the evolution-related content of students' high school biology courses strongly influences students' knowledge of evolution when they enter college. To our knowledge, this is the first quantitative measure of the impact of evolution-related instruction in high school on students' evolution-related knowledge when they enter college.

Although the teaching of evolution in high school increases students' knowledge of evolution when they enter college, the inclusion of creationism with evolution was associated with lower scores on the KEE. We could not determine if these lower scores were due to a decreased emphasis on evolution (e.g., to make time for the teaching of creationism) or to the incompatibility of many types of creationism with basic tenets of evolution (e.g., young-Earth creationism and the fixity of species), but we suspect that it is a combination of both. Indeed, a surprising number of biology teachers either cover evolution in a trivial way or discredit evolution when they teach the subject (Bandoli, 2008, and references therein). Similarly, approximately one-sixth of biology teachers are young-Earth creationists (Berkman, Pacheco, and Plutzer, 2008), and a presentation of young-Earth creationism as legitimate science would presumably confuse students about the basic tenets of science in general, and evolution specifically. Regardless, the inclusion of creationism (which occurs in approximately 25% of biology courses; Moore and Cotner, 2009, and references therein) or the exclusion of both evolution and creationism (another 13% of biology courses) is associated with students knowing less about evolution when they enter college. When compared with students whose high school biology courses included evolution only (i.e., as specified by state science standards), students who have been taught creationism or who have been taught neither evolution nor creationism enter college biology classes at a distinct disadvantage.

Students' evaluations of the adequacy of their high school biology course. Although all groups of students scored poorly (i.e., < 60%) on the KEE, students' knowledge of evolution was strongly associated with their evaluations of the evolution-related content of their high school biology course. Almost 70% of students claimed that the evolution-related content of their high school biology course was adequate or more than adequate; these students' scores on the KEE (58 and 55%, respectively) were not significantly different, but were both significantly higher than those of students who claimed that the evolution-related content of their high school biology course was less than adequate (43%). Whereas students who evaluated their high school biology course as adequate or more than adequate had similar experiences in high school (e.g., 70-72% had evolution-only biology courses; 25-28% had courses that included evolution and creationism), students who viewed their high school biology course's coverage of evolution as inadequate were much less likely to have taken high school biology courses that included evolution only or evolution plus creationism, and much more likely to have taken courses that included creationism only or neither evolution nor creationism. These results support our claim that the evolution-related content of high school biology courses is strongly associated with college students' knowledge of evolution.

Almost 60% of the students who claimed that their high school biology course's coverage of evolution was inadequate had taken high school biology courses that included evolution. These results indicate that students' claims of the academic inadequacy of their high school biology course (and the reduced knowledge of evolution that is associated with these claims; see above) are usually not due to evolution being excluded from their courses. Although we did not measure the quality of the evolution-related instruction given to any of our students, and do not dispute the claim by Alters and Nelson (2002) that "many students have had ample formal and informal educational opportunities to misunderstand evolution," our results were not due to an increase in creation-related instruction, for the percentage of students in this group who were taught creationism (22%) was similar to that of students who evaluated their biology course as adequate (25%) and more than adequate (28%). Indeed, students who claimed that their high school biology course included an inadequate coverage of evolution were dramatically *less* likely to have had biology courses that included neither evolution nor creationism

(Table 2). These data are consistent with the claim that the evolution-related content of high school biology courses is strongly associated with college students' knowledge of evolution. Students having less or no exposure to evolution in high school biology classes did not learn about evolution from other sources (e.g., family, media, religion).

Our data show that students' knowledge of evolution is strongly associated with the evolution-related content of their high school biology course. Students know this; more than half (i.e., 55%) of students agreed that their high school biology course was their primary source of information about evolution. Students who claimed that their biology course was their primary source of information about evolution scored higher on the KEE (i.e. 54%) than did students who claimed that their primary source of information was the media (47%) or family (53%), and scored significantly higher than those who attributed their views about evolution primarily to their religion (i.e., 32%).

***Students' religiosity*.** Students whose views of evolution were based primarily on religion scored lower on the KEE than all other groups of students. This is consistent with reports elsewhere about the importance of religion in people's views of evolution (Barnes, Keilholtz, & Albertstadt, 2008). Students who described their religious views as conservative and middle-of-the-road scored significantly lower than those who described their views as liberal and those who said they were not religious. These results 1) are consistent with the report that students' views of evolution are strongly associated with their religious beliefs (Dagher & BouJaode, 1997), and 2) indicate that among entering college students, those who have conservative religious beliefs know less about evolution than do religiously liberal or non-religious students.

Students' perceptions and prior knowledge of a topic strongly influence students' learning about that topic. This is especially important for evolution, because many students perceive an "overlap of some ideas that the theory [of evolution] advocates with other social, epistemological, and religious beliefs" (Hakoyem & BouJaode, 2008). Indeed, many college students view the consequences of accepting evolution as negative and undesirable (e.g., as increased selfishness, increased racism, reduced spirituality, and a diminished sense of purpose and self-esteem; Brem, Ranney, & Schindel, 2003). Until the teaching of evolution improves in high schools, college instructors should expect large percentages of students to continue to question, reject, and misunderstand the topic.

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Teaching Evolution in the Galápagos

Katherine E. Bruce[1], Jennifer E. Horan, Patricia H. Kelley, Mark Galizio
University of North Carolina Wilmington, Wilmington, NC 28403

Abstract

Experiential learning can be an effective way to teach many concepts, and evolution is no exception. We describe the pedagogical techniques, class structure and learning objectives, travel logistics, and impact of three undergraduate honors-level experiential learning seminars that combined teaching topics related to evolution with a field trip to the Galápagos Islands. One class took place in Spring 2002 focusing on animal behavior, biodiversity, and evolution (13 students), and the other two were held in Spring 2009, with one seminar focusing on international environmental policymaking (3 students) and the other on how the natural history of the Galápagos influenced the development of Darwin's thought (7 students). Qualitative comments from students illustrate both short and long term impact of the class on learning about evolution.

Keywords: Evolution, Galápagos, experiential learning, honors curriculum.

Experiential learning has long been touted as an effective way to introduce students to and immerse them in a subject area, and is a hallmark of many honors-level courses (see, e.g., Braid & Long, 2000; Bruce, 2005; Harper, 2006; Machonis, 2008; Srikwerda, 2007). Using experiential learning to teach evolution can be particularly powerful. In this paper, we highlight three honors-level experiential learning seminars that combined teaching topics related to evolution with a field trip to the Galápagos Islands. One class took place in Spring 2002 with a semester focus on animal behavior, biodiversity, and evolution (13 students), and the other two took place in Spring 2009, with one seminar focusing on international environmental policymaking (3 students) and the other on how the natural history of the Galápagos influenced the development of Darwin's thought (7 students). The Spring 2009 seminars traveled together to the Galápagos, along with a group of 10 adult learners through the university's Continuing Studies program. We describe the three approaches to teaching about evolution in the Galápagos, highlight similarities and differences in course structure, compare the two visits to the Galápagos, and compare student comments and learning objectives.

Seminar Structure and Course Descriptions

All three classes were developed as honors enrichment/experiential learning seminars and students earned one hour of course credit. All were part of the UNCW Honors Scholars Program "International Splash" initiative that encourages short study abroad experiences

[1] Corresponding author's email: bruce@uncw.edu

to whet the students' appetites for more comprehensive international study. Other destinations have included locations such as Paris, Prague, Berlin, the Amazon, and southern Spain. Students from all majors enroll. The typical course format is to hold class for an hour a week during the first half of the semester, then travel during spring break to the related international destination as the capstone experience. Debriefing and follow-up presentations by students are held during the second half of the semester. However, the 2009 Galápagos trip was held in May at the end of the semester to facilitate travel scheduling.

The 2009 Honors Enrichment seminar, *The Shaping of Darwin: Geology and Biology of the Galápagos* (taught by PHK), examined the life and work of Darwin in relation to his visit to the Galápagos. In particular, the course focused on how the biology and geology of the Galápagos archipelago shaped Darwin's understanding of the evolutionary process. Readings were mainly from the primary literature, including Darwin's scientific predecessors and contemporaries (e.g., Cuvier, Lyell, Erasmus Darwin, and Lamarck). Darwin's writings are now available online at http://darwin-online.org.uk/ and students read several of Darwin's works: including the Galápagos sections of the *Beagle* diary and the *Voyage of the Beagle*, Notebook B: [Transmutation of species], and sections of the first edition of *Origin of Species*.

Students selected a taxon to research (Galápagos penguin, tortoises, finches, blue-footed booby, frigate bird, land and marine iguanas), gave a presentation to the class before the trip, and then served as a resource in the Galápagos. Finally, students produced journals based on their visit to the Galápagos using Darwin's work as a model – a field notebook (based on the model of the *Beagle* diary) and a more polished journal (akin to Darwin's *Voyage of the* Beagle) in which they elaborated on their field observations and reflected on their experience, comparing it with Darwin's experience of the Galápagos.

The 2009 Honors Enrichment Seminar, *Managing Evolution's Workshop: Global and Local Interests in Galápagos* (taught by JEH), examined how the various forces (domestic and international) interested in the Galápagos archipelago have shaped its management and conservation. We know that Darwin considered his voyage on the Beagle to have had a transformative impact on his life. It is equally evident that Darwin's visit had momentous consequences for the country of Ecuador and the Galápagos. Darwin's life, the publication of *On the Origin of Species,* and the subsequent development of science, generated the international interest in the archipelago that resulted in the international conservation effort. Although the first decades of the conservation effort were characterized by international support and benign neglect on the part of the Ecuadorian government, in the last two decades, tourism, a democratic transition and international fishing interests have emerged as key elements of the conservation effort. Thus, students examined the impact of each of these events from the international environmental policymaking perspective.

Course assignments included background readings on the Galápagos from both international and domestic political perspectives. In addition to Larson's *Evolution's Workshop: God and Science in the Galápagos Islands,* students read two key reports: *Galápagos at*

Risk produced by the Charles Darwin Research Station and *An Analysis of Nature Tourism in Galápagos* by McFarland. These reports focus on the contemporary pressures confronting the archipelago and provide discussions of various options for continued high quality conservation. Additional background material on the Ecuadorian political system and Galápagos' place in the same, as well as information on exactly what "eco" or "nature" tourism is, were provided via lectures.

Each student selected a park or marine reserve management issue to pursue in greater depth for a classroom presentation. Similar to the other seminar, the students kept a journal in which they chronicled their observations about conservation rules and how they were observed by the officials and local residents.

Faculty leading the 2009 seminars also produced a guidebook summarizing the material studied in each course; this served as a resource not only for the Continuing Studies participants but also for students in the other seminar. Further, both 2009 seminars were part of the UNCW Evolution Learning Community- a campus- and community-wide celebration of the 200th anniversary of Darwin's birth and the sesquicentennial anniversary of the publication of *Origin of Species*[2]. The students had the opportunity to attend lectures by noted Darwin Scholars throughout the semester, including Eugenie Scott, David Buss, Peter Carruthers, Kevin Padian, David Quammen, and David Mindell.

The 2002 Honors Enrichment seminar, *Galápagos: Exploring Evolution* (taught by KEB and MG), centered around the study of the animal life of the Galápagos with attention to island biogeography, behavioral ecology and current examples of evolution. After going over the basics of evolutionary terminology, we assigned two longer readings for discussion over the next few class meetings- Weiner's *Beak of the Finch*, and a section on the Galápagos and island biogeography from Quammen's *Song of the Dodo*. We also viewed and discussed the film companion to *Beak of the Finch*—"What Darwin Never Saw", which highlights the Grants' research on observable evidence of natural selection in the medium ground finch on Daphne Minor. Similar to the other seminars, students chose and researched different species (e.g., lava lizard, marine iguanas, Galápagos penguins, Galápagos tortoises, waved albatross, finches, mockingbirds, boobies, fur seals, and introduced mammals), presented mini field guides to the class before the trip, and served as the "experts" on the species on the trip. Students also kept journals in the Galápagos--part field notes and part personal reflections.

A highlight during the semester was having noted author and nature-writer David Quammen as a featured speaker on campus; the students were able to spend time talking with him informally after his lecture. At the end of the semester, we gathered to share photos and journal entries over an Ecuadorian pot-luck dinner.

[2] http://library.uncw.edu/web/outreach/evolution/index.html

Itineraries

2009 Island-Based Tour

The visit began with a tour of the capital city of Quito. During the tour group members witnessed a common political event, a protest, outside the Presidential Palace. The next day we traveled two hours north to the indigenous community of Otavalo. In our trip through the Ecuadorian countryside, all group members saw the development process, examples of land invasions, examples of incomplete home construction, as well as the various types of national industry. All of these factors provided the background to understanding the context of the management challenges in Galápagos, which include mainland problems with access to land and jobs in a predominantly agricultural economy.

The combination of high population density and land pressure has resulted in migration to the Galápagos in search of tourism-related jobs, which has led to a population explosion. In the 1990s this population growth was also driven by the international fishing industry interest in sea cucumber. Although that fishery is largely depleted, fishing interests have focused on other species for extraction and park, research station and national government officials have increased efforts to divert employment away from marine reserve extraction to tourism. Because the tourism industry has long been foreign-dominated, officials are now promoting what they call a domestically-sustainable model that puts tourism revenues in the hands of Ecuadorians. This means more island-based tours with day trips.

The island of Santa Cruz served as the base for the Galápagos visit, from which day cruises were taken to Floreana and Isabela, as well as to smaller islands for bird-watching (e.g., Daphne Major, Enderby). Exploration of Santa Cruz included the highlands (the Primicias tortoise reserve and volcanic features such as craters and a lava tunnel), as well as Bachas Beach with its marine iguana population. A brief visit was also made to the Charles Darwin Research Station to observe the tortoise breeding program. Floreana offered the giant tortoise reserve and highland springs and caves. On Isabela, a hike to Sierra Negra volcano yielded spectacular views of the caldera. Each day trip also provided opportunities for snorkeling, including deep-water snorkeling in an area frequented by sea lions.

The itinerary thus enabled students in the *Shaping of Darwin* seminar to observe the geology and recognize the role of plate tectonics in creating "evolution's workshop" in the Galápagos. Students were excited to witness the organisms they had researched and to make observations of the fauna and flora similar to those made by Darwin in the *Beagle* diary and *Voyage of the* Beagle. Such experiences allowed them to consider the role of the Galápagos in the development of Darwin's thought.

Students in the *Managing Evolution's Workshop* seminar had the opportunity to discuss park rules and regulations with the tour operator, the naturalist guides, and members of the Galápagos community. Through their experiences during the tours and after hours

around Puerto Ayora, they confirmed and discovered new aspects of the status of the management model and the conservation process.
Each evening at dinner there was a discussion of what students had learned from their tour guides, the boat operators, or locals they had encountered. In addition during the tours and at dinner, the Continuing Studies participants in the tour frequently made use of the student resource persons.

2002 Boat-based tour

As most flights to Ecuador arrive late in the evening, the day following arrival in Quito was scheduled for an introduction to South American bird life. This involved an early morning drive into the Andean forest exploring West Slope cloudforest sites of Mindo and Bellavista. The incredible biodiversity of this region stands in marked contrast to the relative paucity of species in the Galápagos; indeed we recorded more bird species in a single morning in the cloudforest than we were to see during the entire week in the islands. This contrast set the stage for a deeper understanding of the principles of island biogeography that were course themes.

Figure 1. Students and faculty disembark from the panga and try to avoid stepping on sea lions at Isla Lobos, Galápagos.

We boarded our economy-class boat for our six-night cruise after an early morning flight to the island of Baltra, and by early afternoon were hiking on South Plaza Island. Life on the boat generally involved cruising to the next site at night so that we woke up at the day's destination. Morning hikes were following by mid-day snorkeling (sometimes with penguins or sea lions) and then a brief cruise to a second site for an afternoon hike. Evenings were spent debriefing the day's sightings under the stars; highlights each night were the construction of a bird, mammal and fish list by the group and discussion of the significance of what we had seen. The on-board presence of an Ecuadorian park guide enhanced the value of experience by providing a cultural window, as well as through his expertise as naturalist and the local crew gave us additional perspective.

Our itinerary included South Plaza, San Cristobal, Espanola, Floreana, Santa Cruz, Bartoleme and North Seymour Islands—completing a more-or-less clockwise route from Baltra. By visiting these and numerous smaller islands we were able to observe most of Darwin's finches and all four of the endemic mockingbirds that were perhaps even more crucial to Darwin's thinking than the more famous finches, as each is recognizably like the mainland mockingbird, yet quite distinctive.

Figure 2. Students and faculty enjoy the view from the summit of Bartoleme Island, Galápagos.

On South Plaza Island we had our first views of land iguana and aerial views of red-tailed tropicbirds, swallow-tailed gulls and the ubiquitous frigate birds. San Cristobal allowed us to see two of the three booby species at Punta Pitt (masked and blue-footed), the sea lion colony on Isla Lobos, and the spectacular Kicker Rock. Espanola provided good looks at marine iguanas, Galápagos hawks, and the Hood mockingbird. In addition to Floreana, we visited nearby Champion Island to see the Charles mockingbird. While we did not go to Isabela, Bartoleme afforded impressive views of Pinnacle Rock and an introduction to the more vulcanized geology characteristic of the western islands.

In the middle of the week, we anchored at Puerto Ayora on Santa Cruz, and spent a day touring the Charles Darwin Research Center. The students also had a chance to spend an evening in the city and meet local residents, similar to the 2009 experience.

The six-night cruise allowed us to see most of the endemic Galápagos species and to closely observe and consider many of the clues that influenced Darwin's thinking. Returning to Quito, we toured the colonial city, and then had a memorable dinner at a traditional restaurant

Figure 3. UNCW students approach Kicker Rock, Galápagos.

Figure 4. Students, adult learners, and faculty enjoy the ride between islands in the Galápagos, encountering dolphins.

Figure 5. Students and a tortoise at the Charles Darwin Research Center on Santa Cruz Island, Galápagos.

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Figure 6. Students, community members and faculty watch giant tortoises roaming freely on Santa Cruz Island, Galápagos.

Learning Objectives and Student Responses

Instruments

In addition to a standard open-ended response instrument used to record student comments about the class, the 2009 seminar instructors designed a survey to administer on the flight home. Questions were identical for the two seminars except for one question geared specifically for each seminar topic. The 2002 seminar instructors utilized the open-ended feedback instrument only, but added comments from three students seven years later.

2009 Seminars

The learning objectives for the *Managing Evolution's Workshop* course were to develop an understanding of the process of international environmental policy-making, evaluate the impact of scientists on domestic political environments, and understand the obstacles to conservation in the Galápagos. For the *Shaping of Darwin* course, objectives were to understand the scientific and social context of the development of Darwin's ideas, compare Darwin's views on evolution with those of his predecessors, analyze the development of Darwin's thought as revealed in his writings, evaluate the factors influencing the development of Darwin's thought, particularly the role of his visit to the Galápagos, and reflect on Darwin's influence on science and culture.

How well did the travel experience relate to the topics covered in class? Most students noted the strong relation between the travel experience and the topics covered in the class. In some cases, they offered suggestions. Comments included:

- Our class covered mainly the political science of the Galápagos and Ecuador's involvement. The travel experience allowed me to see the management issues that we discussed in class and what "sustainable tourism" implies. However, the experience didn't really relate to the solutions to the issues and all the groups interested in exploiting, profiting or managing the islands.
- The topics covered in class such as information about geological and evolutionary theory wonderfully overlapped with our tour of the Galápagos. The readings of Darwin's essays and journals gave us the chance to witness the things personally described by Darwin.
- I think it related really well to all of the stuff we read by Darwin. I was able to pick up on many of the same characteristics and observations as he wrote about as well as seeing the immense diversity of organisms on the island.
- In-class discussion focused on the shaping of evolutionary thought, but the Galápagos trip focused more on observing the fauna than on discussing its evolution.

What did you expect to get out of this trip and were your expectations fulfilled? Most comments were very positive- "an experience to remember" and "my expectations were far exceeded." Some suggestions were also mentioned:

- I expected to learn about a foreign culture, get up close to the nature of the Galápagos and learn more about the conservation. I didn't learn much about conservation/management but my expectations were more than fulfilled in terms of culture and nature, especially marine life/shore animals.
- I was expecting to have a wonderful experience being in a foreign country, witnessing a different culture, and seeing a unique flora and fauna that I may never be able to see again. Although I, and others, became ill during the trip, my expectations were more than fulfilled.
- The time we spent in the Galápagos was amazing, but there was so much that we did not see and I would have liked to of spent more time in the Galápagos and less time on the mainland.
- I expected to enjoy the trip and continue to learn about the Galápagos. Both of these were fulfilled. However, I was also expecting to discuss a little more about Darwin while we were down there, which we did not do.

What experiences did you find most memorable? What might be the long-term impact of this trip, for you personally? All students mentioned interacting with the animal life, particularly the marine mammals (snorkeling with sea lions, having a large group of dolphins swim with our boat).

- Riding in the front of the boat with the dolphins and swimming with the sea lions. This trip has reminded me how beautiful nature can be when it's unspoiled and given me more drive to want to work to conserve these animals.
- It enhanced my interest in marine biology and may have an impact on my future plans.
- One thing I did not expect was how much I bonded with the other students on this trip. I hope we all stay in touch. I won't forget this trip and all the people who were with me. It was (also) very refreshing to experience a new culture.
- I also learned a lot not just from being in a new place but experiencing all new things with people who were strangers a week ago but are now [my] friends. Hearing other people's ideas and thoughts was really mind opening and realizing I can have so much in common with people who are so different from me was really the most lasting impact on me, as well as taking in true natural beauty of the world and how well it can work in harmony as one.

How well did the travel experience enhance your knowledge of the current management problems in the Galápagos National Park and Marine Reserve?

- The travel experience allowed me to see firsthand the management problems that exist, mostly from tourism, and the issues that Ecuadorians need to address.

How well did the travel experience enhance your knowledge of how Darwin's ideas were shaped by the Galápagos?

- Really well, it made me have a deeper appreciation for his inferences because while after having all the facts it is easy to conclude with natural selection but vis-

iting Galápagos made me see how difficult it must have been to pick out all the right and relevant information.
- Actually observing differences among the tortoises helped me see the role of natural selection.
- It is hard to make the connection to the shaping of Darwin's ideas when many of the plants, especially, and to some extent the animals that we saw are not native of the Galápagos. [commenting on the large number of recently introduced species]

Thus, the survey results for both sections of the 2009 seminars indicated that the travel component clearly enhanced the overall learning experience of the course, both intellectually and in terms of broadening student perspectives. Student comments suggest that these gains will be long-term. A few comments indicated that more deliberate review during the trip of the material covered during the semester (e.g., on evolution and the evolution of Darwin's thought) would have been helpful. Such discussions were held with individual participants or in small groups, but the opportunities for group discussion were hampered by having to divide participants into two groups based on the limited capacity of the boats used for day trips. Some "recapping" of daily experiences was done at meals, but the large size of the group made it difficult to include all participants in these discussions. In addition, 21 of 22 participants were sick by trip's end, hindering the "wrap-up" activities. Had it been possible to make the trip before the end of the semester, such a review would have been built into the course.

2002 seminar

Learning objectives for the animal behavior and evolution seminar were to understand basic concepts of evolution, especially adaptive radiation, biodiversity, and ecological niche, with an appreciation for current examples of natural selection in process. Similar positive responses were made by students in the 2002 seminar on the open-ended feedback instrument. All but one student commented that the class met their expectations; this student did not like keeping a journal and thought the workload was too heavy. All the other students noted that the assignments and readings complemented the visit to the Galápagos, and allowed them to express what they learned in class. As above, several noted that this was the "trip of a lifetime." One student recommended that additional class time be allotted for reviewing travel guides (several were recommended to the students), and one suggested scheduling a hike to practice using binoculars before future trips. Other particular comments and insights are included below, and reflect the positive experience of experiential learning and the benefits of travel to another country.

- It was great to see the evolution we learned about in class in a first-hand situation.
- I would recommend this course to everyone; the style of learning can not be duplicated in a classroom.
- The workload for the class was just right. It was challenging in the sense that the more knowledge you gained [before the visit], the more beneficial the trip to Ecuador was [for you].
- The experience I gained by seeing what life is like outside the U.S. is priceless.

- This course challenged me to learn about a place very different from what I know. In learning about the Galápagos, I unexpectedly learned a great deal about myself and my country.

Long-term impact

We (MG and KEB) contacted three students who traveled on the 2002 trip to ask about long-term impact of the class. While majors of the students in the class ranged from biology, psychology, and geology to education and business, we were able to contact only three students who are currently in doctoral programs in biology. While clearly not a representative sample, the comments from these students are revealing.

Thoughts about experiential learning

- I feel like I never truly understood endemism and how special it is until visiting the Galápagos. The fact that these animals strutted in our path made it even better. I did not have to hunt to find the elusive blue-footed booby, I had to side-step it on the trail. I loved the fact that I had to step over sea lions during hikes…The thought of the trip, even though it was more than 7 years ago, brings a smile to my face to this day.
- One of my favorite parts of the trip was the nightly "list-making" sessions. I loved spending time every evening listing the birds, mammals, fish, reptiles, etc. that we saw each day. I still have my journal and animal list … at my parents' house and I read it nearly every time I visit. I loved that trip and throughout all of my travels have never come close to experiencing a better outdoor classroom.
- The trip to Galápagos was more than a once in a lifetime experience. It was a chance to see first-hand everything that we had read about in texts in action. I had always dreamed of being able to see the famous tortoises, mockingbirds, and finches, but honestly didn't think that was something that could become reality.
- And talk about active learning--going to the Galápagos Islands to see where Darwin first imagined the concept of evolution, seeing the animals he saw, witnessing first-hand the differences in finch beaks and the incredible adaptations (and fearlessness) of island animals is as active as you can get! Before the trip, we all specialized in a particular area, becoming experts and teaching our peers. The upcoming trip made us especially eager to learn all that we could…On the trip, our prior knowledge allowed us to observe not as tourists, but as scientists. We asked more informed questions and understood more fully the differences between the islands when we were there than any tourist could, and we took our understanding of evolution to a [higher] level.

Relation to other Academic Experiences

- I read *Beak of the Finch* for the first time in your class (and have since re-read it twice for other courses). What we got to do that I believe was truly unique was to read this book and then go to the islands and see the finches. Though I regret that I was not the birder then that I am today, I felt so connected to …the process of evolution as we looked at …the finches on the various islands. Seeing Daphne Minor and knowing the great science that occurred on that tiny island… I will never forget that sensation. Last year I heard Rosemary Grant speak [at a conference] and felt so close to her work…like I had been there all along, measuring beaks or avoiding giving water to thirsty birds in times of drought. I think I was able to feel so close to her talk because I had been to the islands and seen "her" finches. When she showed pictures, I felt my chest puff out a little as in "Ah yes, I too have seen that."

- The course started and expanded my deep interest in evolution, natural selection and sexual selection. I have seen things that many other scientists have never experienced because I saw what nature can do when left to its own devices. Since taking the course I have read many books on natural and sexual selection and Darwin. Every time I read about the iguanas or boobies or tortoises I feel truly lucky that I have seen those things with my own eyes. It is one thing to read about a frigate bird's mating display in a book, it is another to see an island with bushes "bleeding" with the red throats of displaying males so rowdy you can barely hear yourself think.
- Since I was young, I knew that I wanted to become a scientist, but in a way that trip opened my eyes to the many possibilities that I could pursue for a research career. I went from studying fish behavior as an undergraduate to behavioral resistances to disease in honeybees in graduate school. I could've gone to any number things, and it was the experience in Galápagos that gave me that insight. I started thinking more outside of my niche and became more interested in a variety of organisms and systems.
- As a PhD student, I am now a behavioral ecologist … a field that draws strongly from evolutionary biology. I have also taken several courses and been involved in several other efforts to better train graduate students in teaching pedagogy and bringing creativity into the college classroom. As I explore both of these fields of interest, I constantly call back on my experiences from my honors seminar that taught evolutionary biology with the capstone experience of traveling to the Galápagos Islands. In fact, this early experience during my sophomore year of college contributed very strongly to my decision to pursue animal behavior and evolutionary biology further, both as an undergraduate and now as a PhD student.
- … This trip … made me dedicated to offering similar experiences for my future undergraduate students when I am a professor.

Importance of Study Abroad

- The trip to the Galápagos was my first experience abroad, the first stamp in my passport. Since then I have been bitten by the travel bug and go everywhere I can afford to go.
- Traveling abroad gave me a greater perspective in my education that I likely wouldn't have been able to achieve otherwise.

Advice

Traveling with students is a gift. However, as can happen with any trip, unexpected situations arise. Participants in each of the seminars experienced unforeseen illnesses and lost passports. The value of scheduling a lay-over in Quito was brought home when one of the students lost her passport and was forced to remain in Miami with one of the group leaders. The passport was recovered and both flew into Quito the next day in time for the Galápagos flight. One of the 2002 participants recounted that she has taken this to heart:

- I carry thoughts of that trip and the lessons I learned with me in my daily life--lessons which also include keeping track of my passport, not eating things I am allergic to, always carrying Dramamine, and not jumping off of a ship with my snorkel in my hand.

Conclusions

The experiential learning component of these seminars, the visit to the Galápagos, was clearly the capstone for the classes. As many of the students commented, while they had read a good bit about evolution, actually seeing the animals, flora, and geology of the islands made the concepts come alive. In all seminars, the students commented that their prior research of the fauna or the park system added depth to their visit to the Galápagos. It is noteworthy that students in all seminars represented a variety of majors. Further, the faculty represented three different disciplines, and each was able to connect discipline topics to the teaching of evolution and its impact on biology, animal behavior, geology, and politics. An important innovation in the 2009 seminars was the inclusion of adult scholars from various walks of life. Their presence underscored the importance of life-long learning to the college students, while offering richness to the discussions that took place on the trip.

While the value of using travel and experiential learning as a foundation for evolution-related classes is evident, the same model can be used effectively for teaching other topics as well. Still, the unique experience of walking the Galápagos Islands in the footsteps of Charles Darwin offers a perspective that is unsurpassed.

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A College Honors Seminar on Evolution and Intelligent Design: Successes and Challenges

Patricia H. Kelley[1]
University of North Carolina Wilmington, Wilmington, NC 28403

Abstract

College honors courses provide an opportunity to tackle controversial topics in an atmosphere that encourages active learning, critical thinking, and open discussion. This venue is particularly appropriate for examining the debate about teaching intelligent design (ID) in public school science classes. A one-credit honors enrichment seminar taught at the University of North Carolina Wilmington provides a model, with associated successes and challenges, for addressing the controversy. This interdisciplinary course consisted primarily of discussions based on a set of weekly readings that presented contrasting viewpoints on evolution and naturalism, ID, theology, and educational issues. In preparation for each class, students constructed charts contrasting the views of each writer on key points presented in the readings and summarizing their own responses. Discussion focused on a set of questions arising from the readings and designed to provoke debate. The *Kitzmiller v. Dover* decision served as a final case study; each student prepared a final paper defending or criticizing Judge Jones' decision in the Dover court case. Prior to the course, some students had not heard of ID and many had limited knowledge of evolution. The course improved student knowledge of evolution, ID, and the issues involved in the controversy, preparing them to make informed political decisions. Challenges included the uneven level of knowledge about evolution among students in this non-science course and the time constraints of a 1-credit course. In addition, because I had decided to serve as a facilitator and not press my opinions, misconceptions were more difficult to correct, although the variety of disciplines represented by the students allowed them to correct one another.

Keywords: Intelligent Design, evolution, honors course, pedagogy.

College honors courses provide the opportunity to step outside the typical curriculum to explore interdisciplinary areas or controversial topics. This venue is particularly appropriate for addressing the current societal debate surrounding the teaching of "Intelligent Design" (ID) as an alternative to evolution in public school science classes. Intelligent design is the concept that life forms are too complex to have developed through natural processes of evolution and instead began abruptly through an intelligent agency (see Scott, 2004, for a concise summary of the main ID arguments).

The modern intelligent design (ID) movement developed in the mid-1980s (Numbers, 1998) and gained strength after the *Edwards v. Aguillard* Supreme Court decision ruled

[1] Corresponding author's email: kelleyp@uncw.edu

unconstitutional the Louisiana law requiring balanced treatment of "creation-science" and "evolution-science." ID attempts to escape issues of constitutionality by not overtly mentioning the activities of a creator, but instead attributing Earth's life forms to an unspecified intelligent agent. However, in the recent *Kitzmiller et al. v. Dover Area School District* decision (Jones, 2005), ID was judged to be religious rather than scientific. Judge Jones's decision stated, "the writings of leading ID proponents reveal that the designer postulated by their argument is the God of Christianity" (Jones, 2005, p. 25-26) and expert witnesses for ID made it clear that the designer is supernatural and thus outside the realm of science. ID was also judged not to be science because it has "failed to publish in peer-reviewed journals, engage in research and testing, and gain acceptance in the scientific community" (Jones, 2005, p. 89). The court also found that the primary argument for ID, Michael Behe's concept of irreducible complexity (Behe, 1996) "has been refuted in peer-reviewed research papers and has been rejected by the scientific community at large…. Additionally, even if irreducible complexity had not been rejected, it still does not support ID as it is merely a test for evolution, not design" (Jones, 2005, p. 79). The court also recognized that arguments against evolution have been countered by the scientific community, but even if they were valid, they would not support ID because the two are not mutually exclusive (or the only) alternatives.

Despite the defeat of Intelligent Design in the Dover case, proposals to include ID in public school science classrooms as an alternative to evolution continue to be argued at local and state levels (Branch and Scott, 2009). Thus courses addressing the scientific, religious, philosophical, educational, and political issues surrounding the ID/evolution controversy remain relevant. In this paper, I describe a one-credit honors enrichment seminar that was taught at the University of North Carolina Wilmington in Spring 2006, immediately following the *Kitzmiller v. Dover* decision (Jones, 2005). The course provides a model, with associated successes and challenges, for teaching about the controversy.

Pedagogical Principles

An honors course is particularly appropriate for addressing the issues surrounding the debate about teaching Intelligent Design in the public schools because of the pedagogical approaches typically involved in honors courses. According to West (2000), the goals of an honors education include developing the abilities of students to reason, express themselves in speech and writing, and to collaborate as well as to work independently. This honors enrichment seminar was designed to further these goals. In addition, an honors education should develop students' capacity to "commit to a position, recognize that it may change, and tolerate uncertainty and ambiguity" (West, 2000, p. 3). These goals are particularly appropriate to the controversial subject matter of this course.

The UNCW Honors Scholars Faculty Handbook[2] encourages faculty to develop courses that "have less lecturing and predigesting of material by faculty; make more use of primary sources and original documents; encourage critical thinking and independent scholarship; … focus on open discussion; follow a colloquium or seminar format; allow pro-

[2] http://www.uncw.edu/honors/facultyHandbook.htm

fessors and students to take risks." These goals are consistent with educational research that indicates that students learn best by doing, e.g. through active learning and collaborative learning rather than formal class lectures (Donavan et al., 1999). Thus this course used a minimum of lecturing, focused on readings from primary sources, and was based on small- and large-group discussions of controversial questions.

Course Design

In Spring 2006 I developed and taught a course entitled "Intelligent Design: An alternative to evolution?" The course was a one-credit honors enrichment seminar; honors students at UNCW are required to complete two such courses, which include a component of participation in campus events outside the classroom. Such courses bear the "HON" prefix rather than a disciplinary designation and are often interdisciplinary. The course enrolled 18 honors students, including 6 freshmen, 10 sophomores, one junior and one senior (honors students at any level may take the enrichment seminars, though many elect to complete this requirement as freshmen and sophomores). Honors enrichment seminars at UNCW have no prerequisites other than formal enrollment in the Honors Scholars Program. The students represented a diverse range of fields as follows: business - 5 students; education - 1 student; nursing - 1 student; humanities - 4 students; social sciences - 4 students; natural sciences - 3 students. In addition, two geology graduate students who were interested in the topic attended class and completed the assignments but did not participate in class discussion, in order to prevent altering the experience for the honors students (they registered for a Directed Individual Studies graduate course).

We met once a week for 70 minutes for ten weeks. The initial class meeting set the tone for the course. Participants were asked to share their interest in the topic and their stance on Intelligent Design. I began by sharing my perspective (a paleontologist whose research focuses on evolution; a person of faith and minister's wife who finds no conflict between faith and evolution; Kelley, 2000, 2009). Students were then invited to share their perspectives. Most were curious about ID and knew it was a national news item; about half the class was sympathetic towards the teaching of ID and a third had not yet made up their minds. A minority of four students opposed the teaching of ID in public school science classes. The first session was also used to establish ground rules of tolerance and respect within the course; all students were encouraged to speak their opinions freely, and were reassured that no one would be criticized (or graded negatively) for expressing his/her opinion.

The first session concluded with a hands-on exercise on the nature of science. In keeping with the goal that honors courses should foster collaboration, students worked together to categorize a set of statements (Appendix A) as either "science," "religion," or "something else." (These statements were ones I had composed and had used successfully in my geology courses that consider the nature of science. Some statements come from my paleontology background; some have a local flavor; they also reflect the largely Judeo-Christian background shared by most of my students. The list could easily be adapted by other instructors to fit their particular situations, reflect other student demographics, or incorporate other fields of study.) We then discussed the criteria that students used to classify statements. This exercise was used to reinforce the idea that science involves the study of the natural world, that it consists of a set of tightly integrated facts and theories, and that the explanations of science must be natural (because science consists of hypothesis testing and only natural explanations are testable). Students then worked together to categorize each statement as either “fact,” “theory,” or “something else.” This exercise led to discussion of how terms such as “fact,” “hypothesis,” and “theory” are used in science (e.g., “theory” as a well-tested, repeatedly confirmed explanation rather than a guess, as used in the vernacular).

Week two included the only lecture of the semester. Because students varied widely in their educational background and thus their understanding of evolution, I felt that a lecture was the most efficient means of bringing all students to a basic understanding of what evolution is. In this lecture, I discussed three different meanings of the term evolution (Thomson, 1982): 1) change in life through time (which can be considered a fact) and the evidence for it; 2) descent with modification (a very strong theory that has been repeatedly tested and confirmed) and the evidence for it; and 3) the process of evolution, especially what is mean by natural selection and how it works (also theory).

The next seven weeks of the course involved discussion of weekly readings from an anthology of primary sources (Pennock, 2001). Pennock’s book, *Intelligent Design Creationism and Its Critics: Philosophical, Theological and Scientific Perspectives,* is a compilation of writings with opposing views, written by many of the key figures in the ID debates. Pennock’s book was selected for its in-depth coverage of the key philosophical, religious, scientific, educational, and political issues involved in the ID debate. We focused on four main topics: 1) evolution and naturalism; 2) Intelligent Design (irreducible complexity and information theory); 3) theological perspectives; and 4) educational issues. Table 1 lists the topics covered and the authors whose readings from Pennock’s book were used.

Each week, prior to class, students (and I) independently completed comparison charts in which they listed the key points of the readings, contrasted the opposing views of the writers on those points, and noted their own response to those views. (Because this course received only one semester-hour of credit, this approach was more appropriate than requiring more time-consuming weekly essays.) Comparison charts were graded based on thoroughness and analytical insight, rather than on the opinions expressed; the charts represented 50% of their grade. Consistent with the expected pedagogy for Honors courses, the class followed a seminar format; class participation represented 20% of their grade. The first 20 minutes consisted of small-group discussion to encourage students who were less comfortable in large-group settings to express their thoughts. During the small-group (3 - 4 students) discussion, students expressed initial reactions to the readings and the time was used to resolve any points of confusion concerning the readings. Because of the breadth of disciplines represented, students were able to assist one another in resolving questions (e.g., science students helped classmates with scientific concepts; philosophy and religion students assisted in understanding theological and philosophical arguments). I migrated among groups to assist as needed and to observe the student interactions. The remainder of the period was spent discussing as a class a set of questions

Table 1. Topics discussed, authors read for each topic, and questions posed for class discussion in Honors enrichment course on Intelligent Design

Topic	Authors read	Discussion questions
Evolution and naturalism	Johnson vs. Pennock	• Does science require ontological naturalism or only methodological naturalism? • Is evolution based on a philosophical assumption rather than evidence? • Is Darwinism incompatible with belief in God? • If evolution by natural selection is wrong, is creationism right?
Evolution and naturalism	Plantinga vs. Ruse	• Are religion and science inherently conflicting? • How should science be defined? • Should miracles be allowed in science? • Should faith be used to evaluate science?
Intelligent Design: irreducible complexity	Behe vs. Kitcher	• How strong is Behe's argument that "irreducible complexity" requires ID? • Are supernatural explanations acceptable in science for unexplainable phenomena? • Should ID be required to explain how design would be carried out? • To what degree should ID allow evolutionary processes?
Intelligent Design and Information	Dembski vs. Godfrey-Smith	• Which is the better argument for ID, irreducible complexity or information theory? • Do you agree that natural causes can't increase "complex specified information"? • What is meant by "chance," and what is its role in evolution?
Theological perspectives	Plantinga, Van Till, and McMullen	• Is conflict or cooperation a more appropriate metaphor for science and religion? • Should science and scripture correct each other? • Is evolution religiously neutral? • Does scripture demand rejection of evolution?
Theological perspectives	Johnson, Murphy, and Peacocke	• Are theism and naturalism incompatible? • If there is a God who is active in the world, is it through the natural order or by supernatural miracles? • What are the roles of chance and law in how life has come to be the way it is?
Educational and political issues	Pennock vs. Plantinga	• Is ID a type of creationism? • If creationism were taught in public schools, would it help or harm religion? • Should we avoid teaching subjects that might contradict someone's religious beliefs? • If creationism were taught, which version should be taught? • Does the constitution protect or prohibit teaching of creationism in schools?

that I developed relating to the readings. Questions were specifically designed to provoke debate (see Table 1 for examples). I moderated the class discussion but deliberately refrained from injecting my own opinion into the discussion in order to maintain a neutral environment.

The *Kitzmiller et al. v. Dover Area School District* decision, published just a month before the class commenced (Jones, 2005), served as a case study to conclude the course. This approach allowed students to synthesize the ideas they had been developing throughout the semester and apply them to an actual legal case. Students read Judge Jones' 139-page decision and were encouraged to read a white paper on ID by Lofaso (2005). The final week's discussion focused on the court case; students also wrote a final essay answering the question "Do you agree with Judge Jones' decision? Why or why not?" This paper represented 30% of their grade. Students were given latitude in terms of their approach to the question, but they were expected to reflect on the decision in the context of the assigned course readings. Grading was based not on the opinion expressed but on the quality and thoughtfulness of the argument, the understanding of the constitutionality issues involved, and the degree to which the essay was informed by the semester's readings.

The honors experience was also enhanced by a visit to campus by philosopher of science Michael Ruse, sponsored by the UNCW Honors Scholars Program. In keeping with the expectation that honors enrichment seminars involve experiences outside the classroom, students in the class met with him for a question and answer period, attended his public lecture, and also had dinner with him. Students had read Ruse's article in the Pennock anthology at the beginning of the semester and benefited greatly from the opportunity to meet him and discuss questions arising from his work.

Outcomes, Successes and Challenges

The approach taken in this course was successful in informing students about the issues involved in the debate about teaching ID, and in enabling them to make an informed decision on the topic (Table 2). This assessment is based on their statements in class discussion, the comments included in their weekly comparison charts, and especially on their statements in the final paper.

Table2. Views of students in Honors course on Intelligent Design concerning teaching Intelligent Design in public school science classes.

Time in Semester	Number of students in class supporting, opposing or undecided about teaching of ID		
	Supporting ID	Opposing ID	Undecided
Start of Course	8	4	6
End of Course	2*	16	0

* one of these students proposed teaching ID in a required origins course rather than a science class

At the beginning of the course, a third of the students knew too little about ID and the issues involved in the public controversy to be able to take a position. For instance, one commented in the final paper:

> When I walked into the Honors Seminar Intelligent Design course on the first day, I had no idea where I stood on the intelligent design vs. evolution debate. I had signed up for this course in a desperate attempt to figure out what was going on.

By the end of the course, all 18 students had reached a decision on the appropriateness of teaching ID in public school science classes. Sixteen of 18 students concluded that Judge Jones had made the correct decision, though some of these students remained sympathetic to ID. One paper commented, "While I agree with Judge Jones' decision, I am pulling for the defense to regroup and fight on." Another stated, "I personally feel there is validity to the argument of intelligent design, but at this time see no appropriate way to include in a high school science classroom." In the final class discussion, several students expressed a desire to include ID somewhere in the curriculum (e.g., as an elective course or in a social science course) but stated it should be excluded from science classes.

Based on student comments during discussions and in the papers, at the conclusion of the course students better understood: 1) the difference between science and religion; 2) what evolution is and how it works; 3) ID and the arguments for and against it; 4) philosophical, theological, scientific, educational and political issues involved in the ID controversy. They were also better prepared to make informed political decisions about the teaching of ID in public school science classes. The following comments in student final papers indicate the course accomplished the above objectives:

- "Before taking this class, I was unsure of where I stood in the evolution vs. creationism debate. After learning all of the aspects of each side, I am now able to take a stance."
- "Reading and comparing excerpts from different authors with opposing ideas not only helped me to find my own beliefs on creation and evolution, but also helped cultivate a more discerning method of learning crucial to any successful scholar."
- "In this class I have been able to fully evaluate where I stand on the subject of evolution versus creationism. The readings and discussions throughout the course of the semester have been a big help in allowing me to reach my conclusion."

One of the more vocal students added a personal note: "I just wanted to thank you for everything. I enjoyed the manner that you taught the class and that not only allowed for significant debate on the various subjects, but also that you put up with me!"

A course such as the one described is not without challenges for the instructor. Students ranged from freshman to senior level, and represented a great diversity of disciplines; only three were interested in pursuing degrees in the natural sciences (biology, chemistry, and geology). Thus students had a very uneven level of knowledge about evolution, which was not entirely ameliorated by the one lecture I gave on the topic. Constraints were also imposed by the time available; the course would adapt well to a two- or three-credit hour setting, which would enable more thorough coverage of all topics, including providing a firmer foundation on the topic of evolution. Because I chose to take the role of discussion facilitator, with minimal lecturing, it was difficult to correct misconceptions. However, the diversity of student backgrounds allowed students to correct one another (e.g., science students could correct other students' misconceptions in scientific areas). Indeed, the students may have learned more from correcting and being corrected by each other than if I had taken a more traditional role in this course.

Conclusions

This honors enrichment seminar provided an appropriate venue for examining the debate about teaching intelligent design (ID) in public school science classes while fulfilling the goals typically recognized for honors courses. A seminar format in which students read and discussed contrasting views on the topic succeeded in informing students about the issues involved in the debate about teaching ID, and in enabling them to make an informed decision on the topic.

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Appendix A: Statements classified by Honors students as "science," "religion," or "something else," and as "fact," "theory," or "something else."

1. Jesus will return on January 1, 2007.
2. The Civil War was fought to put an end to slavery.
3. An atom is made of protons, neutrons, and electrons.
4. Igneous rocks form by cooling of magma.
5. The South Brunswick High School Cougars are the best men's soccer team in North Carolina.
6. Birds are the descendants of dinosaurs.
7. Jesus died for our sins.
8. Ice ages occur during cold phases in cycles of the Earth's orbit, axial tilt, and the precession of the equinoxes.
9. Extinction of the dinosaurs was caused by the impact of a large asteroid.
10. The Grand Canyon was dug by 40,000 angels.
11. There are more Episcopalians than Presbyterians in this room.
12. God created the Earth.
13. Life has changed through time.
14. Human destiny is controlled by our astrological signs.
15. Toyotas are better vehicles than Chevys.
16. The Bible is the word of God.
17. The sea covered this area 2 million years ago.
18. There is one God and Allah is His name.

19. The Earth is about 4.6 billion years old.
20. Nuclear power is safer than burning coal.

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Clearing the highest hurdle: Human-based case studies broaden students' knowledge of core evolutionary concepts

Alexander J. Werth[1]
Hampden-Sydney College, Hampden-Sydney, VA 23943

Abstract

An anonymous survey instrument was used for a ten year study to gauge college student attitudes toward evolution. Results indicate that students are most likely to accept evolution as a historical process for change in physical features of non-human organisms. They are less likely to accept evolution as an ongoing process that shapes all traits (including biochemical, physiological, and behavioral) in humans. Students who fail to accept the factual nature of human evolution do not gain an accurate view of evolution, let alone modern biology. Fortunately, because of students' natural curiosity about their bodies and related topics (e.g., medicine, vestigial features, human prehistory), a pedagogical focus on human evolution provides a fun and effective way to teach core evolutionary concepts, as quantified by the survey. Results of the study are presented along with useful case studies involving human evolution.

Keywords: Survey, pedagogy, biology, evolution, Darwin.

All science educators face pedagogical difficulties, but when considering the social ramifications of scientific ideas, few face as great a challenge as biology teachers. Studies consistently show more than half of Americans reject any concept of biological evolution (Harris Poll, 2005, Miller et al., 2006). Students embody just such a cross-section of society. Much ink has been spilled explaining how best to teach evolution, particularly to unwilling students (Cavallo and McCall, 2008, Nelson, 2008). In this paper I argue that use of basic, widely recognized case studies involving human evolution can make a difference. Fortunately, because people are naturally most curious about themselves, this is easy and fun to do.

My experience after twenty years of teaching general and advanced biology courses with an evolutionary emphasis (including human evolution, evolutionary theory, vertebrate paleontology, and comparative anatomy) is that acceptance of biological evolution is not an all-or-nothing proposition. Not only are most classes a mixed bag in terms of student acceptance of evolutionary thinking, but even among students who end up accepting the factual nature of evolution, views are often severely limited or constrained. Students may agree with the basic notion of biological evolution, but their understanding may be far from what their instructor has in mind. In particular, I have found (via the statistical study

[1] Corresponding author's email: AWerth@hsc.edu

described in this study) that students are most willing to accept biological evolution as 1) an historical explanation for 2) physical features of 3) non-human organisms. In other words, it produced dinosaur bones long ago. In addition, students often develop 4) teleological, Lamarckian notions. Most students emerge from my general classes with a thorough, modern view of evolution, but where some get hung up it is likely to involve acceptance of evolution as (in contrast to the numbered points above) 1) an ongoing process that involves 2) non-physical (e.g., biochemical, physiological, or behavioral) traits, and most of all as a process that 3) affects humans. Students generally accept evolution of peppered moths. As Allchin (1999) has argued, the "hang-up" typically involves human evolution. Regarding acceptance of evolutionary science, this is for most people the final, highest hurdle. Yet as Darwin himself wrote in his "C" notebook (1838) more than twenty years before the publication of his landmark *On the Origin of Species* (1859a), when he was just beginning to piece together his ideas on natural selection, man "is no exception" to evolution. Barely a month before the publication of *Origin*—in which Darwin hinted at but was unwilling to spell out the explicit claim of human evolution—he wrote in a letter (1859b) about evolution that there is "no possible means of drawing [a] line & saying here you must stop."

Like Tycho Brahe, the 16th century Danish astronomer who, after observing planetary motion, aligned his observations with his prevailing geocentric worldview by positing that extraterrestrial planets do indeed orbit the sun but the entire solar system then orbits Earth (Barash, 2007), people often attempt to confront the concrete empirical evidence for evolution by meeting it halfway. In essence, they admit it as a powerful explanatory force but only up to a point, invariably with the proverbial line drawn in the sand up to but not including human beings, as Darwin implied in the letter cited above. The result is a partial acceptance: wrong in that it is not wholly right. As Barash puts it (2007), "Give ground in response to undeniable facts, but if those facts conflict with your more cherished beliefs, hold fast to the latter."

Given the ubiquity of religious, philosophical, and other social objections to evolution, this is not surprising. Many people mistakenly believe acceptance of evolution will shatter their faith or lead to moral nihilism (Brem et al., 2003). They are wary of strict philosophical naturalism. They find the idea that humans can be studied as biological creatures—as animals—alarming, and worry that such investigation degrades and demeans us. They forget that evolution depends on environmental context, and thus they fear, wrongly, that genes fully predetermine rather than predispose. Despite the fact that no legitimate scientific evidence has been found which contradicts evolution, even with tremendous scrutiny, and that instead a huge weight of consilient scientific evidence (multiple independent lines of data) supports the factual nature of human evolution, these social objections carry the battle for a large number of people. Given that many young people whose minds are not yet made up are willing to give fair hearing to objective evidence, it behooves biology teachers to face these issues squarely, clearly, and effectively.

Sadly, educators must not only confront social dimensions of science but must, in many cases, undo years of misinformation or neglect. Students must recognize that evolution is not merely another chapter or section of their textbook: it is the essential, fundamental, unifying theme of all life science. In Dobzhansky's famous words, "Nothing in biology makes sense except in the light of evolution" (1973). Students must see that although evolutionary theory remains a field of vigorous debate, its central, factual nature is not in dispute among scientists. Once students have a clearer grasp of the nature and scope of science and a better comprehension of what evolution does and does not entail, instructors must not retreat in the face of student fears about human evolution. They must confront such qualms head on.

I recommend that instructors, especially at the college level where students are more mature, not shy away from the contentious topic of human evolution, which is the primary reason people are often unwilling to accept the possibility of evolution. Such peoples' "understanding" of evolution is usually grossly misinformed, but it is typically dependent on bones and fossils. Further, I contend that when guided by the skilled hand of a dedicated, well-informed instructor, discussion of human behavior, including thorny new fields of evolutionary psychology and sociobiology, will have greater impact than traditional exposition of paleoanthropology (of which see the excellent review in Alles and Stevenson, 2003). Not only does exploration of human evolution satisfy curiosity, but it is likely to dispel myths and misconceptions and ultimately leave students with a purer, broader understanding of the thriving, dynamic disciplines comprising modern biology.

Here I provide specific ideas for human-based teaching of evolutionary concepts. Second, to demonstrate that such teaching makes a difference, I present results of extensive student surveys. Third, I offer time-tested suggestions, gleaned from this study, for teaching evolution (human and otherwise). Students who flat out refuse to consider the possibility of evolution may never be persuaded, but then they probably don't belong in the classroom in the first place. If students are willing to listen and engage in open dialogue, my tips offer a high likelihood of success.

Materials and Methods

Pedagogical emphasis

In terms of pedagogy, the general Biology 110: Principles of Biology course has been revised at my institution such that evolution is the first topic and a consistent, ever-present theme. The course is required for biology majors and fulfills a basic laboratory science general education requirement for all students; typically half to two-thirds of enrolled students are non-majors. Instead of merely describing a history pageant, I explain evolution as an ongoing process. I present results of evolutionary studies in many species but dwell especially on humans. In lieu of bones and fossils I devote more time to behavior, including complex systems such as language, ethics, and aesthetics. I eschew delineation of various lines of evidence supporting evolution, which are readily found in every biology text and many excellent websites, and focus instead on discussion of what kinds of empirical evidence might constitute evidence *against* evolution (which fits better with the nature and methodology of science). In addition I concentrate on examples of evolution in everyday life, including human social evolution, disease, and "Darwinian medicine" (Williams and Ness, 1996; Burnham and Phelan, 2001; Dawkins, 2004; Cochran and Harpending, 2009).

Case studies are an effective way of teaching evolutionary concepts (Goldstein, 2008), and it is absurdly easy to find human-based studies of evolution, which are available in most modern biology texts and a staple of popular television documentaries, science magazines, and websites. Here are fifteen examples of case studies I have found effective, whose use I heartily endorse:

1) **Metabolic-based cases**, such as why humans (unlike most mammals and some other primates) cannot synthesize Vitamin C and must therefore ingest it, due to mutation in the now inactive human GULO pseudogene, make fascinating stories. Another simple case involves lactose tolerance, which is the exception rather than the rule, and how it may have evolved in populations in concert with domestication of livestock. **Population differences** in alcohol dehydrogenase enzyme is another student favorite.

2) Everyone knows of the sickle cell anemia vs. malaria trade-off, but recently proposed hypotheses suggest similar **stabilizing compromises** such as cystic fibrosis vs. tuberculosis, hemochromatosis vs. bubonic plague, and even high blood sugar levels (leading to diabetes) vs. hypothermia in people, including ancestral Europeans, living at very high latitudes. Such cases offer speculative evolutionary explanations for the **persistence of debilitating genetic conditions** (Moalem and Prince, 2007).

3) **Adaptation to altitude and climate** is a core anthropology topic and thus widely available. Although skin color, folic acid, and Vitamin D make an intriguing story of natural selection (sunlight is needed to create Vitamin D, yet destroys stores of folate), teachers are cautioned not to raise the issue of skin color unless they are prepared to devote much attention to it. Students like to discuss **racial concerns** (especially genetic variation and IQ) yet these often yield more disadvantages than benefits in class. The Vitamin D story is compelling (Jablonski, 2004). Moalem and Prince (2007) point to seasonal variation in cholesterol levels as well as overall high levels of cholesterol (a precursor of Vitamin D synthesis) in some populations, as another evolutionary tradeoff.

4) Quirky **physiological responses** and reflexes, such as the photic sneeze reflex (sneezing after exposure to bright light, especially after emerging from darkness), which some claim offered a benefit to clearing upper respiratory passages from potential pathogens encountered by ancestors in musty caves, offer fun opportunities to discuss human physiology as well as prospective dangers of eager over-reliance on evolutionary "just-so stories."

5) Evolution of **resistance in pathogenic organisms** (such as bacteria responsible for tuberculosis, or mosquitoes and DDT) to antibiotics and other compounds is a widely-known topic, so students are likely to have heard of it, but often they have

basic facts and principles confused, and may not appreciate connections to humans (Levy, 1998).

6) **Host manipulation** by parasites and other pathogens offers an intriguing evolutionary perspective on disease. Paul Ewald (1994) has generated provocative ideas about, for example, why colds are less virulent than other pathogens (so we remain mobile and spread the rhinovirus), whereas pathogens transmitted by non-human vectors (e.g., mosquito-spread malaria-causing *Plasomodium*) keep us in one place, where vectors can find us. Ewald suggests we can influence pathogen evolution toward less virulence , e.g., "selecting" for less virulent cholera by cleaning up water supplies and ensuring infected people don't contaminate them, forcing cholera to become less harmful in order to spread.

7) Predisposition to cancer or heart disease, or other **genetic bases of disease**, are widely discussed in the popular press and hence easy to find and familiar to students. College-age men and women may feel invulnerable, but they will be interested as elder family members manifest health concerns.

8) **Imperfections** are everywhere in the natural world; students are sure to know of many in the human body, including various **adaptive compromises**: pelvis adapted for upright stance and bipedal locomotion yet poor for childbirth; spine from quadrupedal ancestors, leading to back problems; lowered larynx allowing for vocalization yet letting us choke on food. There are also numerous **vestigial features**, including but not limited to the vermiform appendix, coccyx, wisdom teeth, extrinsic ear muscles, "goosebumps" to fluff fur for insulation, and nipples and rudimentary uterus of males. Shubin (2008) is a great source for such examples involving the human body, as is Chapter One of Darwin's *The Descent of Man* (1871).

9) Students enjoy pondering the role of **genes and basic human behavior**, such as thrill-seeking behavior or assertiveness, or autism and schizophrenia (Holden, 2009). But make sure students are aware of epigenetic and environmental effects (e.g., from studies of identical twins, and from behavioral changes with age, and so on).

10) However, students find the rapidly emerging fields of **sociobiology** and evolutionary psychology, which present broader behavioral implications, controversial and inflammatory. These topics may shed more heat than light, but create a smoldering spark that can lead students to see human behavior in evolutionary terms. Two popular areas are human **mating strategies** and **altruism/evolutionary ethics** (Allchin, 2009).

11) A current hot topic is the role of methylation in **epigenetic imprinting of genes**. For example, some biologists argue (Jirtle and Skinner, 2007; nice review in Moalem and Prince, 2007) that the current rise in obesity stems from a "thrifty" gene which helped ancestral humans survive lean times, yet now leads to over-

weight people in cultures where low-nutrition, high-calorie food is abundant. Similar stories implicate smoking in health woes of children and even grandchildren via methylation of the fetal genome. Students enjoy discussing the extent to which their physiology and health are due, or not, to their own lifestyle choices. Study of epigenetic changes suggests something akin to "on-demand" mutations, which should lead to discussion of Lamarck vs. Darwin and inheritance of acquired variation.

12) **Non-coding "junk" DNA** and transposons ("jumping genes," which may have a higher incidence in African primates, including humans) can lead to all sorts of novel variations. High levels of HERVs (human endogenous retroviruses) in the human genome might have provided our ancestors with increased fodder for phenotypic variation, and thus might have been critical in human evolution. This also ties in to concepts of coevolution, such as the origin of eukaryotic organelles via endosymbiosis.

13) The topic of **aging**, and why humans live so long (and with what social costs and benefits) is, to young people, a fascinating but non-threatening way to study evolution.

14) The **Human Genome Project** offers many opportunities to discuss genetic variation (e.g., haplotype mapping) within and between populations and species, as well as the relationship between genetics and health, and the growing possibility of tailored pharmacogenomic drugs.

15) Gene and stem cell therapy and the specter of **genetic manipulation** or "enhancement" in humans is guaranteed to provoke discussion, much of it invariably veering off topic, but one can steer the dialogue toward the human evolutionary past, present, and future.

Suffice to say one could fill a book listing examples of human-based evolution studies. As time permits (or as supplementary readings and fodder for discussion) I recommend use of these and countless other "anthropocentric" studies. Any biology topic is best viewed through an evolutionary lens.

Survey methodology

For ten years (1994-2003 inclusive) I utilized a 25 question anonymous, pre- and post-semester survey to gauge student attitudes about evolution (Werth, 2009), as well as to provide feedback for outcomes assessment and thereby improve teaching in this Principles of Biology course. Results presented here derive from a spin-off of this study, with a shorter, modified questionnaire used for three years (2000-2003) in this course as well as to freshmen and sophomores in a basic Organismal Biology course (primarily plant and animal structure and function), including six cohorts of students (total N=166). [The survey was also attempted in two sections of a human evolution class, but results of such administration are not presented here, as the sample size was small and the self-selected students who enrolled in that course all began highly accepting of evolutionary principles.] Each class was surveyed at the start of the semester (on or around the second day of classes, after the roster had stabilized) and again, using the same questionnaire, during the final class of the semester. Although this longitudinal study followed each student cohort, no attempt was made to track changes in responses of individual students, as all responses were anonymous. No credit was given for this survey; participation was optional, but students were told it was part of a pedagogical study and urged to respond seriously.

The survey involved 12 statements to which students were asked to respond using a simple seven-point Likert scale of agreement or disagreement (1=agree completely; 4=unsure or don't know; 7=disagree completely). The five statements most relevant to the study presented here are:

1. Evolution is a purely historical phenomenon (i.e., all in the past).
2. Evolution applies only to non-human species.
3. Evolution applies only to physical features, like bones.
4. Evolution does not affect complex behavioral systems such as ethics.
5. Evolution works toward a purpose or goal.

The wording of these non-normative statements did not change over the three years of the study. Statements were counterfactual; objective, empirical evidence strongly supports rejection rather than acceptance in all cases. Presuming an effective pedagogical approach, students who initially accept such claims should move toward rejection over the course of the semester. In other words, the null hypothesis is that scoring on the seven-point scale should increase. Note that one of the five statements (#2) deals specifically with evolution of our species, but the expectation is that by teaching human-based evolution students will better understand multiple integrated core concepts of evolutionary theory, not merely human evolution. Also note that instead of harping explicitly on the five points embodied by these statements, my teaching via case studies addressed them indirectly rather than directly.

In addition to this formal survey, I rely on data from an assessment instrument used by my department for all sections of our Principles of Biology course, which involves a brief (approximately twenty minute) "exit interview" with individual students at the conclusion of the course to assess how well we are teaching basic concepts. Although this session is not required, I explain its value as a review session before the final examination, and hence have excellent (~85%) participation. The interview involves five questions, all scored by the instructor on a four point scale to assess student mastery of the material, and in this way I gain even more quantitative and qualitative feedback from my teaching regarding the effectiveness of my emphasis on human evolution.

The Principles of Biology textbook for this 2000-2003 study was *Discover Biology* by Cain, Damman, Lue and Yoon (Sinauer/Norton 2000, first edition, and in the third year the second edition, published 2002), and for the Biology 202 Organismal Biology course the text was *Life: The Science of Biology* (6e), by Purves, Sadava, Orians and Heller (Sinauer/Freeman 2001).

Results

Responses to the five statements, indicated as percentage of students (data from all classes combined; N=166 students) responding in each category (1-7), are shown in Figures 1-5. In general, a majority of students accepted each of the five statements at the start of the semester yet rejected them at the end. The total percentage of students agreeing with each statement (from "agree completely" [response 1] to "agree somewhat" [2] and "agree a little" [3]), as opposed to the percentage of students disagreeing with each statement (from "disagree a little" [response 5] to "disagree somewhat" [6] and "disagree completely" [7]) are displayed in Table 1 (all years combined). Since percentages in Table 1 exclude response 4 (unsure/don't know), they do not total 100%. Notably, whereas a majority of students agreed with all five statements at the outset of the course, only one quarter to one third of them agreed at the end (summarized in Table 1).

Table 1. Results of anonymous survey (2000-2003) on student attitudes toward evolution.

Statement#	*Pre-Semester* Percentage agreeing/disagreeing		*Post-Semester* Percentage agreeing/disagreeing
1. Evolution is a purely historical phenomenon (i.e., all in the past).			
	64 / 25	→	9 / 84
2. Evolution applies only to non-human species.			
	52 / 32	→	20 / 71
3. Evolution applies only to physical features, like bones.			
	53 / 28	→	27 / 61
4. Evolution does not affect complex behavioral systems such as ethics.			
	50 / 30	→	40 / 44
5. Evolution works toward a purpose or goal.			
	52 / 33	→	41 / 48

The biggest change engendered by the shift to a clear evolutionary focus with an emphasis on human evolution concerns the historical versus current nature of evolutionary change (Figure 1).

At the start of the semester, nearly two-thirds of students (64%) agreed that evolution is a thing of the past; at the end, only 9% agreed with this claim and 84% disagreed with it. Likewise there was a significant, substantial shift with regard to whether evolution applies only to non-human species or affects humans as well (Figure 2), as disagreement (at all levels) with this statement jumped from fewer than a third of students to over 70% of them.

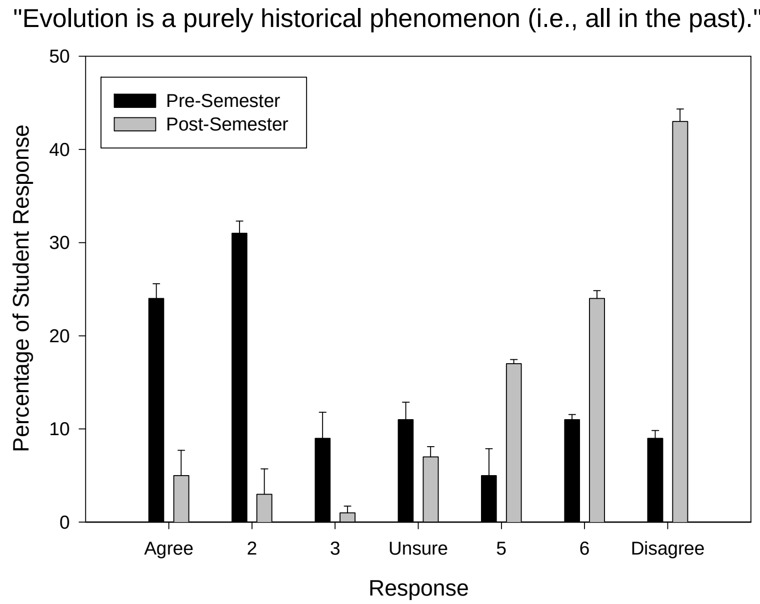

Figure 1. A concerted pedagogical focus on human evolution led students to see evolution as an ongoing process. This and all figures are from an anonymous four-year classroom survey (2000-2003, results from all years pooled), with error bars representing one standard deviation.

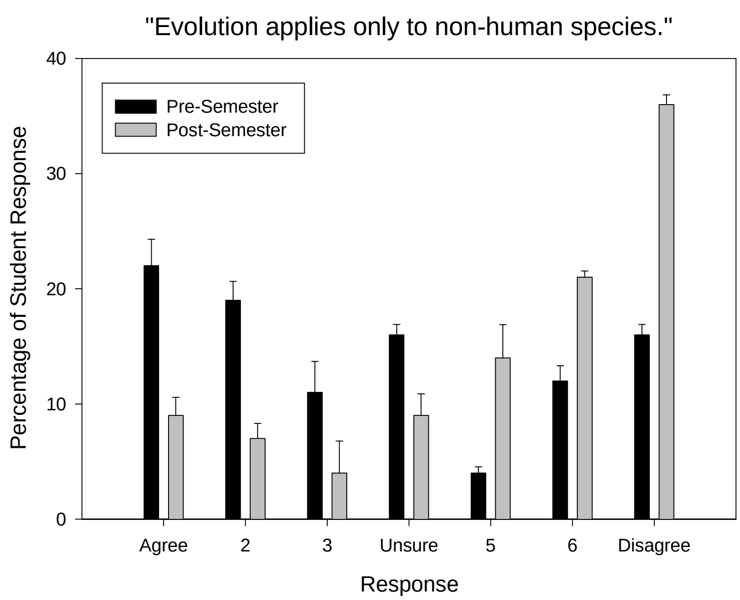

Figure 2. Results show students in the study became more likely to accept evolution of humans.

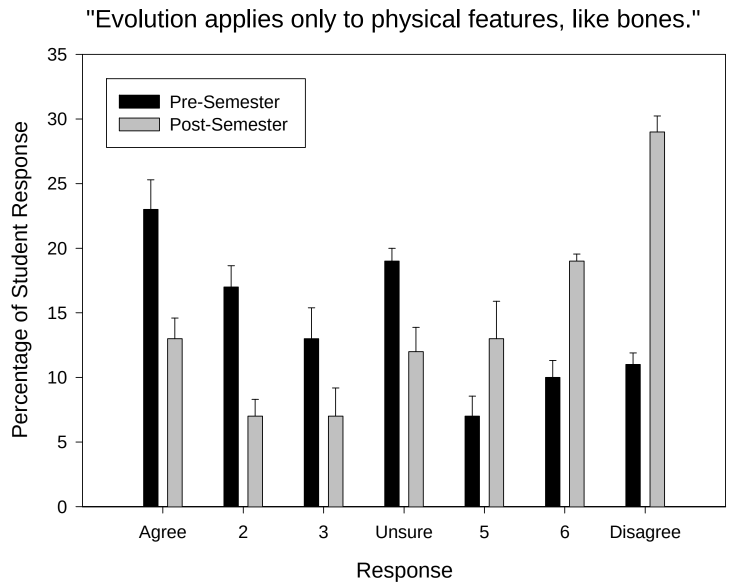

Figure 3. Students became more likely to accept non-physical (e.g., biochemical) evolution.

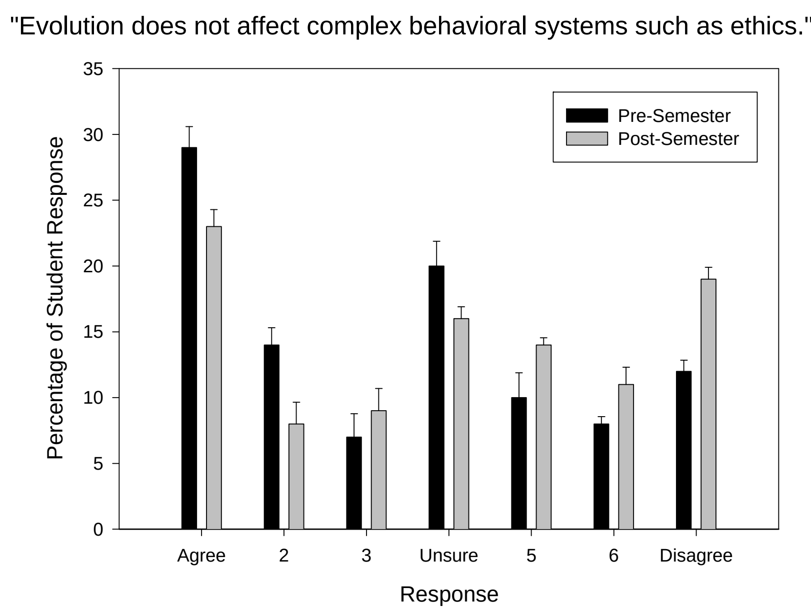

Figure 4. Students also became more accepting of evolution of complex behaviors, but less so.

As Figure 3 shows, slightly fewer students ended up rejecting the claim (#3) that evolution applies only to physical features. Fewer still changed their minds about the likelihood of involvement of evolution in complex behavioral systems (Figure 4), although admittedly this topic was dwelled upon to a lesser degree in class and not dealt with in the text or other course materials. Unlike Statements 1 & 2, both 3 & 4 had a sizable number of students choosing "don't know/unsure" even at the end of the course, although less so than at the beginning.

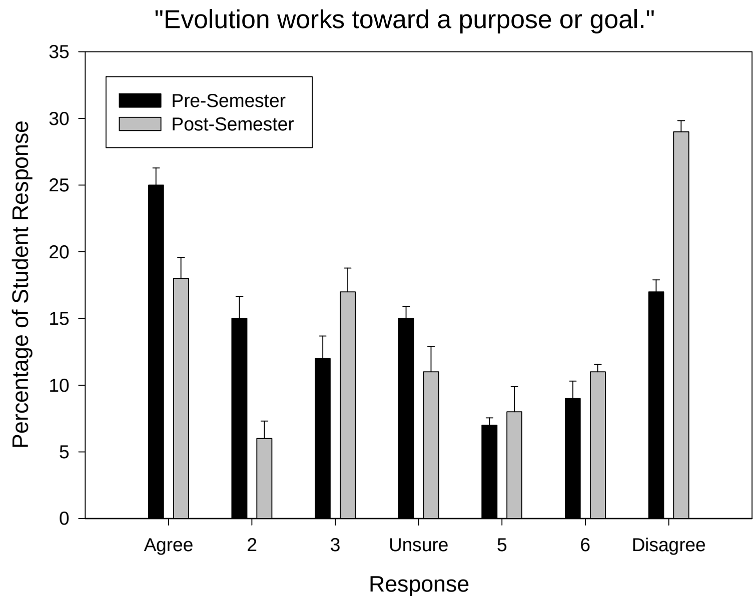

Figure 5. Students were more equivocal about teleological versus mechanistic explanations of evolution. Responses show opinions shifted, though not as strongly as with other statements.

As for Statement 5, which asserts that evolution works toward a goal, there was as in all cases described here a clear shift in opinion, yet a smaller shift. At the end of the semester 33% of students still agree with the claim that evolution is purposeful, although 17% agree only a little, and 29% disagreed completely at the end of the course.

Qualitative non-numeric findings yield similar results as gauged by student responses to classroom questions and comments in discussions, by responses to questions on exams and quizzes (particularly essay or short written answers), and from the end-of-semester oral quizzes and other dialogue outside class.

Discussion

Not all students ended up rejecting these claims as a result of their enrollment, but whereas a majority of students accepted them at the start, most students' views on evolution shifted dramatically. A general finding is that student attitudes vary widely. Initially, many accept evolutionary explanations yet the big "hang-up" clearly appears to be admitting evolution of humans, especially human behavior. In addition to the five points specifically addressed in this paper, other attitudes changed as well. For example, even at the beginning of the course students were much more willing to accept adaptation within species (i.e., "microevolution") than they were speciation or even adaptive radiation (i.e., "macro-" and "megaevolution" involving appearance of new species), but this too changed during the course.

How can I be sure that the changes I found in student attitudes result from my new pedagogical focus, specifically my increased case study-based emphasis on human evolution? Most of all, I can compare results with those from my broader unpublished study (Werth, 2009), which followed students in the same course over a ten year period, the first half of which preceded my shift to an evolutionary focus. Results of similar teacher surveys have been published by Osif (1997), Rutledge and Mitchell (2002), Rutledge and Warden (2000), and Lovely and Kondrick (2008). My data indicate that a broadly-based general biology course is likely to change student attitudes toward evolution, but much more so if evolution is made a central, unifying theme of the course, and if the dynamic nature of human evolution is made a center point (Linhart, 1997).

One of the most basic precepts of evolution is that it is an ongoing process—that it is insufficient merely to claim that all organisms have evolved, since all species are still evolving and moreover doing so in relation to one another in an intricate coevolutionary dance. Results (Figure 1) indicate that at the end of the course students clearly understand this concept. Even if evolution were a purely historical phenomenon it would of course still be amenable to scientific study by the hypothetical-deductive method (Cooper, 2002, 2004). The fact that humans are biological creatures and as such exempt neither from laws of nature nor the process of evolution was likewise grasped by most students. Yes, we are unique—indeed, all species are unique, otherwise they would obviously not be distinct species. Still, we recognize that in many ways, most notably cognitively and culturally, humans stand apart from other species, yet this does not diminish us. In contrast, the fact that we are related to all other living things yet have made great strides on our own might be seen both to ennoble and elevate us.

My results, both quantitative and qualitative, indicate that although a majority of students ultimately accept the evolution of behavioral traits and the non-teleological nature of evolution, they are more conflicted about these concepts, with fewer students changing their views or more adopting an uncertain one. Our teleological nature is indeed deep-seated. As Richard Dawkins (1995) notes, humans have "purpose on the brain." Michael Shermer explains (2006) that we see design everywhere because nature has in fact been designed, yet from a bottom-up rather than top-down process. He advises that we should "quit tiptoeing around" and admit that forms follow function "because evolutionary design is based on functional adaptation." In my experience our default anthropocentric, teleological worldview is firmly entrenched and very difficult to modify. As for the role of genes underlying evolutionary change, students may counter that genes are mere molecules. As Colin Tudge (2000) points out for those who deny the influence of genes, why else do dogs behave like dogs and birds like birds? Of course genes influence behavior, and since evolution is change in gene frequency, behavior evolves. Still, teachers must explain the role of genetic drift and evolutionary byproducts. Every facet of an organism (including behaviors) need not be adaptive. Instructors will rightly complain that their schedule is already stretched so thin, especially in a general biology course, that there is little "flex" time in which to introduce new material. However, human-based case studies need not occupy an entire class to make evolution more relevant and meaningful. They can be inserted as brief examples into lectures or discussions, using examples I have provided here.

Conclusions and Recommendations

Ironically, much of the difficulty in teaching human evolution stems from the fact that humans are naturally predisposed to think in teleological terms (Shermer, 2006; Kelemen and Rosset, 2009). Design that evolved in nature in a bottom-up sense, rather than divine design (imposed in a top-down way; Dennett, 1995), is thus a counterintuitive view that often meets resistance. As E.O. Wilson explains in *Consilience* (1998), the human mind "did not evolve to believe in biology." Darwin himself saw that the deck was stacked against him. As he wrote in *The Descent of Man* (1871), "A belief in all-pervading spiritual agencies seems to be universal." Nonetheless it is paramount to explain that acceptance of evolution does not equal rejection of religious beliefs. It is essential to explain that scientific and spiritual ideas need not conflict, and that science does not address supernatural claims (Meadows et al., 2000).

Throughout this paper I do not refer to "belief" in evolution but rather acceptance of empirical statements. As Shermer (2006) writes, "evolution is not a religious tenet, to which one swears allegiance or belief as a matter of faith." Evolution is an idea, not an ideology, which is why biologists often advocate rejection of the term "Darwinism" (Scott and Branch 2009). Religious objectors may not change their minds easily, if at all, but my aim is to reach undecided fence-sitters who are willing to listen and make up their own minds. Maturing college students generally fall into this camp. Many older adults are unswayable, yet a good number of students are grappling with new ideas and willing to see the world from a fresh perspective. As noted earlier, those who enter college resisting evolutionary teachings often have been misinformed and possess a skewed view of science. Patient, polite, and non-confrontational, non-threatening instructors who are nonetheless clear and firm in their teaching likely bear the best chance of successfully leading students to view evidence objectively. It would be interesting to monitor student attitudes years later, to see if seeds planted in the mind bear fruit years later. Yes, it is true that some reluctant students will not accept evolution no matter what tack teachers take nor how hard they try, but in other cases students will accept a balanced, realistic view of evolution if their concerns are addressed squarely, surely, and sincerely, as a central pedagogical focus on human evolution does.

It is essential to maintain a proper attitude. The approach should always be firm but never confrontational or condescending. The goal is to open minds, not to close them off. As noted above, most classes include a great diversity of views on evolution. I have found that many students who resist evolutionary thinking remain silent and keep concerns to themselves. Not only do they fear their beliefs are threatened, but they do not want to expose themselves to potential criticism from classmates or, worse, instructors. The teacher's tone is paramount in allaying fears and reminding students that there is a place for all beliefs, but that science class is a place to discuss scientific explanations. Never belittle or blame students for not immediately accepting evolution. In addition to demeanor, the language one employs is of utmost importance. The terminology used to present, explain, or even ask questions about evolution makes a huge difference. Myths and misconceptions persist even among students who acknowledge evolution from what they have heard or been mistaught (McComas, 1997). There remains in the minds of college students much confusion about whether evolution is merely one of many equally valid views or if it is scientific "truth." Just as genes are "linked" on chromosomes, views on evolution are often linked to each other as well as, more obviously, to religious faith and views on the compatibility of science and religion.

Finally, as a result of my survey of student attitudes and experience focusing on human case studies as a means of teaching evolution, I can offer a few additional words of guidance for teachers. It is imperative that students understand the nature and scope of science (Alles, 2001; Farber, 2003). The easiest way for them to understand what evolution is all about is to be assured of what it is not about. Students often erroneously equate "Social Darwinism" with Darwinian evolution. Also, teachers must stay current with evolutionary explanations. The field has changed greatly in the past two decades, especially with a proliferation of books on evolutionary ethics, evolutionary psychology, and sociobiology (Allchin, 1999), and with new ideas in molecular and evolutionary developmental ("evo-devo") biology, and hence the possibility of major morphological "leaps" via minor mutations in regulatory genes. As Kirschner and Gerhart (2005) note, the origin of novel structures need not involve "irreducible complexity," as critics of evolution frequently assert. Explanation of epigenetic in addition to genetic inheritance is also essential (Jirtle and Skinner, 2007). I recommend that instructors correct fallacious ideas (e.g., we did not evolve from monkeys or chimpanzees) yet not get bogged down in discussion of the origin of life and chemical evolution. Point out that Darwin was a proponent of hypothesis-based science. Long before hominid fossils were discovered in Africa he claimed it as the likely site of human origins: a testable, falsifiable hypothesis.

Evolutionary biology has changed profoundly in the century and a half since Darwin published *On the Origin of Species* (1859), but his approach remains relevant. He saw that rejection of evolution largely stems from its implications for humans (hence his follow-up work, 1871's *The Descent of Man*), and he recognized that scientists must not stray from science. In his words (Darwin 1880), "Freedom of thought is best promoted by the gradual illumination of men's minds which follow[s] from the advance of science." My advice is to continue on the path Darwin blazed, drawing examples from human biology to teach basic principles of evolution.

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Evolution in Action, a Case Study Based Advanced Biology Class at Spelman College

Aditi Pai[1]
Spelman College, Atlanta, GA 30314

Abstract

The Biology department at Spelman, a historically black women's college has undertaken a major curriculum revision in the last few years. A primary goal of this revision is to increase the breadth of topics in biology classes. Historically, classes in the areas of ecology and evolution have been underrepresented whereas Spelman has always offered classes in the areas of organismal, molecular, and cellular biology. As a part of this curriculum change, I developed the very first Evolutionary Biology class at Spelman. To maximize student interest in evolutionary biology, I attempted to tailor the class to the student population at Spelman. Specifically, because the majority of Spelman students aspire to be health professionals, the course was designed to teach concepts in evolutionary biology using emerging infectious disease as case studies. I surveyed three parameters to gauge if this class was successful. First, I measured student interest in the various assignments of this class. Second, I gave pre- and post- class tests to the students to measure gains in course content knowledge. Third, I examined the data from college administered student evaluations of this class. I found that 1) students showed a high appreciation for case study activities, 2) students' content knowledge improved significantly over the semester, and 3) students perceived their learning experiences in this case study based class to be dramatically better than in the traditional lecture based classes.

Keywords: Evolution, biology, case study teaching, curriculum revision.

Spelman College is a historically black women's college in Atlanta, GA. Ranked among the top 75 liberal arts colleges by the US News & World Report, it has an enrollment of approximately 2100. Biology is the largest major in the college attracting almost a quarter of the entering freshmen (Spelman College Fact Book 2008). The college enjoys the reputation of being among the top contributors of female minority PhDs as well as medical professionals in the nation.

The Biology Department at Spelman recently revised its curriculum. Two main goals of this revision are 1) to expand on the breadth of classes offered to its students and 2) to improve student engagement in their learning. Classes in the areas of organismal, cellular, and molecular biology such as genetics, physiology, immunology, developmental biology etc. were well represented in the old curriculum however classes in areas of ecology and evolution have been underrepresented. Accordingly, in the course of this curriculum overhaul, I developed the first Evolutionary Biology class which would fill one of

[1] Corresponding author's email: apai@spelman.edu

the gaps in the old curriculum and help meet the first goal of the curriculum revision. In designing this advanced elective class, I chose to use the case study method which involves presenting a ‘story’ with an ‘educational message’ (Herreid 2007). This method would maximize active learning opportunities in the classroom and thus address the second goal of the curriculum revision.

Because, this course was custom-made for Spelman Biology majors who typically aspire to become health professionals, my overall approach was to explain concepts in evolutionary biology in the framework of human health and welfare. The case study technique was suitable not only because it provides active learning opportunities, but also because of the widespread use of the case method in medical school (Herreid 1997) and the obvious attraction of that fact to our pre-health professions students. Additionally, case study based science teaching might be particularly attractive to female and minority students (Lundeberg & Yadav, 2006 a).

Previous research has shown that the case study technique is extremely effective as an active learning method where students are ‘learning by doing’ (Herreid 1994). In particular, the case study method has been found to be useful in promoting problem solving ability, analytical reasoning and decision making skills, as well as the ability to work in teams and communicate effectively (Herreid 1994). To further promote student engagement I decided to select cases that would appear to be relevant to them, this was accomplished by selecting case studies related to emerging infectious diseases such as avian flu, SARS (Sudden Acute Respiratory Syndrome), MRSA (Methicillin-resistant *Staphylococcus aureus*), XDR-TB (Extreme Drug Resistant Tuberculosis) etc. or of economic importance such as GMOs (Genetically Modified Organisms), invasive species etc.

Research question

Given that this was a new class both in terms of the subject as well as the teaching method, I was interested in asking three main questions about this class: 1) what are the students’ responses to class activities and assignments, 2) what is the students’ gain in content knowledge, and 3) how does student perception of their learning in this class compare to their experiences in other Biology department classes? The answers to the questions posed above are clearly useful for other instructors using a case study method and particularly those using this method for teaching evolutionary biology.

Study design

I designed two separate surveys to measure student response to case study work and students’ gains in content knowledge respectively. Also, I examined data from the college administered end- semester survey to compare student perception of their learning in this class with their experiences in other biology department classes. Here, I describe this new course and present the results of the assessment.

Student population

This class was taught with an enrollment of 25 in spring 2008. All students enrolled in this class were senior Biology majors and females of African descent.

Course structure

'Evolution in Action' comprised equal measure of case study work and traditional lectures. The class met twice each week for two hours each time. In a typical meeting, the first hour was a lecture in which students learned new concepts and the latter half of the class period was used for case study activities which gave them an opportunity to apply concepts they had learned in the lecture. However there were some topics, for which rather than a case study, other activities were designed (Table 1).

There was no text book used for this class because the case studies on emerging infectious diseases were selected based on the stories that were in the news. By using the most current stories about evolution unfolding before our eyes I expected to maximize student interest. Thus, instead of relying on a text book, students had to rely on recommended readings and lecture notes. I based some of my lectures on materials drawn from different text book sources such as Campbell and Reece (2005), Freeman and Herron (2007), and Stearns and Koella (2008).

The semester was divided into four main modules and a final conference. Briefly these were: 1) basic principles in evolutionary biology, 2) understanding evolutionary thinking with avian flu as a case study, 3) understanding host-parasite coevolution with emerging infectious diseases as case studies, 4) application of evolutionary principles, and 5) 'In the light of evolution' symposium. In the first module students worked on short cases on some of the major concepts in evolutionary biology such as natural selection, speciation etc. The second module involved three guest speakers and five different case study activities surrounding avian flu. The third module included two guest speakers and four different short cases on emerging infectious diseases other than avian flu. The fourth module illustrated the application of evolutionary theory in areas other than infectious diseases using three case studies.

Case study materials

Case materials were typically garnered from popular media and ranged from newspaper or magazine articles, excerpts from books, to videos, as well as cases from the National Center for Case Study Teaching in Science website[2]. Details of the case studies used for each module are as follows:

[2] http://ublib.buffalo.edu/libraries/projects/cases/case.html

Basic principles in evolutionary biology

The first module, 'Basic principles in evolutionary biology ', served to educate students about the fundamental concepts in evolution such as the scope and importance of studying evolutionary biology, history of evolutionary theory, natural selection, genetic drift, speciation, population genetics, and phylogenetics. Six different case studies related to the above concepts were selected for this module (Table 1).

Understanding evolutionary thinking with avian flu as a case study

In the second part of the semester, I used avian flu as a case study to explain evolutionary thinking. The lectures focused on general information about avian flu, its significance for human health, and the evolutionary history of flu viruses. There were five case studies for this module (Table 1).

Understanding host-parasite coevolution with emerging infectious diseases as case studies

The third module of this course used the context of emerging infectious diseases to understand host-parasite coevolution. Four assignments were used for case study work including SARS, XDR-TB, MRSA, and Helicobacter pylori (Table 1).

Application of evolutionary principles

The fourth section of this class was different from the previous modules because it did not use human diseases as case studies. Instead, for this part of the class, I chose case studies which show the relevance of evolutionary thinking in other contexts such as the economic importance of invasive species, artificial selection, and GMOs, and the importance of understanding human evolution. Three case study assignments were used in this section (Table 1).

'In the light of evolution' symposium

Students were asked to do presentations on assigned topics in a mini-conference titled 'In the light of evolution' on the last day of class. For this project, students had to research the assigned topic and show an understanding of various phenomena in humans such as lactose intolerance, obesity epidemic, aging, mother-offspring conflict, male-female conflict etc. from the evolutionary history perspective.

Case study work

Case study work was typically done in groups of three (there were nine groups total: seven groups of three and two groups of two). These were 'permanent' groups i.e. students continued to work with the same group members throughout the semester. Group members were selected by the students themselves at the start of the semester.

Table 1: Case study materials, source, case study activity in class and the assignment that students had to turn in for a grade (NA = unpublished materials).

Case study activities for module 1 Introduction	**Source**	**Activity and written assignment**
1.1 Emerging diseases articles Birdflu, MRSA, XDR TB	• Anonymous (2007) http://abcnews.go.com/GMA/OnCall/Story?id=3231184&page=2 • Anonymous (2008) WSBTV.com • MIT (2008) http://www.sciencedaily.com/releases/2008/01/080106193222.htm	Classroom discussion None
1.2. FAQ on evolution	http://www.pbs.org/wgbh/evolution/library/faq/	Classroom discussion Written answers to questions on website
1.3. Natural selection case study: white striped clover	Krufka et al (2007) http://www.sciencecases.org/clover/clover.asp	Small group discussion Written answers to questions at the end of the case
1.4. Essay on Evolution by T. Dobzhansky	Dobzhansky (1975) http://people.delphiforums.com/lordorman/Dobzhansky.pdf	Discussion Submit three questions based on reading
1.5. Book chapter by Francis Collins	Collins (2006) Chapter 5 from Language of god 2006, p 109-142	Discussion Submit three questions based on reading
1.6. Speciation case study: Trouble in paradise	Hewlett (2001) http://ublib.buffalo.edu/libraries/projects/cases/paradise/paradise.html	Submit summary of plan for performance Various performances (skits, puppet shows, rap songs, magazines, documentary etc)

Case study activities for module 2 **Avian flu case study**	**Source**	**Activity and assignment**
2.1. Book chapter by Jared Diamond	Diamond (1997) Chapter 11 from Gun, Germs and Steel, 1997, 191-215	Discussion Submit three questions based on reading
2.2. SARS case study	Sanchez (2005) http://ublib.buffalo.edu/libraries/projects/cases/ubcase.htm#medicine	Discussion Written answers to questions in the case study
2.3. Clustal W/Workbench demonstration	http://www.ebi.ac.uk/Tools/clustalw2/index.html	None
2.4. Review article on Evolution of flu	Webster et al, 1992.	Small group discussion followed by classroom discussion Written answers to questions specified to each small group Presentation

Case study work varied considerably in its nature in terms of the preparation as well as the product expected from the students. Thus, whereas in some cases, students were expected to have read the case before hand, at other times students were handed the materials in class. Similarly, the product expected from the students also varied widely and ranged from something as simple as having to submit a previously prepared list of questions, in class writing assignments, and quizzes; to relatively more difficult work such as submitting a documentary, performances such as skits, puppet shows etc. The performance based assignments were designed keeping in mind the nature of the 'millennial' students, who prefer to learn with technology and entertainment (Jonas-Dwyer & Pospisil, 2004). Students were assigned points for their case study work every class period with only one exception (see Table 1). Depending on the nature of the activity and the assignment, some cases involved only individual grade, some only a group grade whereas some included both an individual grade as well as a group grade.

Case study activities for module 3 Pathogen evolution: emerging infectious diseases	**Source**	**Activity and assignment**
3.1. TB documentary	"Rx for survival". http://www.pbs.org/wgbh/rxforsurvival/	Classroom discussion
3.2.MRSA case study	Lemmons and Huber (2001) http://www.sciencecases.org/infection/infection.asp	Small group discussion followed by classroom discussion Written answers to questions specified to each small group
3.3. *Helicobacter pylori* strategies	*H.pylori* strategies to evade host immune system NA	Small group discussion followed by classroom discussion Written answers to questions specified to each small group
3.4. Review of vocabulary using Pyramid game	Cases in 3.1, 3.2 and 3.3	Game show

Course assessment and data collection

To assess student perception of case study work, I administered a survey near the end of the semester to solicit feedback from students on each of the case studies. This survey asked students to rate each of the case study assignments listed in Table 1 on a scale of 1 to 10. Students were asked to give high scores for case studies they found interesting and/or useful and low scores for cases they did not find interesting and/or useful (Table 2). They were also asked to provide written comments explaining their scores. I decided *a priori* that a student response score below 7 (70% is equivalent to a grade of C) would be

Case study activities for module 4 Miscellaneous topics in evolution	**Source**	**Activity and assignment**
4.1.Tainted-tacos: debate on GMOs	Taylor (2004) http://www.sciencecases.org/gmo/gmo_adv.asp	Small group discussion followed by classroom discussion Written answers to questions specified to each small group
4.2.Improving on nature	Kingery (1999) http://www.sciencecases.org/nature/nature.asp	Small group discussion followed by classroom discussion Written answers to questions specified to each small group
4.3.Dating game	Tobias (2003) http://ublib.buffalo.edu/libraries/projects/cases/hominid.html	Enactment of the dating game as described in the case Individual assignment as specified in the case

an indicator of low student enthusiasm for a case study.

To assess student gains in conceptual knowledge, I administered pre- and post class tests to students. This test had 17 questions on basic concepts in evolutionary biology such as natural selection, population genetics, speciation, phylogenetics etc., rather than on the details of case studies.

To determine how student evaluation of their learning experience in this novel case study based class was as compared to other traditional lecture based biology classes, I obtained summary statistics on student evaluation scores of this class as well as all other Biology classes offered that semester from the college-administered end-semester course evaluations. I elected to use this college wide survey rather than designing my own survey to avoid any biases resulting from my own attitude in influencing student responses (Lundeberg and Yadav 2006b). The survey included 22 questions on three main topics:

Table 2: Student evaluation of whether a case study (see Table 1) was interesting and/or helpful on a scale of 10 (1 being least and 10 being most useful and/or interesting).

Case study activities for module 1 Introduction	Score (mean)	Std. Dev
1.1	9.15	1.18
1.2	8.25	1.11
1.3	8.26	1.30
1.4	8.05	1.39
1.5	8.90	1.13
1.6	9.09	0.99
Case study activities for module 2 Avian flu case study		
2.1	8.76	1.26
2.2	8.84	1.16
2.3	6.85	1.78
2.4	8.11	1.27
Case study activities for module 3 Pathogen evolution: Emerging infectious diseases		
3.1	9.45	0.75
3.2	8.95	1.05
3.3	8.77	1.00
3.4	9.1	1.11
Case study activities for module 4 Miscellaneous topics in evolution		
4.1	8.52	1.38
4.2	8.72	1.22
4.3	9.38	0.77

1) instructor organization and clarity of presentation, 2) course management and quality, and 3) learning experience. Because I was specifically interested to see if the case study method was perceived by students as being effective in improving their learning, I only examined evaluation scores for the questions on the survey related to students' learning experiences. I did not use questions from the other two categories because they were explicitly about the quality of instructor and not student learning. There were eight questions relating to students' learning experiences on the college administered survey (see Table 4). Students could mark their response as follows: strongly agree (5), agree (4), neutral (3), disagree (2), and strongly disagree (1).

Data analysis

The data from the above surveys was analyzed on JMP statistical package (SAS Institute, Cary, NC) or on MS Excel. Student responses to case studies among the four different modules were compared using an Analysis of Variance Model using the module as the independent variable and student response score as the dependent variable. No data were collected on students' responses to the symposium hence it was not counted as a separate module in this analysis. I compared the responses in the evolution class to other Biology classes using a t-test.

Results

Response to case study work

Student scores for case study work was on average 8.65 (SD 1.17) and ranged from 6.85 (Clustal workbench demonstration of analyzing flu virus phylogeny) to 9.45 (documentary on XDR TB) (see Table 2 for Standard Deviations and other scores). Student engagement in the four modules differed significantly (Table 3). Specifically, students showed a significantly lower interest in the module on Avian flu compared to all other modules namely, basic principles module, host-parasite coevolution module as well as application of evolutionary principles module (Tukey Kramer HSD, $P < 0.05$).

Student gain in conceptual knowledge

There was a significant improvement in students' performance in the post- class test on basic concepts in evolutionary biology compared to the pre-class test (t-test, $t_{1, 42}=3.59$, $P = 0.0008$). In the pre-class survey, the scores ranged from 3 to 14 out of 17 (average 8.63 ± 1.96, 50.76%), whereas in the post-class survey the scores ranged from 6 to 16 (average 10.86 ± 2.14, 63.88%).

'*Evolution in action' as compared to other Biology classes*

Student response to the evolution class overall was more positive than other Biology classes (Other Biology classes average 4.15 on 5 point scale, median 4.25; Evolution in action average 4.7 on a 5 point scale, median 5; see Table 4 for details). Moreover, a comparison of student perception of learning experiences in the evolution class and other Biology classes shows that students' perception of their learning experiences in the

Table 3: Analysis of variance comparing students' responses to case study work in four modules.

Source	DF	Sum of Squares	Mean squares	F ratio
Model	3	37.14	12.38	7.56
Error	328	536.98	1.63	Prob > F
Total	331	574.12		<0.0001

Table 4: Comparison of 'Evolution in action' to other Biology classes in spring 2008.

Questions relating to learning experience in the survey	Evolution in action Mean (standard deviation)	Other Biology classes combined Mean (standard deviation)	Result of t-test
The course improves my understanding of concepts and principles in this field	4.81(0.40)	4.16(0.94)	$T_{2,317}$=14.84 P <0.005
Course activities and assignments assist with learning the course content	4.62(0.59)	4.18(0.95)	$T_{2,319}$=9.81 P <0.005
Exams and assignments accurately reflect the course objectives	4.52(0.68)	4.19(0.95)	$T_{2,317}$=7.49 P <0.005
The course is intellectually challenging	4.52(0.60)	4.19(0.95)	$T_{2,317}$=7.40 P <0.005
I can apply information and skills learned in this course	4.43(0.74)	4.19(0.95)	$T_{2,317}$=5.33 P <0.005
The course encourages me to think critically	4.48(0.68)	4.19(0.96)	$T_{2,317}$=6.38 P <0.005
The course motivates me to do further exploration in this area	4.38(0.74)	4.19(0.92)	$T_{2,320}$=4.39 P <0.005
I learned a great deal from this class	4.76(0.43)	4.16(0.95)	$T_{2,319}$=13.52 P <0.005

former was significantly more positive than students' perception of their learning in other biology classes (Table 4).

Discussion

Given the newness of teaching evolution at Spelman College, the primary goals of this study were to assess if the case study approach to teaching evolutionary biology was 1) perceived to be interesting and/or useful by the students, 2) perceived to successful in enhancing the learning experience of the students, and 3) effective in improving students' content knowledge. Course assessment revealed that in general, students found the case studies to be very useful and/or interesting (Table 2) and this case study based class to be significantly better for their learning as compared to other traditional lecture based classes (Table 4). In addition, students showed significant improvement in course content knowledge over the semester. Thus, together these data show that the case study based approach to teaching evolutionary biology was successful in engaging students and enhancing their learning.

One of the key challenges of teaching evolutionary biology at Spelman College has been the perception among students that evolutionary biology does not have any relevance to human health and welfare. In addition, many students have a misconception that principles of evolutionary biology are in opposition to their religious beliefs. This course was deliberately designed to deal with the above issues. Thus, the choice of particular case studies which illustrated the applicability of evolutionary biology to human health and welfare was intended to help address students' misconception that evolutionary biology had no relevance to human populations. Similarly, the choice of readings such as the book chapter from 'The Language of God' by Francis Collins and 'FAQs on evolution' (see Table 1) early in the semester which explicitly deal with evolution and religion was intended to deal with the students' mistaken idea that evolutionary theory is in opposition to religious beliefs. The current study suggests that both of the above strategies were successful in dealing with the two misconceptions on evolutionary theory mentioned before. The fact that the enrollment for this class had more than doubled from the first time it was taught in 2007 ($n = 10$) to the next time in 2008 ($n = 25$) and remains at capacity in the present semester (spring 2009), lends further support to this conclusion.

Based on the responsiveness of students to the discussion on the relationship between evolution and religion, in future I plan to expand the reading assignment by including some essays by Stephen Jay Gould (1997) and Richard Dawkins (2006). This would expose students to the diverse views on the relationship between science and religion and make for a better discussion on the matter.

Though the course design was successful in solving the challenges stemming from students' misconceptions about evolutionary biology, it creates other separate challenges for the instructor teaching such a class. One major difficulty to the instructor is in finding the most current and exciting case studies in the news and media that are illustrative of the relevance of evolutionary theory to society. The stories that have the most interest to the students are the stories that are unfolding in the news in 'real time' (for example evolution of flu viruses such as avian flu or swine flu), but because of the relatively scant scientific information on such 'breaking news' types of cases, it is hard to gather information on them and therefore, the instructor may need to spend a lot of time in preparing for the classes. A second issue related to this course design is the amount of grading it necessitated. To ensure rigor, students had to turn in some assignment in every class, which poses a large burden of work for the instructor. A third problem resulting from the diversity of formats of assignments (from performances, discussions, to written answers to questions) was the formulation of sound grading rubrics. Finally, a minor concern was planning the class time in fine detail to ensure that all activities from instructor's lectures to students' presentations were accommodated in the class period. These challenges to the instructor would make this course design very difficult for classes of more than 25.

A major finding of this study is that students' perception of their learning was significantly higher for this case study based course compared to other biology courses in the same semester which did not use a case study based approach. Although this result is strongly suggestive of the successfulness of the case study approach, it is not conclusive. Because this study did not attempt to control for the other variables besides a case study approach that might be influencing the students' perceptions such as the instructor, class topic, students etc., caution should be used in interpreting the findings of this analysis of students' perception of their learning. Future studies should be designed to address the shortcoming of the present study by following research protocol for class room research as described in Lundeberg and Yadav (2006 a, b).

Another notable result from this study was that student rating for the module which involved the most in depth discussion of a case was lower compared to rating for the modules which involved a series of short cases. Specifically, the avian flu module involved five different cases / activities on the avian flu story whereas the other modules had shorter case studies. The above data suggest that it is easier to sustain student's enthusiasm through short cases rather than long and in-depth cases. However, because of other confounding factors such as changes in instructors, differences in nature of the assignments etc., this interpretation is not definite. Future studies should explicitly test whether students are more enthusiastic about short cases (one class period) or long cases (more than one class period) with careful experimental design (Lundeberg & Yadav, 2006, a, b).

Although the course was successful in enhancing student knowledge of evolutionary biology, the improvement in post-test survey compared to pre-test was relatively modest (~13%). To improve this aspect of the course I plan to make three main changes to the course structure. First, I will recommend that students buy a text book such as Evolutionary Analysis by Freeman and Herron (2007). This textbook would serve a reference as well as a source for additional in-depth assignments to be done by students outside of class time. Secondly, I will make the final exam a comprehensive one, which should further push students to put more effort into mastering the materials. Third, this class will include a lab component starting in spring 2010. Having an opportunity to practice applying evolutionary theory in lab exercises should improve students' understanding of the course content. In addition to the changes in course structure, I will also examine data from the pre- class survey more carefully in future, to identify precisely which areas the students are weak in. This knowledge will help me better adjust my teaching to promote their learning.

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Preparing Teachers to Prepare Students for Post-Secondary Science: Observations From a Workshop About Evolution in the Classroom

Caitlin M. Schrein[1a], John M. Lynch[a], Sarah K. Brem[a], Gary E. Marchant[a], Karen K. Schedler[b], Mark A. Spencer[a], Charles J. Kazilek[a], Margaret G. Coulombe[a]
[a]*Arizona State University, Tempe, AZ 85287*
[b]*Arizona Foundation for Resource Education, Phoenix, AZ 85004*

Abstract

This paper summarizes the content and results of a workshop about the teaching of evolution presented to public middle school and high school science teachers by individuals involved both in university education and the professional development of teachers. The goals of the workshop were to: (1) provide teachers with knowledge and resources to more effectively teach evolutionary theory, (2) increase teacher awareness of legal and cognitive issues associated with the teaching and learning of evolution, (3) address teacher misconceptions about evolutionary theory, (4) assess teachers' acceptance of evolutionary theory, and (5) make inferences about the preparedness of Arizona's public school students for a rigorous university life science curriculum that includes evolutionary biology. Participating teachers created concept maps about evolutionary theory, completed the Measure of Acceptance of the Theory of Evolution (MATE) survey at the beginning and end of the workshop, and responded to a survey the week following the workshop. The results of these measures indicate that some Arizona science teachers have misconceptions about evolutionary theory that may be passed on to their students, and these misconceptions, if not corrected, must be addressed in introductory-level science courses at the university level. Based on feedback from the follow-up survey, different teachers with varying levels of acceptance of evolution are all keen to learn from university educators and attend professional development workshops. Such workshops – and engagement between secondary and tertiary educators - can clearly have an effect on the conceptions of both teachers and students, and thus on the acceptance of evolution generally. We therefore strongly encourage the involvement of university educators in science education outreach that addresses evolutionary theory.

Keywords: Workshop, evolution, teachers, science education, outreach

As America's need for professionals in science, technology, engineering, math (STEM) and health and medical fields increases, so does the need for rigorous pre-collegiate science curricula and high quality teaching of those curricula. To better prepare future high school graduates for college-level science coursework, the strengths and weaknesses of pre-collegiate education systems must be assessed and directly addressed. In addition, college and university educators must be made aware of how prepared their incoming students are and how and why they are so prepared. What is achievable in the university

[1] Corresponding author's email: Caitlin.Schrein@asu.edu

or college classroom is highly dependent on the foundation laid during a student's secondary education. Thus, engagement between secondary and tertiary level educators benefits both groups in substantial ways.

One particular area of science education that suffers from weaknesses is the teaching of evolutionary biology in public school science classrooms. Due to social, political, legal, ethical, and/or scholarly issues associated with the teaching of evolution (enumerated and discussed in great detail elsewhere in the science education literature), public high school biology teachers might not teach evolutionary theory, even if it appears in their state education standards (Moore, 2002). Hessler (2000) concluded that 40% of biology teachers in Minnesota, a state with above average coverage of evolution in its state standards, spend little or no time teaching evolution (Lerner, 2000; Moore, 2002). Rutledge and Mitchell (2002) reported that 33% of 552 Indiana public high school biology teachers surveyed in 1995 spent fewer than three days addressing evolution in their classes, though Indiana has excellent coverage of evolution in its standards (Lerner, 2000). A survey of 1369 Minnesota university students who attended public high school found that 24% of those students were not taught evolution in their high school biology courses (Moore, 2007). Twenty-two percent of those students also reported that their teachers taught both evolution and creationism (Ibid.).

Moore (2004) suggested that teachers' refusals to teach evolution are due to pressure (from school boards and/or parents), unfamiliarity with laws about teaching religion in schools, lack of time, and/or lack of training (see also "Science Teachers Report Feeling Pressured to Teach Evolution," 2005 and Moore & Kramer, 2005). Five hundred fifty two Indiana public high school biology teachers, when tested on the subject, demonstrated "only a moderate level of understanding of evolutionary theory," providing correct responses to 71% of questions on a supplied-response questionnaire (Rutledge & Warden, 2000). Rutledge and Warden (2000) reported that many teachers had difficulty with questions related to the following concepts: environmental change, reproductive success, the process of evolution, the role of genetic variability in natural selection, the approximate date of the first life on earth, and radiometric dating principles. Rutledge and Mitchell (2002) reported on the 235 of the 552 Indiana teachers who, in addition to completing the above-mentioned questionnaire, also constructed a concept map about evolution that was used by the researchers to assess the teachers' conceptions of evolutionary theory. One misconception identified in the concept maps was the characterization of evolution as "only a theory" or "only a hypothesis" (Rutledge & Mitchell, 2002, p. 24).

Teachers' acceptance of biological evolution influences how they approach the subject in their classrooms. Rutledge and Mitchell's (2002:22) survey showed "a significant association between teacher acceptance of evolutionary theory and the amount of time devoted to evolution in the school year." Of the Indiana teachers surveyed, 33% were undecided about or not accepting of evolutionary theory and 43% reported that they either avoided or only "briefly mentioned" evolution in their classes (Rutledge & Mitchell, 2002, p. 22). Weld and McNew (1999) found that approximately one-third of teachers in Pennsylvania did not accept evolution as being central to biology and more than one-third of teachers in South Dakota supported the teaching of creationism in science classrooms. Based on Rutledge and Mitchell's (2002) results, one can infer that the amount of time dedicated to teaching evolutionary theory was not adequate in all classrooms in those states.

Weld and McNew's (1999) findings are also significant because research has shown that students' knowledge structure tends to reflect that of their teachers (Bates, 1976 and Diekhoff, 1983 cited in Rutledge & Mitchell, 2002; Moore & Cotner, 2009). Recent research by Moore and Cotner (2009) also shows that university students' attitudes toward evolutionary theory and creationism strongly reflect - though are not solely based upon - how their high school biology teachers addressed the topic of evolutionary biology. One thousand eight students at a state university in Minnesota were surveyed using the Measure of Acceptance of the Theory of Evolution (MATE) instrument created by Rutledge and Warden (1999) and reliability-tested by Rutledge and Sadler (2007). Those students whose public high school biology teachers taught evolution (and not creationism) were more accepting of evolutionary theory than those students who were taught creationism (with or without evolution; Moore & Cotner, 2009, p. 430). This implies that if public high school biology teachers are unaware that public schools are required to be religiously neutral according to the First Amendment of the Constitution (therefore making the teaching of creationism as the explanation for life's origins in biology class illegal) and/or have misconceptions about evolutionary theory, students may enter college with preconceptions about the epistemology of evolutionary biology and/or may lack knowledge of evolutionary theory all together.

College and university instructors would benefit from an awareness of the misconceptions of high school biology teachers for two major reasons. Firstly, such knowledge would allow tertiary instructors to teach more effectively; if they know the misconceptions that their incoming students inherit from their teachers, they can design coursework to correct these ideas sooner rather than later in the student's college career. Secondly, it encourages tertiary educators to be proactive in aiding the professional development of teachers to prevent misconceptions from being taught in the first place. This can be made particularly relevant for those instructors who are employed by state universities or colleges where a majority of the student body hails from the state in which the institution is located. One such institution is Arizona State University (ASU).

On May 9, 2009, a teachers' workshop called "Translating Evolutionary Science into the Public Classroom" was presented to Arizona public middle school and high school science teachers on the Tempe campus of ASU as part of a year-long series of events in celebration of Charles Darwin's 200th birthday (darwin.asu.edu). ASU is a public university that, in Fall 2007, had over 50,000 full-time equivalent (FTE) undergraduate students enrolled in the University's various colleges, including over 22,000 in the College of Liberal Arts & Sciences and nearly 3,000 in Education or Teacher Education (ASU Fact Book, 2007-2008). The student body included 40,000 students who had a permanent address in Arizona at the time of enrollment and approximately 90% of those Arizona students had permanent addresses in Maricopa County, where ASU is located (ASU Fact Book, 2007-2008).

Despite the large number of Arizona students attending ASU, only about 50% of Arizona's 2006 high school graduates qualified to enter one of its three state universities ("Arizona High School Eligibility Study," 2006). In 2005, 51% of Arizona's eighth grade public school students were performing below the basic level of achievement in science ("The Nation's Report Card," 2008). And in 2008, Arizona high school students (many of whom were in eighth grade in 2005), took the first science exam administered as part of the Arizona Instrument to Measure the Standards (AIMS); more than 62% of those students who took the science portion failed it (Madrid, 2008). Though the science AIMS test is *not* a requirement for graduation from Arizona's public high schools, unlike the reading, writing and math portions of the AIMS, the Arizona State Board of Education will require three credits of science "in preparation for proficiency at the high school level on the AIMS test" for the class of 2013 (Arizona Administrative Code, 2009). This means that Arizona science teachers are more obligated than before to teach evolutionary theory because questions pertaining to evolution appear on the AIMS science test. As a result, many teachers will need professional development opportunities, such as university-lead workshops, on evolution.

The issues surrounding the teaching and learning of evolution in Arizona's public schools concern not only potential high school graduates, but all students who attend ASU. ASU requires that all students in a bachelor's degree program fulfill 35 semester hours of approved general studies courses, including eight semester hours of "Natural Sciences." Courses that may fulfill these requirements include (but are not limited to), *General Biology I* (BIO187), which deals extensively with evolutionary theory, and *Bones, Stones and Human Evolution* (ASM104), an introductory physical anthropology course[2]. Many non-science majors enroll in these courses to partially fulfill their general studies hours; of 1080 undergraduate degree students with a declared major who signed up for ASM104 between Fall, 2003, and Spring, 2007, only 121 were Anthropology majors. Therefore, adequate training in high school biology can potentially contribute to the success of students of all majors at ASU[3].

The foundations for the "Translating Evolutionary Science into the Public Classroom" workshop were the relatively new standards-based emphasis on teaching and learning science in Arizona's public schools, the need to better prepare Arizona's middle and secondary school students for challenging science coursework at the university-level, and the myriad concerns, social, political, psychological, legal, and scholastic, that teachers have about the teaching of evolution in their schools. Therefore, the goals of the workshop were to: (1) provide teachers with knowledge and resources to more effectively teach evolutionary theory, (2) increase teacher awareness of legal and cognitive issues associated with the teaching and learning of evolution, (3) address teacher

[2] Students who receive a score of 4 or 5 on the Advanced Placement (AP) Biology exam in high school receive 8 general studies hours, equivalent to BIO187 and General Biology II (BIO188). Although approximately 75% of the AP Biology curriculum is based on evolutionary theory (College Board AP, 2009), some ASU students report that they did not learn about evolution in their AP Biology courses (CMS, unpublished data).

[3] In the 2007-2008 academic year, 16.85% of students who completed BIO187 received a grade of D or E (the equivalent of an F at other universities; azcentral.com Data Center, 2009). From Fall, 2003, to Spring, 2007, 7.5% of students enrolled in ASM104 withdrew and 13.6% received a D or E.

misconceptions about evolutionary theory, (4) assess teachers' acceptance of evolutionary theory, and (5) make inferences about the preparedness of Arizona's public school students for a rigorous university life science curriculum that includes evolutionary biology. In what follows, we summarize the components of the workshop, but focus on the results of the measures of teacher acceptance and conceptions of evolutionary theory. In so doing, we hope to demonstrate how and why educators can and should be involved in improving student preparation for college and university science coursework to ultimately maximize the achievements of tertiary educators in their own classrooms.

Workshop Summary and Outcomes

Applications for participation in the evolution workshop were solicited from public school science teachers in Arizona and thirteen teachers were accepted. At the time of the workshop, two teachers were employed at middle schools and eleven teachers were employed at high schools, all within 50 miles of ASU. The experience of the teachers ranged from 1-2 years to more than 21 years of teaching science in public schools. Science classes taught by the participants included, but were not limited to, 7th grade science, 8th grade science, Biology, Honors Biology, AP Biology, International Baccalaureate (IB) Biology, Anatomy and Physiology, Earth Science, and Environmental Science. Teachers were compensated with a stipend upon completing the workshop. Table 1 summarizes the results of a follow-up survey question that asked the teachers to indicate why they attended the workshop (teachers were given 6 provided responses and an option to write-in a response).

The teachers were given four pre-workshop reading assignments culled from material from the National Center for Science Education, Nature Magazine, and the National Academies Press. The workshop was divided into seven mandatory sessions with an optional eighth session. The sessions, with a short description, are listed in Table 2. The total contact hours between the teachers and workshop faculty were seven and one half.

Teacher acceptance of evolution

The Measure of Acceptance of the Theory of Evolution (MATE) survey created by Rutledge and Warden (1999) was given to the teachers at the beginning of the workshop and again after session 7 (see Rutledge & Sadler, 2007, for a discussion of the reliability of and concepts addressed by the MATE). Teachers were asked not to write their names on the MATE, however all participants optionally provided their gender and/or age. The goals of administering the MATE twice were to assess the consistency of the teachers' responses and note any potential influences of the workshop on their acceptance of evolution (these cannot be clearly distinguished). The MATE includes twenty statements to which the teachers were required to respond "strongly disagree," "disagree," "undecided," "agree" or "strongly agree." Individual answers were scored using Likert scaling (1 = low acceptance of evolutionary theory and 5 = high acceptance of evolutionary theory) and, based on their total score, teachers' responses were assigned to an acceptance category created by Rutledge (1996; see Table 3).

Table 1. Responses of teachers about why they attended the workshop (*n = 11*).

Statement: "I attended the workshop…"	**Strongly Disagree**	**Disagree**	**Un-decided**	**Agree**	**Strongly Agree**
to increase my working knowledge of the principles of evolutionary theory.				2	9
to learn more about the laws associated with the teaching of evolutionary theory.	1		1	2	7
to learn more about how to properly address the evolution/creationism issue in my classroom.	1		1	2	7
to learn about other teachers' experiences with teaching evolutionary theory in their classrooms.			2	7	2
to learn about resources for teaching evolutionary theory effectively (e.g., print and web resources).				2	9
because of the stipend.		5		6	

The mean score for the pre-workshop MATE was 89.9 and the mean for the post-workshop MATE was 93.3 (both "very high acceptance"). Six respondents' category of acceptance of evolution changed from "high" to "very high," but three individuals had a lower score on the post-workshop MATE than the pre-workshop MATE (by 9, 10, and 3 points), causing two of them to drop from the "very high acceptance" category into the "high acceptance" category. The teacher whose score dropped by 9 points changed his/her view about items related to the evolution of humans, a topic that was not specifically addressed in sessions 1-7. The participant whose score dropped by 10 points primarily changed his/her responses to items concerning the support - both evidence-based and in the scientific community - for evolutionary theory. It is unclear what aspect(s) of the workshop, if any, lead these teachers to change their views. There was no single item for which every participant provided the same response on the post-workshop MATE as he/she did on the pre-workshop MATE.

Table 2. Workshop sessions.

Session	**Description**
1. Concept Mapping	Teachers were introduced to concept mapping as a tool for assessing knowledge structure (Novak and Cañas, 2006) and were given a focus question for constructing their own concept maps about evolution that were used by the workshop leaders to assess their conceptions of evolutionary theory.
2. Presentation: “Teaching Evolution One Icon at a Time”[4]	Teachers were introduced to the strategies (e.g., “intelligent design”, “teach the controversy” or “teach the strengths and weaknesses of evolution”) that are being used at the state and local level to weaken the teaching of evolution and ways of dealing with those strategies were discussed.
3. Presentation: “Why is evolution so hard to accept?”	The session addressed innate and developmental biases that encourage people to look for centralized, intentional agents as causal forces, making evolution counterintuitive.
4. Presentation: “Evolution, Creationism and the courts”	Teachers were provided with a summary of recent court cases and legal issues surrounding the teaching of evolution and creationism in America’s schools.
5. Web exploration	Teachers were introduced to online biology resources and given the opportunity to explore the World Wide Web to search for resources about evolution (and issues surrounding evolution and creationism).
6. Misconceptions about evolutionary theory	This session addressed misconceptions identified in the teachers’ concept maps (constructed in session 1).
7. Presentation: Evolution, standardized tests, and preparing for college	Discussion of evolution in standardized exams, such as the AIMS science test and AP Biology exam, requirements for graduation from AZ high schools and general studies requirements for ASU students.
8. Optional tour of ASU’s Institute of Human Origins (IHO)	Teachers were given an overview of the subject matter that can be presented by researchers to students on a field trip to the IHO.

[4] Slides from this session are available online at http://www.slideshare.net/jmlynch/teaching-evolution-one-icon-at-a-time.

Table 3. Results of MATE survey (*n = 12*)[5].

Category of Acceptance (MATE score)	pre-workshop MATE	post-workshop MATE
Very high acceptance (89-100)	6	10
High acceptance (77-88)	6	2
Moderate acceptance (65-76)	0	0
Low acceptance (53-64)	0	0
Very low acceptance (20-52)	0	0

Though confounding factors and small sample sizes prevent us from identifying a statistical correlation between attendance at the workshop and level of acceptance of evolution, comparisons of pre- and post-workshop MATE responses indicate that the majority of teachers were more confident about the scientific basis for evolutionary theory after completing sessions 1 through 7. The item for which the mean score increased the most (1 point) from pre- to post-workshop was the statement, "Current evolutionary theory is the result of sound scientific research and methodology." In the follow-up survey, participants were asked: "How has your attendance at this workshop affected your confidence about teaching the material (i.e., vocabulary, concepts, etc.) associated with the topic of evolutionary theory?" Nine out of ten respondents to this question[6] reported that they felt "more confident" or "much more confident" (one respondent reported no change). In reply to the question, "Given any social, legal, or ethical concerns you may have, how has your attendance at this workshop affected how you feel about teaching evolutionary theory in your classroom?," eight out of ten participants said they felt "more comfortable" or "much more comfortable" (two respondents reported no change). This is theoretically significant because teachers' acceptance of evolution correlates with the amount of time spent teaching about evolution in their classrooms (Rutledge and Mitchell, 2002). Therefore, if teachers' acceptance of evolution as a scientifically valid theory can be increased, the likelihood that they will spend more time teaching about evolution is increased. And, if one assumes that the quality of teaching about evolution is, in part, related to teacher confidence and comfort, then, overall, this type of professional development for teachers would lead to better preparation of middle or secondary school students for a college or university life science curriculum.

Teacher conceptions of evolution

The first session of the workshop comprised a discussion of concept maps as "graphical tools for organizing and representing knowledge," an introduction to web-based concept

[5] One teacher did not respond to the pre- or post-survey using the responses required, so his/her surveys were not included.
[6] The electronic follow-up survey was not started by all participants, nor was it completed by all respondents.

mapping software (CmapTools), and an exercise requiring the teachers to construct their own concept maps about evolution (Cañas et al., 2004; Novak and Cañas, 2006:1). Some teachers indicated that they had used concept maps previously in their classrooms.

At the start of this session, one of the workshop leaders discussed some mechanisms of evolutionary change with the teachers and wrote these on a white board. The teachers were then given a focus question on which to base their concept maps: "What are the components and implications of evolutionary theory?" Teachers were permitted to use the discussed mechanisms as part of their parking lot[7] for constructing their concept map. The leader encouraged the participants to put 15-20 words or short phrases in their parking lot before constructing their concept maps. Participants had approximately 20 minutes to complete this exercise.

The teachers' concept maps were collected and analyzed by workshop leaders to identify misconceptions about evolutionary theory[8]. The most common misconceptions noted in the concept maps fell into three categories: misconceptions about Charles Darwin's role or discoveries, about mechanisms of evolutionary change, and about the meaning of commonly used terms or phrases in evolutionary biology. Instead of presenting the teachers with a list of their misconceptions, scientifically accurate statements were provided that addressed the concepts teachers had trouble with, ensuring that their notes from this session would include information that was scientifically correct (see Table 4).

The workshop session addressing teacher misconceptions was well received by the participants. Ten of eleven respondents to a follow-up survey question about this session reported that they were "satisfied" or "very satisfied" with the session's content[9]. Open-ended feedback about this session included the following: "*This was the best part of the entire day…I believe that there are numerous misconceptions about the whole process of evolution and the history behind it. I know that I have some. As an educator it is so difficult to find time to read all that is out there and it is wonderful to have an expert in the field clarify some of those. I would really enjoy attending workshops that deal* [just] *with misconceptions and the content area of the theory.*"

This feedback indicates to us that there are teachers eager to learn from professionals in the sciences about the evidence for evolution and history of evolutionary theory. This passing of knowledge from expert to teacher would affect classroom instruction, and presumably, classroom learning. Approximately 86% of participants ($n = 9$) indicated that the content of session six would "likely" or "very likely" affect their approach to teaching evolution. It is therefore crucial for experts in the fields of life sciences, geology, the history of science, psychology of education, and others, to work with elementary and secondary school educators to clarify the epistemology of evolutionary

[7] A "parking lot" is a list of terms or short phrases associated with the topic in question and can be used to construct the concept map (Novak and Cañas, 2006).

[8] One teacher constructed a map closely resembling a string map (see Novak and Cañas, 2006:11) and one teacher did not use linking words at his/her cross-links, which made them more challenging to analyze than the others.

[9] One participant responded "dissatisfied;" however, he or she wrote, "*I thought it was a very valuable piece,*" so the response "dissatisfied" is taken as an inaccurate reflection of the individual's opinion.

theory and improve public school science pedagogy. The pragmatic benefit of this for tertiary-level instructors would clearly be less time and effort spent battling the misconceptions their students have carried over from their earlier school days.

Table 4. Scientifically accurate conceptions intended to address common misconceptions of teachers.

Topic	**Concept**
Charles Darwin's Role and Discoveries	Darwin did not invent the idea of biological evolution.
	The Galapagos Islands and their finches played a relatively minor role in the development of Darwin's idea.
	Darwin was not aware of Gregor Mendel's work.
	Darwin accepted other mechanisms of evolutionary change besides natural selection.
Mechanisms of Evolutionary Change	Today we accept natural selection, mutation, genetic drift and gene flow as separate mechanisms.
	Natural selection has no forethought.
	Natural selection *is* differential reproductive success, not the *cause* of it.
	Natural selection (or evolution generally) is not driven by mutation.
	Fitness refers to reproductive success.
	Fitness is defined relative to an environment – environmental change leads to different selection pressures.
	Artificial selection is usually done with some goal in mind – natural selection is not thought of as goal-oriented.
Commonly used phrases or terms	"Missing link" has been a misleading term that has implied that there is a direct evolutionary sequence among living species.
	"Survival of the fittest" is misleading shorthand for natural selection. There are many reasons besides actually dying that lower reproductive success.

Conclusions

As part of the follow-up survey, 100% of the participating teachers indicated that they would recommend this evolution workshop to other educators, though 70% ($n = 10$) said they would prefer a multi-day workshop with more content to a single-day workshop with the content described above. The greatest proportion of criticism related to the teachers' dissatisfaction with the amount of time dedicated to particular sessions. Many of the teachers wanted to spend more time in session 3, which addressed innate and developmental biases that make evolution counterintuitive. Only a short segment of the entire workshop was spent addressing specific content and misconceptions about evolution, and based on the follow-up survey, all of the teachers attended the workshop to increase their working knowledge of the principles of evolutionary theory and learn about resources for teaching evolution effectively (see Table 1). If this workshop were offered again, more time would be dedicated to biases, misconceptions, content and resources for teaching.

Clearly, there is a demand for professional scientists who are willing to reach out to educators in their community and share with teachers their expertise, which can then be passed on to school age students. One respondent wrote on his/her follow-up survey: "*I would like to help ASU scientist[s] to translate/communicate their science to their future students, currently my science students.*" The benefits incurred by the tertiary educators reach beyond the personal rewards of community outreach and into their classrooms; if college and university educators can contribute to the knowledge, confidence, and comfort of America's public school teachers when it comes to teaching evolution, fewer teaching challenges will be met at the post-secondary level.

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