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Learning and Intending to Teach Evolution: Concerns of Pre-service Biology Teachers

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Introduction

The scientific community has accepted that evolution is a unifying theme in biology, just as Dobzhansky (1973) stated in his oft-cited article, "Nothing in biology makes sense except in the light of evolution." Yet this scientific theory has provoked much public discord around the world despite eight professional scientific organizations convening to issue a joint statement detailing their acceptance of evolution (Futuyma 1999), in addition to at least two science teacher organizations that have proclaimed their support for the teaching of evolution in public schools (NAS 1998). Scientists continue to teach that evolution is a central concept in natural sciences, yet many teachers do not understand or accept evolution as an explanation for the diversity of life on Earth (Alberts and Labov 2004; Brem et al. 2003; Miller et al. 2006; Verhey 2005).

Despite scientists' acceptance of evolution as a central concept in biology, Moore (2000) found that only 57 % of teachers across the USA regard evolution as a unifying theme in the science. Trani (2004) found that 16 % of Oregon public high school biology teachers do not present evolution at all and concluded that teachers who do not personally accept evolutionary explanations for diversity of life or who do not understand it do not present it in their classrooms. In other words, teachers' attitudes about evolution and learning it affect their willingness to teach it. To meet the objective of improving Americans' understanding of evolution, it is imperative that teachers not only understand and accept evolution but intend to teach it as well. Hence, exploratory studies of how pre-service teachers learn evolution are valuable. This study sought to identify how six pre-service biology teachers, enrolled in a college evolution course, made meaning of evolution and how this contributed to their intentions to teach evolution as teachers.

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Background

Learning and Teaching Evolution

Teachers often avoid teaching evolution if they do not understand key terms or processes. Some of the common documented misconceptions include: evolution is unobservable, not testable, and explains the origins of life; evolutionary changes are directed by organisms; evolution is progressive: humans are at the end of the "ladder;" organisms evolve from simple to complex; fit animals are the strongest animals; animals that are more closely related to humans have more control over their evolution; natural selection is the only mechanism of evolution, there is no directional selection; evolution is random; and mutations occur because they are induced by the environment because organisms need them (Anderson et al. 2002; Antolin and Herbers 2001; Bishop and Anderson 1990; Demastes et al. 1995; Settlage and Jensen 1996).

Of the many identified alternative conceptions, some may arise due to confusing colloquial definitions that differ markedly from scientific ones; these include adaptation, fitness, competition, biological evolution, belief, and theory (Anderson et al. 2002; Bishop and Anderson 1990; Bizzo 1994; Demastes et al. 1995; Rector et al. 2012; Rowe 2004; Smith 1994). Adaptation is most often thought to refer to Lamarckian changes that an organism makes within its lifetime. Students equate acclimation with adaptation, and some students believe that acquired characteristics are heritable (Anderson et al. 2002). Fitness is often mistakenly identified as the physical or intellectual ability of an organism, as opposed to an organism's relative ability to survive and reproduce (Bishop and Anderson 1990). Settlage and Jensen (1996) coined the term "Disney effect" to describe the misconception that "furry, cute" animals are more intelligent than scaled or feathered ones. Bizzo (1994) found that students in Brazil had difficulty recognizing the difference between biological competition and fighting and also between biological and cultural evolution.

Some students develop pre-conceived explanations of natural phenomena that are often incompatible with scientific theories (Crawford et al. 2005). Students at both high school and college levels use anthropomorphic language to describe animals and often use teleological explanations in the process (Demastes et al. 1995; Rowe 2004; Settlage and Jensen 1996; Southerland et al. 2001). These findings reveal that students believe organisms can control and direct their own evolution. In addition, Catley and Novick (2009) described students' difficulty in reading phylogenetic trees, an indication that students do not understand how evolutionary biologists document relationships between homologous species. In fact, they argue these findings indicate students' lack understanding of how speciation occurs.

Rutledge and Warden (2000) found that there was a correlation between acceptance and teaching of evolution in their study of Indiana state teachers. They analyzed data from 55 % of all 989 public high school teachers who participated in their study. At least a fifth of all high school biology teachers in this study were undecided about or did not accept (a) the validity of evolution, (b) that humans are the result of evolutionary processes, (c) that evolution is well-supported, (d) the current accepted scientifically-determined age of the earth, and (e) the ability of evolution to explain phenomena. Sinatra et al. (2003), in their study of non-majors in college, found that there was no relationship between beliefs and understanding of evolution, though. They argued that science educators must integrate nature of science concepts with evolution instruction. Smith (1994) pointed out that students might interpret the term "belief" to mean faith, opinion, or conviction as opposed to the term "acceptance." As a result, Smith advised science educators to avoid using the word belief because it leads to discussions of evolution as being open to religious examination. However, Ha et al. (2012) suggested that what is more important is for science educators to help their students make sense of words, their meanings, and the importance in scientific contexts.

People develop their ideas about evolution from many different sources, which may be personal (religious beliefs) or societal (schools or media). In turn, students bring their religious understanding of the world and the origin of species with them to classrooms (Winslow et al. 2011). In this vein, Nieswandt and Bellomo (2009) suggested that more research is needed on the role that students' worldviews play in the development of their "meaningful understanding of evolutionary theory" (p. 353).

Conceptual Change Theory

Educators have long been interested in how learners identify and resolve their misunderstanding about scientific concepts. The process of becoming disillusioned with one's own alternative conception and replacing it with a scientifically accepted conception is described in the *conceptual change model* (Posner et al. 1982). Within this model learners' cognitive frameworks are described as conceptual ecologies with interconnected relationships. If one concept is changed, it will have epistemological consequences. The conceptual change model (CCM) assumes that learners must first be dissatisfied with a prior conception before finding an alternative one intelligible, plausible, and fruitful. Hence, the new conception should be one that is understandable to the learner, can explain prior knowledge, and can be used to make sense of novel examples. Despite being criticized for not incorporating sociocultural factors such as motivation, achievement goals, and beliefs (Linnenbrink and Pintrich 2002; Pintrich et al. 1993), Strike and Posner (1992) explained that the CCM was not intended to exclude affective factors. Subsequently, Demastes-Southerland et al. (1995) reported that affective factors are indeed important in the conceptual change process. It is not always understood why some learners are able to resolve their dissatisfaction by finding new conceptions to be feasible alternatives (Duit and Treagust 2003; Sinatra and Pintrich 2003). Levels of engagement have been reported to affect reflection, learning, and conceptual change (Dole and Sinatra 1998) and are influenced by how valuable students determine their efforts to be, which can be measured through learners' achievement goals (Linnenbrink and Pintrich 2002).

Sociocultural Theory and Studying Meaning Making

Learning is influenced by context: topic, group members, accepted language, leaders, learning goals, rituals, and prior knowledge (Stryker 2008; Shanahan and Nieswandt 2011). Sociocultural theorists recognize that people learn by interpreting and using language and symbols (Gee 2004; Lemke 2001). As a result, learning is situated and contextual (Brown et al. 1989; Lave and Wenger 1991). Greeno and van de Sande (2007), using a situated view of group interactions in learning environments, examined how conceptual growth can occur. They argued that groups can *problematize* or resolve understandings through their interactions and, in the process, change the sense of conceptual agency. Through a construction of *perspectival understanding*, the authors were able to better explain how class participants underwent conceptual growth. In other words, the learning context and a shared sense of agency can affect conceptual understanding. Taking account of affective factors when studying learning allows a more meaningful examination of the learning process because learning can be context dependent (Greeno 1997; Johnston et al. 2006).

Dole and Sinatra (1998), in an effort to integrate the CCM and sociocultural factors, constructed the cognitive reconceptualization of knowledge model (CRKM) in which "the message" is as critical to conceptual change as is the learner's response to it. They recognized that the learner's struggle between affective and cognitive understanding could be influenced by external factors. For example, the CRKM takes into account that "social context" may affect the learner's engagement level. The authors recognized that some learners are intentional about their engagement because of a desire to understand the concepts. To examine meaning making, researchers must study what the learner says and does in or in response to the social context because these are indications of what they think and believe (Charmaz 2005). Grounded in conceptual change and sociocultural theories of learning, this study sought to identify how pre-service biology teachers learned evolution as well as their intentions to teach evolution.

Research Questions

This naturalistic study began with an overarching question: How do undergraduate biological science education (BSE) students make meaning of natural selection and evolution in a college evolution course? The following three research questions (RQ) guided this study:

1. Did BSE students change their conceptions about evolution by the end of the course?
2. What were participants' perceptions of the learning environment?
3. How might participants' perceptions of the learning environment explain what they learned (or did not learn) about evolution?

Methods

This grounded theory study was informed by multiple methods from which various types of data (diagnostic pre/posttests, interviews, written responses, and field notes) were collected and analyzed. Following the Chicago School of grounded theory I recognized that human behavior should be studied from a constructivist perspective, that individuals learn in social settings, and that experiences shape how we make sense of our world. Charmaz (2000) described five tenets of the Chicago School of grounded theory, which include: (1) establishing a close relationship with participants; (2) focusing on dialogue, behaviors, and gestures used to communicate; (3) recording and finding meaning in communication; (4) being sensitive to the meaning placed on objects and language; and (5) studying how words and actions are used in communication. This study was initiated with no *a priori* predictions about outcome and a constant comparison of data sources began as data were collected, in the tradition of grounded theory methodology (Strauss and Corbin 1990).

Setting

This study took place in an undergraduate Evolution course offered at a public university in the upper mid-western USA. There were 35 upper-division students (30 juniors/seniors and 5 graduate students) enrolled. The course was required of all Biology and BSE majors; however, other life science majors were also enrolled during the study.

The Course

The course met twice a week for 1.5 h each period. The instructor described two central themes of the course as, "1) all life processes are completely physical and chemical and 2) all organisms and characteristics are products of evolution." The definition of evolution used in class was cited as that used by Futuyma (1998) "descent with modification." The topics covered included: historical background: origin of species, patterns of evolution, genetic systems, Hardy–Weinberg equilibrium, polymorphisms, evolutionary rates, molecular evolution, and co-evolution/evolutionary interactions (Table 1). These topics covered all ten sub-constructs assessed in the diagnostic instruments used (described below), and were confirmed through field notes and interviews with the course professor. Students were assigned readings and one presentation each during the semester, which could highlight either an example of natural selection or a speciation event. Other students were expected to read at least two journal articles that the presenting student used to develop his/her presentation. There were always three students who read the papers chosen by each presenter to ensure that there were short discussions following the presentations. Points were awarded for the following assessments: class participation—which included the presentation/questioning and three exams. The exam format was short response and short essay questions. The textbook used for the course was *Biological Evolution* (Price 1996).

The Instructor

The instructor was a Euro-American male who was a tenured professor in the Biological Sciences department with a background in botany. He had taught evolution for the previous

Table 1 Participants were categorized as having "learned evolution" if they demonstrated understanding of the following 10 sub-constructs of evolution by natural selection, assessed using the CINS instrument and essay (see "Appendix" for prompts). All potential sub-constructs that could be drawn upon to answer each essay are listed depending on how in-depth each participant responded. The units within the course that covered each of the sub-constructs are also listed

Evolution sub-construct assessed on CINS (Anderson et al. 2002) diagnostic test	Questions on CINS	Unit within evolution course that covered each sub-construct	Essay prompt that covered each sub-construct
		History of evolutionary thought	
1. Biotic potential	1, 11	Patterns of Evolution	1, 3
2. Natural resources	2, 14	Patterns of Evolution	1, 3, 7, 8
3. Population stability	3, 12	Hardy–Weinberg Equilibrium	1, 2, 3, 4, 5, 6, 7, 8
4. Change in population	4, 13	Patterns of Evolution; Hardy–Weinberg equilibrium; genetic systems and change	1, 2, 3, 4, 5, 6, 7, 8
5. Limited survival	5, 15	Genetic systems and change; Hardy–Weinberg equilibrium	2, 3, 7, 8
6. Origin of variation	6, 19	Polymorphisms; genetic systems and change	4, 6
7. Inheritence of variation	7, 17	Genetic systems and change;	2, 4, 5, 6
8. Origin of species	8, 20	Origin of species; evolutionary rates	3, 4, 5, 8
9. Fitness	10, 18	Genetic systems and change; Hardy–Weinberg equilibrium	2, 7, 8
10. Variation within a population	9, 16	Patterns of evolution; genetic systems and change; co-evolution/ evolutionary interactions	1, 2, 3, 4, 5, 6, 7, 8
		Molecular evolution (Evolution of new genes)	
		Evolution and society	9

16 years. The instructor was well read on the nature of science and philosophy of science and had incorporated discussions of these into a summer course that was offered to teachers in M.Ed. programs. The instructor used a direct instruction format, and although questions were not solicited, they were answered when asked by students. He made slide handouts available to students a few hours before class, which guided note taking during class. The instructor often integrated rich descriptions and stories into his teaching and used the blackboard to illustrate certain points (e.g., the role of demes in island biogeography studies). He was clearly passionate about research and teaching of evolution and was willing to spend time with students outside of class (before/after class or during office hours) to discuss concepts. He also engaged in discussion with students during class if they asked questions.

Participants

This paper centers on six BSE students who volunteered (self-selected) to participate in a larger study that included 20 students (all volunteer participants) enrolled in this course. Although, there were an additional six BSE students enrolled in the course, they did not volunteer to participate. Thirty-three of the students were Euro-American, and two were Asian American. All study participants were Euro-American and 21 or 22 years old, with the exception of one "career changer" (a BSE student who was 33 years old). The graduate students were present during all class activities except during the administration of the diagnostic pre- and posttest. Graduate students were expected to attend a journal-reading group. As a result, they became familiar with one another, sat together during lectures and studied together outside of class.

Data Collected

Diagnostic Test

A field-tested published diagnostic test, *the Conceptual Inventory of Natural Selection* (CINS; Anderson et al. 2002), was administered the first and last weeks of the course. To determine if participants were representative of the whole class as well as non-participating BSE students, *t* tests were conducted using JMP Pro 10.0.2, ©2013 SAS Institute Inc. The 20-point multiple-choice test was designed to evaluate knowledge of 10 sub-concepts of evolution, with two questions per sub-concept. These sub-concepts, as identified by the test developers, include: biotic potential, natural resources, population stability, change in population, limited survival, the origin of variation, inheritance of variation, the origin of species, fitness, and variation within a population. The test scores, along with interview and written responses, helped me establish which of the participants learned and understood evolution by natural selection.

It is important to note that the CINS has been examined and critiqued since its publication (Battisti et al. 2010; Nehm and Schonfeld 2008, 2010). Using a modified item response theory model Battisti et al. (2010) identified that some distractors used in the CINS instrument were problematic. For example, they concluded some distractors might have been chosen or avoided because of the wording. Nehm and Schonfeld (2008) suggested that the CINS can falsely overestimate student understanding of evolution by natural selection and were critical of forced-response instruments. In addition, Nehm and Ha (2011) argued that the context of learning affects assessment of evolution understanding. Opfer et al. (2012), in response, developed and tested a new instrument, Assessing Contextual Reasoning about Natural Selection (ACORNS) that relies on open-response items. This new instrument was published after the current study was conducted and was not used for that reason. The CINS instrument has been criticized if used as the sole assessment of student understanding of natural selection, but because I used other data sources (including talk aloud interviews after both the pre- and posttests) I was able to more reliably measure participants' conceptions of each sub-construct.

Essays

All of the undergraduate students were asked to respond to essay prompts via electronic mail. The purpose of the essays was to assess how well respondents could transfer their knowledge of evolutionary concepts, presumably learned in lectures, to novel examples. This assessment was not intended to be a spontaneous response (as during an interview), rather a thoughtful, reflective response and participants could use their class notes or textbook to construct responses. Reflective writing about evolution has been shown to be important in helping college students make meaning of evolution (Balgopal and Montplaisir 2011). I collaboratively constructed the essay prompts with the instructor, and after review by one other evolutionary biology professor, these were sent to students, who had one week to respond. The instructor gave little instruction on how to respond to essay prompts. Students were told that the instructor and researcher developed the prompts together but that all essays should be submitted to the researcher. Participation points were awarded to students who completed the assignment in a timely manner. Reflective essays were generally a half to two typed pages long. Some prompts were in the form of a scenario for which students were asked specifically to apply the concepts learned in class when responding to the prompt (see "Appendix"). Other prompts asked students to define terms and describe whether they were satisfied with their understanding. Students were encouraged to interact with peers, use class notes, and read the textbook when constructing their essays. The instructor was open to discussing the questions in class; however, during the semester, no students directly asked about the essay prompts.

Interviews

Each student was interviewed three times during the semester; interviews immediately followed the pre- and posttests, and one was conducted mid-semester. The pre- and posttest interview questions centered around the answers that students chose on the CINS in a think-aloud format. Each interview session lasted 60–90 min and was held in a quiet office on campus. All interviews were audio-recorded and transcribed. The second interview involved three questions for which students were asked to transfer their understanding from lectures (see "Appendix"). Interview data were particularly important in answering RQ1; however, they also helped me to establish participants' understanding of evolution and any conceptual changes that learners underwent (RQ2; RQ3). The instructor was formally interviewed the week prior to the beginning of the semester as well as after the course. Each interview lasted about 30 min during which the instructor described his goals for the course, his perception of the learning needs of the students, and the role that he felt he played in helping students learn about evolution. The second interview also included the instructor's observations about the evolution education class discussion.

Data Analysis

As a participant observer, I recorded discourse, behaviors, gestures, and interactions between the instructor and all students. I engaged in memo writing to capture inferences and reflections made during data collection and analysis (Glaser and Strauss 1973). Through interviews with participants and classroom presence throughout the 15-week course, students got to know me and greeted me in and out of class. I was able to then focus on dialogue, behaviors, and gestures of participants. As I transcribed interviews and reorganized my observational field notes, I formed initial (open) codes and found bridges between categories. Initial codes included: learners' comments regarding their self-identification with their major (BSE), their class status (undergraduate), their pedagogical knowledge (peer interaction, instructional delivery, discursive practice, instructor-student interactions, etc.), and their awareness of perceived challenges (concerns) of their future profession (biology teacher). Constructing student portraits (described in findings) helped me to empathize with the participants so I could interpret written and spoken language, as well as actions from their perspectives. Because meaning making is a dynamic process I continued to record observations of interactions as they occurred in the classroom.

By being sensitive to meaning that was placed on objects and language, I was able to engage in a close study of how participants responded to the instructor's and other students' actions. In a traditional college lecture course, it is not uncommon for much of the time to be used by the instructor for lecturing. Although students were not always engaged in dialogue, they were listening, writing, and interpreting the lectures. Often my notes included actions (e.g., gestures, such as hand-raising to ask questions; placement of chairs during class; lining up to talk to the instructor before/after class) and were interpreted in conjunction with written discourse and interview transcripts. In other words, if a participant explained during an interview that she was confused about content, I asked how she might resolve that confusion, while noting in my memos whether or not this student had actively asked questions of the instructor prior to/during/after class instruction. I was careful to not loosely interpret behaviors without confirmation through other data.

In this process, I examined the open codes and collapsed salient themes into more defined (selective) codes: concerns that others (society, professional peers, personal) had expectations of them. Using narratives and notes regarding classroom behavior, gestures, and discourse, I triangulated examples from the data set to support each theme (Denzin 1989). I continued to do this throughout the study until each coding category was saturated. It emerged that participants often referred to "others," who were categorized initially as science undergraduate classmates, education undergraduate classmates, science graduate students, evolutionary biologists, the instructor, Christian evangelists, Christian non-evangelists, science teachers, future high school students, students' parents, high school administrators, and community members. This broad list was consolidated based on how the participants interpreted these individuals: those who belonged to the participants' community (of practice) and those who did not. For each participant this differed; however, this helped me to describe factors that motivated each individual to learn. Finally, expectations were broadly categorized into selective codes: *professional*, *personal*, or *social concerns*. I subsequently looked for patterns between comments regarding expectations and learning evolution.

The importance of the participants' personal goals, as well as their perceptions of others' impressions and expectations of them, helped me to explicate these students' gestures, language, and behavior in class and their level of willingness to resolve any confusion about evolution concepts. I will describe three "dispositions" that I interpreted during analysis of four main sources of data: pre- and post-scores on a diagnostic test, a total of almost 1,600 min of transcribed interviews (with the instructor and six participants), written documents (10 essays/participant), and field notes that were collected and consulted throughout the study.

Measuring Conceptual Change

For each of the sub-constructs identified in the CINS, student responses were classified as demonstrating "understanding" (a claim that was supported with examples or explanation), "partial understanding" (a scientifically correct claim was made but it was not supported), or "no claim/no support." A matrix was created to organize these data, which were examined by the expert panel. These data collectively were used to determine which participants changed their conceptions to demonstrate understanding.

Establishing Trustworthiness

Throughout the data analysis process, I discussed emerging propositions with a senior colleague who has been a grounded theorist for over 40 years. I regularly consulted with the academic advisor of the six participants who provided other insights about her advisees that helped me concretize my interpretations of their learning. The instructor was consulted over three sessions and gave feedback on the findings, which was integrated into the final propositions. Although all participants scored higher on the posttest than they did on the pretest, not all students were able to justify their reasoning or apply their knowledge about evolution during interviews or reflective writing. These data were shared with an expert panel (three evolutionary biology faculty members), who were recruited as inter-rater coders. They reviewed a subset of both written and oral transcripts after discussions about the coding scheme/process; this helped me construct the matrix. We came to consensus about participants' understanding of evolution, and our agreement rate was 90 %. This was an important process because it helped me classify which participants had undergone conceptual change. The evolution instructor was also an inter-rater coder but only after the course ended, and participated in discussions about which of the participants demonstrated an understanding of evolution. The instructor did not review any essays, interview transcripts, or CINS data during the course. After multiple rounds of coding and debriefing with the expert panel about the findings of student conceptions and perceptions, the salient themes were identified (Strauss and Corbin 1990).

Findings

This study sought to describe how six pre-service biology teachers enrolled in a college evolution course learned evolution, and their intentions to teach evolution. Participants were classified as having one of three dispositions: "Learned evolution/intends to teach evolution," "Did not learn evolution/does not intends to teach evolution," and "Did not learn evolution/intends to teach evolution." The first two dispositions are not surprising and have been described in the literature. The third disposition, "did not learn evolution/intends to teach evolution," warrants discussion because of the possibility of naïve conceptions being perpetuated by teachers.

Based on diagnostic scores alone, the BSE students were representative of the whole class. Participating and non-participating BSE students performed similarly on the diagnostic test (two-tailed t (10)=0.2288; p=0.82). The class as a whole (those who took both the pre- and posttests) performed significantly better on the posttest (CINS) than on the pretest (two-tailed t (27)=4.33, $p<0.05$). There was no significant difference between the pretest scores when comparing both participating and non-participating BSE students to the whole class (participating BSE: two-tailed t (32)=−0.0504, p=0.96; non-participating BSE: two-tailed t (32)=0.8012, p=0.43) or on the posttest (participating BSE: two-tailed t (32)= −0.4922, p=0.63; non-participating BSE: t-tailed t (32)=0.8069, p=0.43).

Although diagnostic tests are useful in assessing groups of individuals, they do not always capture what individual learners understand about a sub-construct. During interviews following the pre- and posttests, participants displayed alternative conceptions primarily about biotic potential, the origin and inheritance of variation, speciation, and fitness when explaining how and why they chose certain responses (Table 2). During interviews, participants were able, for the most part, to explain biotic potential and fitness. However, the origin and inheritance of variation was a source of continued confusion.

All participants (1) identified their dissatisfaction with their knowledge about evolution that they wanted resolve at the beginning of the course, (2) were affected by perceptions of expectations they believed others had of them during the course, and (3) had shortcomings in their understanding of evolution (sometimes resolved, but not always) at some point during the course despite regular attendance and submission of assignments. With a few exceptions, they regularly took notes and appeared to be listening to the instructor during class. Two participants demonstrated increased understanding on three data sources: the posttest, the essay responses, and the interview responses. The other four participants increased their scores on the CINS test

Table 2 A summary of the six participants' conceptions regarding natural selection and evolution. Participants took the Conceptual Inventory of Natural Selection (Anderson et al. 2002) pre- and posttests, and these scores, along with changes in scores are provided. Interview and written data, along with test scores, were used to determine whether participants demonstrated an understanding of evolution theory. Participants' primary concerns, identified predominantly through interviews, were categorized as professional, personal, or social. Reliability of essay codes was established through comparison of codes, with inter-rater coders who were not associated with this study

Participant	CINS pretest	CINS posttest	Area of conceptual confusion	Under-stands evolution after course	Concerns	Intention to teach evolution
Anita	0.7	1.0	Origin of variation; speciation	Yes	Professional: knowledgeable, job security	Yes
Emily	0.8	0.95	Origin of variation; heritable traits	Yes	Professional: knowledgeable, job security	Yes
Kayla	0.45	0.6	Origin of variation; heritable traits; changes in populations speciation fitness	No	Professional: knowledgeable, job security Personal: instructor approachability Social: graduate students	Yes
Toby	0.85	0.95	Heritable traits; speciation; nature of science	No	Professional: knowledgeable, job security	Yes
Peggy	0.75	0.80	Population stability; variations within a population	No	Personal: fidelity to church Professional: sensitive, caring teacher Social: non-Christian judgments	No
Carol	0.70	0.90	Biotic potential; nature of science	No	Personal: fidelity to church Social: non-Christian judgments	No

All names used are pseudonyms

but they were unable to demonstrate understanding on all 10 sub-constructs of natural selection and were therefore not classified in this study as having "learned evolution" (Table 2).

Participants were aware of their *social* roles as learners, their *professional* roles as future teachers, and their *personal* roles (as learners and as Christians). Two participants (Anita and Emily) were able to negotiate all three of these concerns and demonstrate understanding and intentions to teach evolution. Two participants (Peggy and Carol) were unable to negotiate the three concerns and conflicted in their understanding of evolution (demonstrating alternative conceptions of both the nature of science and speciation) and reconciling the expectations of teaching evolution while maintaining fidelity to their faith. Two participants (Toby and Kayla) recognized concerns about their personal understanding and professional expectations but also demonstrated alternative conceptions, as well as an intention to teach evolution.

"Learned Evolution/ Intend to Teach Evolution"

Only Anita and Emily demonstrated, through a combination of their posttest scores, essay answers, and interview comments, that they had substantively changed their prior conceptions about evolution to scientifically accepted conceptions (Table 2). Anita was a returning student after working for 11 years as a microbiologist at a major food company in a large city. She had a B.S. degree in biology from the same institution and decided that she wanted to return to college to earn a teaching license. Anita often described herself as a scientist and as a Christian; however, she felt that these were separate parts of her identity. An organized and meticulous student, Anita took copious notes. She engaged in discussion with classmates after class if she had questions. Unlike Anita, Emily was a junior who had started college as a BSE student. She referred to her science content courses just as often as she mentioned her education courses. She did not define her family as extremely religious. Both Anita and Emily greatly enjoyed learning genetics; Anita had learned genetics as a microbiology research assistant and Emily had taken an advanced genetics course.

Both Anita and Emily demonstrated an increased understanding on their CINS scores, which were reconfirmed during follow-up interviews (1 and 3) and essay responses. For example, on the first essay Emily wrote, "variability is an important factor when considering natural selection because the difference between organisms is how we classify and organize them." She conflated the terms variation (differences within species) and diversity (different species), and on her pretest she, incorrectly answered one of the questions about variation within populations. However, by the end of the semester she not only answered both questions on the posttest correctly, she was able to explain the importance of variation during the interview. Although she reported being confused about the difference between variation and speciation in the first interview, by essay 8 Emily wrote, in response to the question about why intermediate species may not be extant,

> I would guess there are a few reasons why these horses didn't continue on. First, maybe they didn't have the right characteristics to survive, either morphologically or genetically and therefore, they were not fit, with the climate change and environmental changes; they weren't able to continue on.

Anita and Emily still wanted to learn more about evolution, despite demonstrating learning gains by the end of the course and already discussing intentions to teach evolution. Both mentioned wanting to learn more about human evolution:

> I still need to go back and review some things for my own personal benefit so I have a clearer understanding of what's going on… I wanted to cover human evolution. We

> didn't even get to it at all 'cause I know that is the main hot topic in high schools, like, if you want to teach them evolution, they're like, 'oh, you're saying we came from monkeys. (Anita, interview)
> I could study [human evolution] on my own, stuff that I don't know. That's something you don't want to really get messed up, I guess. (Emily, Essay 10)

Both Emily and Anita stated that they intend to teach evolution in high school.

> I would at least try to teach the processes that happen and the different aspects of evolution. I think it's important to know because, I mean, when a lot of people hear 'evolution' they think of well, like how monkeys got into humans. They want to know about that part but there's a lot of other stuff that happens that you can't actually see that I would actually go for. (Emily, interview)

Emily explained her excitement about teaching genetics and the origin of variation. Anita echoed the importance of teaching genetics during evolution instruction.

> You know, they have got all of this genetic proof of how similar everything is down to the gene level, so it's, like, obviously there is a tie-in there somewhere. I just want to get that across to [students] that, you know, we are a lot more similar to other creatures than we are different. (Anita, interview)

Emily, though committed to teaching evolution in high school, also acknowledged some professional concerns of other BSE students in class: "I think job security has a lot to do with it. Yeah, that has a lot to do with it." During the class discussion on teaching evolution in schools, however, neither Emily nor Anita shared their views or asked questions. Both of these participants recognized the professional and personal concerns that are associated with teaching evolution. They also both identified some social concerns (classroom dynamics); however, they seemed to overcome these concerns once they felt comfortable with their understanding of the origin and inheritance of variation (i.e., genetic level processes).

"Did Not Learn Evolution/Does Not Intend Teach Evolution"

Two participants, Carol and Peggy, still held on to alternative conceptions about evolution by the end of the course and also struggled with the professional expectations of teaching. Both of these students felt that their professional concerns were conflated with their personal ones (as Christians). Carol was a junior and grew up as a Lutheran. Starting college as a biotechnology/ microbiology major she switched to BSE after taking two years off to work in a wheat genetics laboratory. Carol did not participate in class discussions and sat on the side of the room towards the back. She often brought the college newspaper to class that she sometimes read discretely during class; she did not take many notes during lectures.

Also a former microbiology major, Peggy was a transfer student from a community college in a nearby farm town who switched to BSE. Like Carol, she kept to herself and did not talk to classmates. She came from a family of teachers and had always considered teaching a career possibility. She discussed her recent conversion to evangelical Christianity after being brought up as a Lutheran. Peggy indicated that her husband and in-laws had a major impact on the personal decisions she made regarding her professional and family goals; they were very disapproving of mothers working outside of the home. When the study began, Peggy seemed very excited about becoming a science teacher. This excitement waned towards the end of the study when she confided in me that her husband wanted her to be a "farm wife and mother." By the end of the study, Peggy told me that she was pregnant.

Carol and Peggy had both improved their test scores and both displayed confidence when explaining how and why they chose each answer on the CINS. They both appeared to have a solid understanding of molecular genetics and the origin of species by the end of class. As microbiology students (before becoming BSE majors) they both had completed several courses that covered molecular biology and bacterial genetics. Yet making the connection between genetic changes and evolutionary processes was new to them. Carol explained in the last interview, "I think I had a lack of understanding of natural selection. It's not correct to think that mutations occurred to meet the needs of the finches. Genes aren't smart. They don't make decisions that better themselves." Unlike other participants they made distinction between "microevolution" and "macroevolution," indicating that they accepted that genetic changes accumulate over time which can result in adaptations but that when those adaptations reproductively isolate populations from one another, as happens in speciation events, they found this less acceptable.

> I don't have a problem with microevolution–changes within bacteria becoming antibiotic resistant, but the whole evolution, you think 'monkeys to man.' That's what I have problems with. I think microevolution is changes that happen like small changes. I am talking the changing, I don't know, like antibiotic resistance or a weed becoming resistant to a pesticide. Those are small changes. When you talk about one species becoming a different species, like a fish turning into a reptile, that's what I have a problem with. (Peggy, interview)

Carol was able to explain the process of speciation in response to essay prompts. Her responses demonstrated an understanding of the role that natural selection plays as a mechanism for evolutionary change. She even accepted that it should be considered a unifying theme. She did express, however, her reservations regarding human evolution:

> I think [the theory of evolution] brings a broader understanding of how the body works and how life on earth is in constant friction and is changing and adapting. I personally have a problem with teaching it as the "origin of man" or the explanation for life on earth, but that is because I don't feel that it has been proven or that it can be proven.

These two participants felt that their classmates were not sensitive to the concerns of creationists who try to balance their fidelity to their religious beliefs while learning about the theory of evolution. Without knowing each other's beliefs both participants revealed how they felt isolated from the rest of the class:

> I think it's really easy for people who are not going into teaching to say, 'oh, you have to do this; this is something that you have to do' when it's not always cut and dry. (Carol, interview)
>
> He said 'people who believe in creation,' people who believe in creation… was he talking about everyone? I didn't really understand and so it was just, I kind of felt the whole class was building against creation. (Peggy, interview)

Peggy and Carol discussed their struggles to maintain fidelity to their religious beliefs while accepting evolutionary theory as the explanation for diversity. Both of them had personal expectations of not compromising their religious identities and each reached pivotal points that helped them decided that they could not teach in evolution as teachers. Peggy struggled with her dilemma to be a faithful evangelical Christian while studying to be an informed teacher. She felt that burdening her students with making a choice was unethical. Peggy reached a pivotal point during the second interview during which she broke out into tears. We interrupted the interview so Peggy could regain her composure. After this interview Peggy seemed much more calm and sure of her convictions.

> It's like telling one side of the story. I am never going to walk into a classroom personally and say evolution… I won't say that. I am going to say the theory is this and you don't have to believe in that. I am never going to put the pressure on someone, on a child to believe in it. [Peggy, crying]

By the third interview Peggy had resolved some of her personal dilemma. She was still committed to her identity as a future teacher but felt that by teaching in a public school she would be compromising her personal identity as an Evangelical Christian. She had lost her anger and frustration towards the instructor after discussing her "crisis" with her husband and reading Christian literature. Peggy had decided that she would seek a job at a parochial school where she could embrace both her personal and professional identities equally.

> I am becoming comfortable in knowing what I believe and not letting someone else's views affect my views. It's not my job to teach a child religion, but it's also not my job to teach a child that their religion is wrong. (Peggy)

Peggy's resolution came after she felt great relief that the instructor had acknowledged her concerns during class. She disclosed her concerns with the instructor during a conversation that he initiated about how evolution should be taught in public school. It was the first time that she engaged in a dialogue with the instructor during class. She had asked a few clarifying questions up to this class period. She explained that "some people can't separate their religious views from their daily lives," and in response, the instructor agreed. Peggy appeared to be relieved and was attentive during the entire class discussion.

Carol did not appear conflicted by her strong affiliations to both the teaching profession and to Christianity. However, she felt alienated by the class as a whole during the discussion about how to teach evolution, a pivotal point in her perceptions of the learning environment. When the instructor presented his view that religion should not be taught in a public school, Carol visibly held up the college newspaper in front of her desk hiding her face. She eventually got up and noticeably walked out of class while the instructor was leading the class discussion. She explained later that she walked out on purpose and wanted to convey to the professor and students that she was displeased with how the issue of teaching evolution in schools was being discussed. This action was important to Carol who felt she was publicly communicating her dissatisfaction with the conversation. The instructor did not appear to notice Carol getting up to the leave the class, he did not watch her rise and leave, nor did he make any comments about this to his students. Carol did not agree with the discussion that evolution should be taught without mentioning creationism. Carol resolved to integrate the two issues (evolution and creationism) in her own classroom but still planned to seek a public school job. She said she felt obliged to give her students "a choice."

> I think it's important that students know the different theories that go with that [origin of human species]. In the case of that, I don't think a teacher should say, 'Well, that this the only part of evolution that can't be proven since you can't go back and prove it.' But, I think it's important to know that this is what has been said and so much has been proven. Let them form their own conclusions. They are not stupid.

When asked what choices she would give, she replied,

> [laughing] I would go out of my way to present [evolution] in a way that my students could decide what they.... There are more than just two [explanations for diversity of life]. They are all pretty ridiculous, like aliens sprinkling spores on the earth and then we grew, and then there's another one I can't remember. They were all pretty ridiculous, but there are more theories than just two.

The instructor revealed during the interview that he was extremely committed to improving biology teachers' understanding of evolutionary mechanisms. He also reiterated that evolution describes the origin of diversity and not the origin of life. In class, he acknowledged one participants' comment that it is difficult for pious Christians not to consider their religious explanations for the world's diversity when studying evolution.

> Yes, that's an important point. We can't say, 'You must believe/accept evolution magically and throw away personal beliefs.' We shouldn't tell people what to believe or to change their beliefs, but presenting the world is what education is about. Helping people make informed decisions. I don't mind the debate, but creationists don't understand evolution and criticize things without understanding it.

Peggy and Carol, despite demonstrating an understanding of genetics, did not completely demonstrate understanding of evolution by the end of the semester. Although both of these participants improved their posttest scores, during their interviews they revealed that they still held alternative conceptions about the nature of science (e.g., not distinguishing between personal and scientific theories).

"Did not Learn Evolution/Intends to Teach Evolution"

Two participants did not demonstrate complete understanding of evolution yet expressed intentions to teach evolution (all 10 sub-constructs). Kayla was a junior who had entered college as a BSE major. She had a strong identity as a teacher and had worked one summer as an ecology field research assistant. She was from a mixed Catholic and Lutheran background and identified herself as religious. Another participant, Kayla's friend, Toby, was also a junior. He described his family as 'Christian mainstream.' He did not share much about his religious upbringing; however, he did discuss his strong identity as an athlete. He was motivated to not only teach high school but to coach American football and entered college as a BSE major.

Both Toby and Kayla were uncertain about their understanding of genetic level changes of evolutionary processes (e.g., origin of variation, inheritance of variation). While Toby demonstrated understanding of the sub-constructs on the CINS and answered 95 % of the answers correctly on the posttest, he demonstrated during the third interview that he was still confused about the inheritance of variation.

> I chose 'any characteristics that were positively influenced by the environment during a finch's lifetime.' [silence 8 s]. I know that the environment…[looking at test] I *think* the environment can have an effect on, um, on the finches' traits and with those traits, they are passed down to the offspring. For some reason the picture in my mind says that the genetic traits can be determined by the environment. I don't know, to be honest with you [looking up].

On an origin of variation question, Toby explained that his answer "was a guess." There were other instances when Toby indicated doubt but could not explain why. Toby was aware of his confusion during the first interview regarding the origin of variation: "You know, I really don't know, to be honest with you. I don't know where they [different beak types] come from," as well as the importance of variations that lead to adaptations:

> That's another thing—they say the giraffe neck was short but how did it become longer? Did it just stretch their neck out? I kind of understand how their food source might have gotten higher so the ones with the longer necks live longer, but I don't know how they essentially get longer (Toby, interview).

He also demonstrated confusion about the nature of science as it relates to evolution research and stated that it is “just” a theory. Unlike Kayla, Toby had no formal research experience and had naïve conceptions about scientific theories.

> I don’t feel that evolution’s been proven yet. It’s just a theory because I feel they’re trying to prove this theory, and uh…I don’t know [laughter]…I guess, I really… have things been proven in science? [to himself] Yes. I don’t think evolution has been proven, but I think people are on the right track to do that with different techniques, using molecular, going so far in depth with that. (Toby, interview)

Kayla performed the most poorly on both the pre- and the posttests. Much of her confusion was tied to her alternative conceptions or confusion about genetics. She admitted, “I have never been able to answer why a species can be highly variable and not be considered several separate species.” For example, when asked during the second interview, mid-semester, about the origin of variation, Kayla used very short responses that were separated by pauses and nervous laughter.

> Where did variation come from? Trial and error. If things are successful and beneficial, they will continue in the population….genetics [laughter] a gene? Hmmm…something like this [drawing on paper] a receptor site; even though it’s not a receptor model or lock and key, but that’s what I think. It’s like that vision of a small molecule connecting to something to click in the trait…it makes up [laughter, sighing]…I don’t know.

When asked about her comfort level in explaining the origin of variation and inheritance of traits, Kayla laughed and stated:

> I feel I learn concepts but I don’t know how to put them all together in a population setting. I can’t apply it. I can just learn them in the context to what I have learned them in. I can’t apply them to another example, another species. It’s a stretch. Like, I know what I should be looking for and I have heard them before, but I can’t pull them out.

Kayla was aware of her confusion and expressed it both during her interviews and in her essays. When asked during interviews why she did not ask questions during class, Kayla explained that she felt inhibited by both her classmates and the instructor. “It intimidates me to have [the grad students] in the class and I know it does for other people too.” And “I don’t really feel like I want to develop a rapport with [the instructor] because I don’t think he would want to volunteer his time at all.” She was also critical of his instructional style:

> I get frustrated because [the instructor] is just doing I-lecture-you-listen format of a classroom and I know I don’t learn that way. I am not being able to reflect on what I have learned. I come in with a stereotype of the class that it’s difficult because of his teaching style. (Kayla, interview)

Despite confusion about the mechanisms of evolution through natural selection, both Toby and Kayla expressed interest in teaching it.

> I believe that evolution should be taught in schools today because evolution is a theory about a process involving science. Just because it is not liked by some communities doesn’t mean that it should be taken out of lesson plans. Some students may be going into biology; it is good for educators to provide their class with evolution materials because it may help them if they have to take the class like I did. (Toby, essay 10)

Toby, though indicating he would teach evolution, recognized two potential barriers: personal conceptual understanding and professional expectations.

> I feel I could [teach it] but there are some things that obviously everyone needs to touch up on and there are some parts of evolution that I could learn more about….It kind of depends on the community that you are teaching in. It might cost you your job. I mean, if your superintendent or principal says you can't teach it, I think I would have to be open with the people you work with…I don't know what I'd do. I will have to wait and see. I won't be afraid after tenure. (Toby, interview)

Likewise, Kayla explained during both interviews and in essays that personal conceptual understanding was a barrier, but one that she wanted to overcome:

> I feel that I know more than I did coming into this course and that I will be able to identify different mechanisms of evolution and natural selection a little bit better, but I still feel that both topics are still quite abstract. I know that I will definitely need to re-teach myself the concepts before I am able to teach them to students in my classroom. (Kayla, essay)
> I feel that in order to come across as knowledgeable and able to defend it as to the reasons as to why I teach it the way I am I'll have to be very prepared. (Kayla, interview)

Both Toby and Kayla were categorized as not having learned evolution because they were unable to demonstrate understanding of all 10 sub-constructs of evolution identified in the diagnostic test. Toby's score was high yet he was unable to substantiate his responses with explanations during follow-up interviews. Both of these participants appear to have struggled most with explaining the genetic origins of variation and the inheritance of variation. However, both expressed a desire to improve their conceptual understanding and teach evolution. Kayla explained that the class discussion on teaching evolution solidified her resolve to strengthen her understanding of evolution.

Summary

In summary, two students demonstrated changes in their conceptions of natural selection and evolution (Anita and Emily), whose professional concerns and personal understanding of genetics contributed to their intentions to teach evolution. Two other participants felt the need to defend their roles (as teachers, Christians, etc.), highlighting the importance of social concerns (classroom dynamics) and personal concerns (religious beliefs) when learning evolution. Although these two participants demonstrated that they had an understanding of genetics they could not transfer that understanding to human evolution (Carol) or even to just vertebrate evolution (Peggy). Both of them also held naïve conceptions of scientific theory and the nature of science. The last two participants discussed their negotiation of all three concerns: personal (learning and accepting evolution); professional (intending to teach but needing to feel prepared); and social (overcoming conceptual confusion and seeking help in class). Their conceptual confusion centered on two particular sub-constructs—the origin of variation and the inheritance of variation, both genetic level processes that are essential to understand how biological evolution takes place. Despite awareness of their conceptual confusion, these two participants both intended to teach evolution.

Discussion

Participants in this study of pre-service biology teachers described three types of concerns: personal (learning evolution, being religious), professional (teaching evolution), and social (learning in this particular classroom environment). Participants' concerns, in turn, had an impact on their conceptual change and intentions to teach evolution. The participants represented three dispositions: (1) *Learned evolution/ intend to teach evolution*; (2) *Did not learn evolution/-does not intends to teach evolution*; and (3) *Did not learn evolution/intends to teach evolution*. While studies have identified personal (such as religious beliefs; see Griffith and Brem 2004 and Jackson et al. 1995) and professional (potential barriers in schools; see Long 2012 and Griffith and Brem 2004) concerns about teaching evolution, the current findings indicate that social concerns also influence pre-service teachers' willingness to learn and teach evolution. More importantly, the findings indicate that sometimes teachers may accept evolution, not fully understand it, and intend to teach it. This begs the question of how many teachers perpetuate naïve conceptions about evolution even after having taken a semester long evolution course.

In general, the alternative conceptions identified in this study are consistent with what other researchers have found (Anderson et al. 2002; Batissti et al. 2010; Nehm and Schonfeld 2008). Even though an introductory genetics class was a prerequisite for this evolution course, all of the participants identified (and sometimes resolved) confusion about the origin and inheritance of variation. Kayla and Toby were unable to completely resolve their confusion about genetic changes. Kalinowski et al. (2010) argued that if scientists hope to educate evolution literate college graduates, we must pay particular attention to students' understanding of DNA sequences when teaching natural selection. They suggest that discussions and activities on DNA sequences should be interwoven into all introductory biology courses to help students identify and resolve alternative conceptions, in particular about natural selection.

The combination of concerns that students exhibited influenced their intentions to teach evolution. Two participants (Peggy and Carol) wanted to learn about evolution because of their *personal concerns* of being better able to before depend their religious doctrine. Both indicated that they felt it was their duty to defend Christianity because they did not think their professor understood their worldviews. Winslow et al. (2011) found that Christian college students were more at ease learning about evolution seeing that Christian professors were able to accept evolution. There are several studies devoted to the issues of teacher (in- and pre-service) understanding, acceptance, and beliefs of evolution (Rutledge and Warden 2000; Deniz et al. 2008; Brem et al. 2003; Trani 2004; see Smith 2010a, for a discussion of these studies).

All participants described their *professional concerns*. Long (2011) claimed that it is unrealistic to expect science teachers to ignore the political and social landscapes in which they are expected to teach evolution. Likewise, the participants perceived evolution to be a loaded topic that causes controversy in public schools and as a result, anticipated that they would be required to placate various stakeholders (students, parents, peers, and administrators) within their professional environment. In short, some of the participants expressed anxiety about teaching evolution as in-service teachers. Regardless of what concepts are being taught, novice teacher have anxieties about job security (e.g., Moscovici 2007; Sexton 2008). All of the participants were aware of (a) "the controversy" of evolution appearing to replace religious beliefs and (b) the difficulty of learning an abstract and sometimes complicated theory. The participants said they struggled with the task of appeasing all of the stakeholders who will have input on their professional performance and success.

The desire to be good teachers and to be prepared to face potential conflict with administrators, parents or students about evolution were driving factors for four participants (Toby, Anita, Emily, and Kayla) to want to better understand evolutionary principles. Griffith and Brem (2004) found that some of the 15 in-service teachers in their study were stressed about teaching evolution and resorted to different coping mechanisms: avoiding conflict in their classrooms (selective), ignoring non-science discussions about evolution (scientists), and allowing students to explore their own emotional concerns (conflicted). Brem et al. (2003) reported that learners perceive the teaching of evolution in a negative light, which describes how participants in my study spoke of their fears about teaching evolution. (Smith 2010b provides a comprehensive review of research describing the teaching of evolution.)

In this study, participants' perceptions of their learning environment often returned to *social concerns* about others' perceptions of them, as well as their concerns about their interactions with the professor. Classroom interactions allow students and educators to co-construct meaning of scientific concepts, and students' level of comfort in the learning environment increases when they feel that their teacher values dialogue (van Sickle and Spector 1996). At the same time, social interactions in formal learning environments can elicit concerns in pre-service teachers; these concerns may be internal ("am I comfortable teaching this content?" or "do I understand this content?") and centered on the "I," or they may be external ("how do I convince others that I know this content and think it should be taught?") and centered on the "me." The participants in this study were aware of their generalized selves (the "me") as they interacted with others and concerns emerged when they presumed that others had expectations of them that they either could not or did not want to fulfill. Sexton (2008) explored the transition that pre-service teachers undergo as they move from personal concerns about teaching to professional concerns. Through an interactionist lens, she identified how novice teachers in her study brought their own experiences and worldviews with them to their teacher education program. She challenged teacher educators to consider how they are perceived by their students and, in turn, to engage in dialogue with students to collaboratively explore how teacher identities develop.

These findings are consistent with what others conclude about the importance of social dynamics in learning environments (van Sickle and Spector 1996; Stryker 2008; Shanahan and Nieswandt 2011). Ha et al. (2012) suggest that researchers should move beyond studies centering on people's worldviews or religious affiliations in order to recognize the complexities involved in acceptance of potentially challenging concepts. Shanahan and Nieswandt (2011) examined the social setting of a school in order to understand how students perceive their school science role and argued that individuals' perception of role has meaning for members of social groups. "A key area for future research involves …examining the processes that influence the ways that students work to reproduce the role through their interactions with others and, on the other side, the way that interactions work to reproduce the role or recreate and subvert it. In particular, interactions that involve the teacher require further study" (p. 391). In this vein, participants were exploring their roles as both evolution students and future biology teachers expected to teach evolution. As a result of role negotiation, participants either were able to resolve conceptual confusion or not, and decided to teach evolution or not. It is problematic both if teachers decide not teach evolution in biology classes or if they do not understand yet decide to teach it.

Implications

It is important for evolution educators to allow pre-service teachers the opportunity to explore what influences their own learning of evolution since this may affect and be affected by their intentions to teach evolution. Goldston and Kyzer (2009) call on researchers to further explore the cultural contexts of teaching evolution and of teachers' perceptions of school cultures in which they might teach evolution. For this reason, follow-up studies of pre-service teachers in the classroom are valuable in order to ask questions such as: Are the concerns (e.g., job stability) of pre-service teachers warranted (do teachers who exhibit high levels of concern lose their jobs more often)? Do pre-service teachers' concerns change once these individuals are employed in schools? What are the impacts on student learning for teachers who have had many concerns versus those who have had few concerns regarding evolution instruction?

How can we improve evolution education of pre-service science teachers? First, both evolution educators and science pedagogy experts must collaborate to meet the needs of future biology teachers. Second, evolution educators, many whom are not necessarily teacher educators, should engage in discussions with students about concerns that future teachers might have about learning and teaching evolution. Third, an accompanying science education course or component (e.g., recitation section like the one that the graduate students in this study had) should be considered because it would allow pre-service teachers to develop their role identity as future science teachers. Finally, explicit instruction on genetic processes that help students explore the origin of and inheritance of variation is necessary. Through these strategies, increased scientific instruction along with opportunities for exploration of personal, professional, and social concerns is likely to be effective in helping increase both understanding of evolution and intentions to teach evolution.

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Appendix

Appendix A. Questions used in semi-structured interviews with research participants

Interviews 1 and 3

1. Please explain what answer you provided on the CINS diagnostic test.
2. How did you arrive at this answer?
3. Do you feel comfortable with your answer? Why or why not?
4. How has the act of interviewing influenced your understanding of natural selection?
5. How has the act of writing reflective essays influenced your understanding of natural selection?
6. Can you describe anything about the learning environment that has influenced your learning of natural selection?

Interview 2

Question A

Students were presented three boxes of insects (ladybird beetles, tiger moths, and red-spotted purples) that are highly variable within each population.

1. Can you describe to me what you see in each of these boxes?
2. How would your answer change if I tell you that all the individuals are of the same species and were part of the same population?
3. Could you please describe to me, to the best of your knowledge, what a species is?
4. Why do you think that these differences (variation) between individuals in a population are important for the evolutionary success of this species?
5. Are differences within a population limited to physical characteristics?

Question B

Students examined a data table of parasitic wasp fitness correlates (head capsule width, longevity, lifetime fecundity, and survivorship of offspring to adulthood).

1. Can you describe to me what these data mean?
2. These are real data from a study on wasps and these are fitness correlates. Can you tell me what fitness means?
3. How do these (presented data) measurable traits affect fitness?
4. [if the topic comes up, ask students to define viable and fertile and fecund].

Question C

Students were given blank paper and colored pencils or markers and were given the opportunity to use these materials to answer the following questions.

1. So far, we have discussed how individual animals may differ in a population, and that some traits may be associated with the individual animal's fitness, but how do these differences arise?
2. When are these variations arising?
3. Are these variations being passed to offspring? If yes, how does this occur?

Question D

For students who are concurrently answering directed reflections.

1. Are you satisfied with your understanding of evolution? [If no, then ask why and what alternative ideas they think might make sense]
2. How has your understanding of evolution been affected by this course?
3. Has the activity of writing a weekly email reflection question influenced your understanding of evolution in any way at all?

Appendix B. Essay Prompts

1. In class the instructor described some of the thinking and interpretations of geologists and naturalists in the seventeenth to nineteenth centuries. Describe the importance of variability within organisms and how this concept may have contributed to the developing concept of natural selection.
2. The instructor stated in class that "survival of the fittest" uses circular logic. Please explain what he meant by that and describe how natural selection works.
3. Consider the following scenario:

   Chironomids are aquatic midges that live in water as eggs, larvae and pupae. Upon emergence as adults, they leave the water, are non-feeding for the most part and mate before dying soon afterwards. The midge larvae burrow in the mud and create tubes from which they emerge to feed. There are two benthic (lake) populations of midges in the genus *Chironomus* that are found adjacent to one another in the same deep lake environments. A group of scientists are studying these organisms and propose that they are different species based on physical body characteristics and feeding behavior. *Chironomus plumosus* is a filter feeder and feeds on diatoms, whereas *Chironomus anthracinus* is a deposit feeder and does not feed on diatoms. Imagine that this paper has been sent to you for review before a journal will accept it for publication. Please respond to the following issues:

(a) What definition of species are the scientists using? Identify any other definitions that they should consider.
(b) What process of speciation are the scientists considering has taken place? Explain this process.
(c) The scientists believe that parapatric speciation has taken place, in which two species arose from the same ancestral species in adjacent geographical areas. Describe any studies that the scientists should conduct to test their hypothesis of speciation?

4. Do you think the modes of speciation in plants and animals are basically the same and should they be treated as such? Please explain your answer.
5. Can speciation be reversed after full reproductive isolation between two populations has evolved so that the two forms merge into a single species? Under what conditions is that probable or improbable? Please explain your answer (hint: think of RIMS).
6. Would you predict that the evolutionary potential of sexually reproducing organisms is greater than, less than, or equal to asexually reproducing organisms? Justify your answer.
7. Consider the following fictional scenario and answer the following questions:

   You are a researcher studying the emerald finches (an imaginary bird) off the coast of Florida on the small island of Tangerina. An exact date for the founding population (n=10) is known since there are diligent bird watchers in the area. Birders have also noted that finches disperse regularly between the mainland and the island. The tenth year after finch establishment on Tangerina you recorded a population of 50 birds and a high allele frequency for the long red tail trait (continental birds usually have short pink tails). When you return 20 years later, you a record a population of 90 birds and a much lower frequency of the red tail allele (so, more birds have short pink tails now).

   (a) Explain what types of selection may have been occurring in the island population of finches and distinguish between the different types during the 30 year period.
   (b) What would you expect to observe (in terms of tail type) in the Tangerina population of finches if feral cats wiped out the continental finch population along the coast? Very few birds (if any) are left for migration to Tangerina.

8. Please read the following passage about horse evolution and respond to the questions below. It might help if you diagram the relationship between the horse groups while reading since I have not supplied a figure.

   The evolution of horses has been well studied and described in evolution textbooks. It is only when we examine all of the intermediate groups that we see how general trends can explain the anatomy of modern horses; however, not all lineages followed general trends. *Hyracotherium*, browsing horses, roamed North America and Europe during the Eocene epoch. Their descendants evolved following noticeable trends: larger bodies, longer limbs, dental changes, elongated skull and diminished fourth toes. During the late Oligocene there was a branching off into *Parahippus* and *Anchitherium*, both of which were browsers. *Parahippus* continued to evolve longer faces, longer limps, a diminished fourth toe and dental changes, whereas *Anchiterium* retained the characters prior to the branching; however, its body size continued to evolve (got larger). During the early Miocene there were dramatic climatic changes that corresponded with pronounced anatomical changes (morphological changes in the skull and teeth were more suited for grazing) in descendants of the *Parahippus* known as *Merychippus*. The grazing descendants of *Merychippus* branched off further into two distinct groups: *Nannipus* (which were dwarfed in size and no longer extant) and *Pliohippus* (whose side toes became reduced in size and the central toe/hoof became enlarged and more suited for running; the chewing teeth became more complex and adapted for grazing). *Pliohippus* evolved into *Dinohippus* and then subsequently into our modern day *Equus* (the hoofed grazing horse).

(a) Use one of the following pairs of words to describe the relationship between *Hyracotherium* and *Equus* (derived/ancestral; primitive/advanced; lower level/higher level; simple/complex). Indicate why you chose this pair of words.
(b) There were two intermediate horses that did not evolve into our modern horse. Give at least two examples from the passage above of lineages that did not follow the general trend from *Hyracotherium* to *Equus*.
(c) Propose some explanations for why these intermediate horses are not longer extant.
(d) Many people describe evolution as progressive and directed. Please respond to this statement and justify your position.

9. Several national research science organizations, along with the National Research Council and the American Biology Teachers Association, made a joint statement a few years ago that biological evolution is a unifying theme in life sciences and should be taught as such. Respond to this statement reflecting on your own studies as an undergraduate. (Following are some questions that might guide your answer: explain why these scientists agree that evolution is a unifying theme, whether or not you agree and why and whether you feel that evolution has been a clear theme in your own studies.)
10. Your honest, thorough answers are appreciated:

(a) How did the process of answering essay questions help you determine which concepts you knew well or were confused by? If you can, please give examples of concepts that you discovered you were confused by or that you understood well.
(b) Before taking this course, what was your normal method of studying? How has your studying changed during this course in evolution? How has your learning (connecting new knowledge with prior knowledge) changed after writing regular essays?
(c) Are you comfortable with your understanding of natural selection and evolution as the semester is ending? Do you feel that you have a better understanding of these concepts compared to your prior understanding at the beginning of the semester? If yes, what helped the most? If no, what would have helped you?

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