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CURRICULUM AND EDUCATION ARTICLE

# “Are Humans Evolving?” A Classroom Discussion to Change Student Misconceptions Regarding Natural Selection

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**Abstract** Natural selection is an important mechanism in the unifying biological theory of evolution, but many undergraduate students struggle to learn this concept. Students enter introductory biology courses with predictable misconceptions about natural selection, and traditional teaching methods, such as lecturing, are unlikely to dispel these misconceptions. Instead, students are more likely to learn natural selection when they are engaged in instructional activities specifically designed to change misconceptions. Three instructional strategies useful for changing student conceptions include (1) eliciting naïve conceptions from students, (2) challenging nonscientific conceptions, and (3) emphasizing conceptual frameworks throughout instruction. In this paper, we describe a classroom discussion of the question “Are humans evolving?” that employs these three strategies for teaching students how natural selection operates. Our assessment of this activity shows that it successfully elicits students’ misconceptions and improves student understanding of natural selection. Seventy-eight percent of our students who began this exercise with misconceptions were able to partially or completely change their misconceptions by the end of this discussion. The course that this activity was part of also showed significant learning gains ($d = 1.48$) on the short form of the Conceptual Inventory of Natural Selection. This paper includes all the background information, data, and visual aids an instructor will need to implement this activity.

**Keywords** Evolution · Natural selection · Science education · Active learning · Conceptual change · Human evolution · College biology

## Introduction

In order to learn, students must actively construct knowledge by linking new concepts with prior ideas (Jones and Brader-Araje 2002). Not surprisingly then, students learn more when they analyze, synthesize, and evaluate ideas in the classroom than when they merely listen to lectures (Hake 1998a; Bonwell and Eison 1991). There are many ways to stimulate such thinking during lectures; small group discussions, for example, are particularly effective at increasing learning and motivation (Smith et al. 2009; Springer et al. 1997). Alternatively, instructors can use part of a class period to have students write, analyze data, or solve problems (Bonwell and Eison 1991; Hake 1998b; Crouch and Mazur 2001). A growing body of literature

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shows that such activities, often called interactive engagement or active learning (AL), tend to be twice as effective as standard lectures (e.g., Hake 1998a; Crouch and Mazur 2001; Knight and Wood 2005).

Although instruction that employs AL is more effective than lecturing, AL strategies alone are unlikely to help students recognize and replace misconceptions. Natural selection is one of the most important biological processes for introductory biology students to understand, but many students enter introductory biology courses with preexisting ideas that prevent them from learning how natural selection operates (Mayr 1982; Bishop and Anderson 1990; Greene 1990; Lord and Marino 1993; Gregory 2009). For example, students often believe that evolution occurs as individuals change—either because they need to, because they use or disuse body parts, or because the environment directly changes them (Gregory 2009). Such misconceptions are remarkably resistant to instruction. Simply telling students that these ideas are incorrect is almost completely ineffective, and students are very likely to retain misconceptions after taking traditional lecture-based courses. Nehm and Reilly (2007) reported that 86% of students completing a traditional introductory biology course had at least one major misconception regarding natural selection. When Nehm and Reilly added active learning to their course, students' understanding of natural selection increased, but 70% of students still retained misconceptions (Nehm and Reilly 2007).

Instruction is much more effective when teachers use active learning strategies *specially designed to change student misconceptions*. There are a variety of instructional approaches available for teaching for conceptual change (TCC). In the approach we describe here, three instructional strategies are useful for helping students replace misconceptions with scientific conceptions: (1) eliciting students' naive conceptions, (2) challenging non-scientific conceptions, and (3) emphasizing conceptual frameworks (Posner et al. 1982; Vosniadou 2008). Metacognition—or considering one's own thinking, learning, and knowing—is an important component of each of these three strategies of TCC. In order to correct a misconception, a student must continually monitor what she is learning, how it relates to what she already knows, and how her thinking may be changing (Hewson et al. 1998).

Multiple examples of a concept help prepare students to transfer their knowledge to novel questions (Bransford et al. 2000; Catrambone and Holyoak 1989) while facilitating the TCC strategies described above. Experts in biology organize their knowledge around larger concepts, such as natural selection, but students need practice with multiple examples of these concepts in order to be able to recognize when the concept is relevant to a new problem (Bransford et al. 2000). By presenting multiple examples and pointing out similarities and differences between the examples, instructors help students make connections and see meaningful patterns that may seem obvious to the instructor, but may have gone unnoticed by the student (Bransford et al. 2000). Students who learn to recognize these patterns will build more sophisticated conceptual frameworks and will be more likely to transfer their understanding to new questions (Bransford et al. 2000; Catrambone and Holyoak 1989).

Educators and researchers have made many calls for instruction that teaches for conceptual change (Bransford et al. 2000; Alters and Nelson 2002; Hestenes 1979; Kalinowski et al. 2010; Nelson 2008). Biology instructors are beginning to answer this call for classroom and lab activities (Heitz et al. 2010; Kalinowski et al. 2006a, b), but there are still too few TCC activities for introductory biology courses. The purpose of this paper is to describe a classroom activity that uses TCC strategies to teach students how natural selection works. Essentially, the lesson is a class discussion in which students attempt to answer the question "Are humans evolving?" This activity can be used in a class of any size and requires no special materials. We designed this activity to elicit students' conceptions about natural selection, to challenge misconceptions that students have, and to emphasize conceptual frameworks. The activity provides students with detailed examples of natural selection at work. In this paper, we will describe the classroom activity, provide background information an instructor would need to use the activity, and present data which show that this activity effectively corrects common misconceptions about natural selection.

## Activity Description

The fundamental goal of this activity is to improve students' understanding of natural selection. More specifically, this classroom activity had the following objectives:

1. Elicit student misconceptions about natural selection;
2. Facilitate rejection of non-scientific ideas about natural selection; and
3. Engage students in an activity they perceive to be interesting and valuable.

Before using this activity, instructors will need to describe the basic mechanisms of natural selection. In our course, we preceded the human evolution discussion with a lecture that emphasized there are three requirements for natural selection: variation for a trait in a population, heritability of the trait, and differential reproductive success.

The instructor began the discussion of human evolution by asking students: "Are contemporary populations of humans evolving? Please explain how you know." Students wrote their responses to this question, hereafter called the

**Table 1** Common misconceptions and examples of students' answers

| Category | Description of misconception | Examples from students' answers |
|---|---|---|
| Teleological/Intentionality | Student believes change happens as a result of need or desire | "Humans are evolving to be protected against new diseases. This evolution is due more to choice than to natural selection."<br>"When the human population needs to evolve to change to its surroundings, it will."<br>"I doubt that the earth will allow humans to become different species." |
| Principle of inertia | Student believes selection has always occurred and so will continue to occur | "Evolution is a process that will never stop, even in the human species."<br>"I believe humans are still evolving because there is no reason why this process would have gone on for so long without stopping and suddenly come to a halt."<br>"If we accept the theory of evolution as an explanation for historical data, we must assume that we will continue to evolve." |
| Use and disuse | Student believes traits that are used are retained and those that are not used are lost | "I think that the human head will increase in size because as a race, humans are acquiring more and more knowledge."<br>"Some people are born without wisdom teeth because they are for chewing much tougher things that have long since been lost in the human diet."<br>"I think that the pinky-toe on our feet will get smaller and smaller until it goes away because it doesn't seem to have a purpose."<br>"More and more people are being born without an appendix. Seeing as this is not useful to us, this makes sense, and is evidence of evolution." |
| Lack of selection/natural selection as all or nothing | Student believes natural selection no longer occurs in first world countries OR that selection only happens when organisms die | "Medicine has halted natural selection by enabling the defined 'weaker' of the species to live longer."<br>"There is no differential fitness in the modern world for humans."<br>"There isn't any sort of predator around that attacks and causes the weak to die."<br>"There is nothing favoring the survival of only specific people."<br>"Everyone can survive in our environment." |
| Uniform species | Student believes all organisms in a species are essentially alike | "There is a significant amount of recorded human history, and they don't seem that different from us."<br>"I am no different from my mom and she isn't any different from her mom." |
| Natural selection as speciation | Believes evolution equals speciation | "No, because evolving equals change from one species to another."<br>"I don't believe we will become a new species." |

"Human Evolution Question," on index cards. Written responses are important because writing forces students to clarify their thoughts, and the index cards can be collected to provide the instructor with a glimpse of how students in the course are thinking about the question. After students finished writing their individual responses, the instructor asked them to discuss their answers in small groups in order to determine whether they could come to a group consensus. These peer discussions provide students with an opportunity to verbalize, clarify, and defend their ideas, and allow them to "try out" their ideas on peers before they present them to a larger audience. Small group discussions may lead to greater learning than classroom-wide discussions because students are more likely to participate when other students, instead of instructors, lead discussions (Philips and Powers 1979).

The instructor then solicited verbal answers from a wide range of students. He used a class list to randomly call on students and recorded their answers on a PowerPoint slide. This approach ensured that the answers obtained were representative of the class and helped prevent students from taking a passive role in the activity. Student answers to this question are predictable (Table 1, also see Gregory 2009 for an extensive review of common misconceptions about natural selection). For example, students will argue that humans are evolving to "lose" their appendix, to have worse eyesight, to have less hair, to have larger brains, and to be fatter. In contrast, other students will report that human evolution has stopped because "there isn't any sort of predator around that attacks and causes the weak to die."

Next, the instructor proposed to work through the list of student ideas and began by pointing out that there was a wide diversity of answers and that some of them contradicted each other. He asked students to apply the three requirements of natural selection to assess each idea. For example, students frequently propose that humans are evolving to have less hair (becoming more bald). The instructor would then ask the student to consider each requirement (i.e., Is there variation in baldness? *Yes.*; Is baldness heritable? *Yes, at least for some types.*; and Are bald men having more children than men with full heads of hair*? Probably not.*). We have found that structuring this discussion with the requirements for natural selection quickly dispels some student misconceptions, including the ideas that humans are evolving to be fatter, smarter, and balder. Unlike a misconception such as "individuals evolve" which has likely been built over a lifetime of personal experience with being able to "adapt" to new situations, these ideas are probably not created until we ask this specific question.

After the discussion of students' ideas—most of which relate to traits that are probably not evolving—the instructor discussed two traits that likely are favored by natural selection: HIV resistance and height. He began by presenting how HIV may be selecting for specific immune system genes. We suggest presenting the height example second because human height has been affected by both genetic and environmental factors, and students find this combination challenging. The next section of this paper provides instructors with the background information necessary to discuss how natural selection may be affecting HIV resistance and height (Table 2 details additional resources that can be found in the Electronic Supplementary Material, ESM).

At the end of the discussion of HIV resistance and human height, the instructor asked students to review and critique their original answers to the Human Evolution Question. On the same index card, he asked students to "Re-read your answer to the question (Are contemporary populations of humans evolving?) and evaluate your reasoning. Is there anything you said that was incorrect? Was there an important part of the answer you were missing?" Hereafter, we call this the "Revision Question." Asking students to examine how their ideas have changed encourages metacognition and promotes conceptual change. We knew from past years that our students can be reluctant to criticize their previous answers. To encourage them to think critically about their initial ideas (Hewson et al. 1998), the instructor provided students with five sample student answers and asked them to critique the answers in groups before he asked them to critique their own answers. Each group discussed one sample answer and then the class discussed what was correct and incorrect about each answer. Table 1 provides examples of student answers that display common misconceptions; these examples can be used for this part of the activity. At the end of class, the instructor collected both the Human Evolution Question and the Revision Question and used them to gauge student learning in preparation for the next class period.

## Two Examples of Contemporary Human Evolution to Use in the Classroom

As we discussed above, it is important that instructors expose students to multiple examples of a concept (Catrambone and Holyoak 1989). This section of the paper (and the supplemental materials described in Table 2) provide the back-

**Table 2** Supplemental material description

| **Discussion tools** | **Goal of this item:** |
|---|---|
| Sample student(s)–instructor dialogue | To show the pattern of logic we use to directly address student misconceptions |
| Relevant cartoon | To provide a visual representation of a common student misconception (humorously) |
| **Example tools** | **Goal of this item:** |
| *CCR5* and HIV interaction diagram | To show students how the *CCR5* protein interacts with HIV on a cell surface |
| *CCR5* DNA sequences | To provide a concrete representation of variation in the population at the *CCR5* locus |
| Table of allele frequencies | To show students how the frequency of the mutation varies around the world and provide a basis for discussing how evolution is likely to change allele frequencies in parts of the world differentially affected by HIV |
| Graph of human height change over the last two centuries | To provide a visual representation of the change in human height that students often mention as evidence of evolution |
| Details about height data | To provide instructors with a large data set that can be used to create graphs and address questions about human height |
| Histogram of height | To show students how height varies in the human population |
| Heritability of height graph | To provide a simple visual representation of the evidence that height is heritable by comparing father and son height |
| Map of chromosome sections associated with human stature | To show students how quantitative traits (traits controlled by multiple genes and the interactions between those genes) can be the result of multiple DNA segments |
| Reproductive success and height graph | To show students evidence that height is associated reproductive success |

ground information necessary to present these examples of human evolution to students, as well as numerous citations an instructor could use to find additional information.

## HIV Resistance and the *CCR5* Locus

AIDS is a disease of the human immune system caused by the human immunodeficiency virus (HIV) that kills over 2 million people each year (Joint United Nations Programme on HIV/AIDS 2009). Most people in the world are highly susceptible to HIV infection, but individuals who are homozygous for a rare allele at the *CCR5* locus are essentially immune to the disease (Samson et al. 1996). Simply put, HIV enters a white blood cell by binding to the *CCR5* protein. A rare resistant allele, called *CCR5-Δ32*, has a 32-base pair deletion in the DNA sequence of the *CCR5* gene. This deletion causes a frame shift, creating a non-functional receptor and preventing HIV from infecting the cell (Samson et al. 1996).

### *Is There Variation in the Population?*

*CCR5-Δ32* has a frequency of around 10% in many European countries and in Russia (Samson et al. 1996; Stephens et al. 1998), but this mutated allele is essentially absent in Asia and Africa (Samson et al. 1996). Students often believe that mutations occur because they are needed, and if that were true, the *CCR5-Δ32* mutation should be most common in Africa where HIV is more prevalent.

The reason why European populations have high frequencies of the *CCR5-Δ32* allele is not well understood. Mathematical models suggest that a random drift of a neutral allele cannot explain the high frequency of *CCR5-Δ32* in European populations (Stephens et al. 1998), meaning that selection was likely responsible. However, debate remains about what may have caused this selection pressure. Some researchers suggest that outbreaks of the bubonic plague, which killed 25–33% of Europeans about 650 years ago, are the most likely source of strong selective pressure for this mutation (Stephens et al. 1998). Other researchers argue that the plague would not have provided sufficient selective pressure to create the current frequency and distribution of the *CCR5-Δ32* allele (Galvani and Slatkin 2003). Studies have also shown that the *CCR5-Δ32* allele does not confer resistance to the plague in mice (Mecsas et al. 2004). Instead, Galvani and Slatkin (2003) suggest it is more likely that the *CCR5-Δ32* allele conferred resistance to smallpox and was therefore strongly selected. Finally, one hypothesis proposes that selective pressure from outbreaks of both smallpox and hemorrhagic plague explains the current frequency and distribution of the mutated *CCR5* allele (Duncan et al. 2005).

### *Is This Trait Heritable?*

The immunity conferred by *CCR5-Δ32* is inherited as a simple Mendelian trait, so it is heritable. We use this example to emphasize to students that the ability of organisms to survive and reproduce is influenced by genotypes present at a specific loci. This should help students connect natural selection with Mendelian genetics (two of the most important concepts in biology). We also show students the DNA sequence of *CCR5* and *CCR5-Δ32* alleles in order to provide a concrete example of how DNA sequences influence phenotypes (Kalinowski et al. 2010). Later, we use *CCR5-Δ32* allele frequencies as an example to illustrate Hardy–Weinberg proportions.

### *Does Having This Trait Affect the Ability of an Individual to Survive or Reproduce?*

Two copies of *CCR5-Δ32* (homozygosity) confer a high level of resistance to HIV infection (Samson et al. 1996). Even one copy of *CCR5-Δ32* provides protection from AIDS (Stewart et al. 1997), most likely by prolonging the transition from HIV infection to AIDS. As long as HIV affects an individual's reproductive success in the human population, there will be selection for the *CCR5-Δ32* allele. Globally, only 42% of individuals in need of treatment for AIDS are being treated (Joint United Nations Programme on HIV/AIDS 2009), suggesting that if *CCR5-Δ32* exists in a population, it will be selected for.

## Human Height

Students frequently suggest that humans are evolving to be taller, and human height provides an ideal example to illustrate some of the complexities of natural selection. As students suspect, human height *has* increased substantially over the past three decades (Smith and Norris 2004; Freedman et al. 2000). However, only some of that change in certain populations seems to be due to evolution rather than improved nutrition and medical care (Mueller and Mazur 2001).

### *Is There Variation Within the Population?*

Human height is clearly variable, and a histogram shows human height has a "bell"-shaped distribution. We have provided height data collected by Karl Pearson (Table 2) to illustrate this point, but a similar figure could be made from students' heights. Pearson's data are from the early twentieth century, and as many students will note, people in most countries are taller now. Average adult height has increased about one inch between 1960 and 2002 (Ogden et al. 2004).

### *Is Height Heritable?*

Human height is highly heritable, and in fact, the first studies of heritability examined human height. Sir Francis Galton started this work and his younger colleague, Karl Pearson, developed the statistical method of correlation to analyze father–son height data. Current studies estimate heritability of height in humans to be 0.8, meaning that about 80% of the variation in height within populations is due to genetics (Visscher 2008).

Height is a quantitative trait, which means that it is controlled by many genes of small effect. At least 20 genes have been found that contribute 0.2–0.6 cm to height per allele (Weedon et al. 2007, 2008). These genes explain only about 3% of the variation in human height (Weedon et al. 2008), which suggests that many more genes of small effect will be found.

Twin studies are an interesting method of understanding heritability. Studies show that after birth, monozygotic (identical) twins grow to be more similar in height than dizygotic (fraternal) twins. Monozygotic twins reared apart are more different in stature than monozygotic twins reared together, but are still more similar than dizygotic twins who grew up together (Chambers et al. 2001). In dizygotic twins aged 14–36 months, 61–82% of variation in height can be attributed to genes (Chambers et al. 2001).

### *Does Being Taller (or Shorter) Affect an Individual's Ability to Survive or Reproduce?*

Several studies have shown a positive relationship between height and reproductive success—in particular for men. For example, height was positively related to number of children in a sample of Polish men (after controlling for other factors that affected height in this sample, such as locality of residence; Pawlowski et al. 2000). A study of West Point Cadets (class of 1950) also showed that taller men had more children (Mueller and Mazur 2001). This study did not control for potential environmental differences, but used a highly homogeneous sample—mostly middle-class men of European descent who came from rural backgrounds and had parents who had at least a high school degree. Finally, a study of British men born in 1958 found that taller men were less likely to be childless than shorter men, and men who were taller than average were more likely to find a long-term partner *and* to have several long-term partners (Nettle 2002b). This study controlled for socioeconomic status and serious health problems. Together, this research suggests that—in some populations—men are evolving to be taller, but it is likely that in other populations, male height is not evolving; selection could even be moving height in the other direction.

Selection for taller men is likely due to sexual selection, meaning that the increase in reproductive success is mediated by opportunities to mate. Women frequently prefer taller men for dates, sexual partners, or husbands (Buss and Schmitt 1993; Ellis 1992; De Backer et al. 2008). For example, a study of personal ads showed that 80% of women advertised for men six feet or taller, even though the average American male is five feet nine inches. Interestingly, studies of reproductive success do not show that taller men have more children within any single marriage, but instead are more likely to remarry and have a second family (Mueller and Mazur 2001).

Female preference for tall men is not likely to lead to unconstrained directional selection. Extremely tall men (those in the top decile) are slightly more likely to be childless. They are also more likely to have a work-impairing, long-standing illness, and they have a slightly higher mortality (Nettle 2002b). Additionally, mating partners who are more similar in height are more likely to have non-induced labor and have higher numbers of live-born children (Nettle 2002a, b).

The relationship between a woman's height and fitness is more complicated. In developed countries such as America and England, the average woman is five feet four inches. In these countries, shorter women have the highest reproductive success and are least likely to be childless (Nettle 2002a). In contrast, in less developed countries such as Guatemala and Gambia, a woman's height is positively related to reproductive success. In these countries, tall women are more likely to have healthier children (Sear et al. 2004; Pollet and Nettle 2008). In all studies, the effect of height on reproductive success of women is less drastic than in men.

### *What Else Affects Human Height?*

As students are likely to note, human height is strongly affected by nutrition and health care as well as by genes. Because of this, the average height and weight of children is often used to monitor the health of populations worldwide. For example, several studies have shown that North Koreans are shorter than South Koreans (see Schwekendiek and Pak 2009 for a meta-analysis), and researchers attribute these differences to nutrition. Similarly, height increased in the Japanese population in the generation born after World War II (Ali et al. 2000). Height also tends to vary by socioeconomic status within countries; children from more well-off families are taller than children from poorer families (even in developed countries like the U.S.; Eveleth and Tanner 1990). Both nutrition and childhood illness are oft-cited sources of growth limitations. These two forces can form a positive feedback loop. Infections cause nutritional status to deteriorate, and malnourished children are more susceptible to illness (Eveleth and Tanner 1990).

In summary, height is highly heritable in ideal conditions, but the effects of childhood illness and malnutrition can have large and lasting effects on overall height. This point is both important and challenging for many students. Understandably, they have a hard time imagining the mechanisms through which genes could have some effect but not complete control, and instead often consider a trait a result of *either* nature or nurture, but not both.

## Assessment of Activity Goals

We assessed the effectiveness of the human evolution activity described above in an introductory biology course on ecology and evolution. The first half of this course dealt with evolution and was taught by one of us (STK). The course had 58 students and met for lecture three times per week for 50 minutes and three hours once a week for a laboratory (e.g., Kalinowski et al. 2006a, b). Most students in this course reported planning to pursue a career in medicine (e.g., physician, pharmacist, physician's assistant). In this section of this paper, we present assessments of how well the human evolution paper met its three goals: (1) to elicit misconceptions, (2) to facilitate the rejection of misconceptions, and (3) to engage students in an activity they found interesting and educationally useful.

### Goal 1—To Elicit Student Misconceptions About Natural Selection

We reviewed students' initial responses to the Human Evolution Question and categorized all answers as either: "definitely containing a misconception," "probably containing a misconception," and "not containing a misconception." While scoring answers, we defined a misconception as an idea that: (1) is inconsistent with a scientific understanding of natural selection, (2) represents a misunderstanding of one of the major aspects of natural selection, and (3) is commonly held. This meant that we did not necessarily score factually incorrect ideas as misconceptions. Two raters independently coded all students' responses, and disagreements were resolved through discussion.

Table 1 displays the variety of misconceptions elicited by this activity. Forty-four percent of our students' answers to the Human Evolution Question definitely exhibited a misconception, and another 10% of their answers suggested they held misconceptions, but the response was too incomplete or unclear to easily classify as a specific misconception.

### Goal 2—To Facilitate Rejection of Non-scientific Ideas About Natural Selection

We measured student rejection of misconceptions using three different tools. First, we compared the misconceptions displayed in the initial Human Evolution Question (categorized as stated above) to misconceptions displayed on the Revision Question. For the Revision Question, we measured whether students rejected misconceptions by categorizing their answer as showing signs of "no improvement," "partial improvement," or "complete improvement." Two raters independently coded all students' responses, and disagreements were resolved through discussion.

Twenty-seven (54%) of our students began this activity with misconceptions (i.e., gave responses scored as either "definitely" or "probably" containing a misconception). By the end of this discussion, 78% ($n$=21) of these students had at least partially improved their answers on the Revision Question. Eleven students had completely improved their answers by correcting all misconceptions and ten students partially improved their answers by correcting misconceptions. In total, 68% of our students provided an initial or revised answer that contained no misconceptions and another 20% revised their answers to partially correct misconceptions. Only 12% of students ended this activity unable to at least partially correct misconceptions they had about natural selection.

Next, we used the ten-question version of the Conceptual Inventory of Natural Selection, called the CINS-II Short Form (CINS-II; Anderson et al. 2002; Anderson 2003; Fisher K, Williams K, Lineback J, Anderson D. Conceptual Inventory of Natural Selection II—Short-Form, 2011, unpublished) to measure student learning gains. Each distractor on the multiple-choice CINS-II questions represents a common student misconception about natural selection. We used the CINS-II because we wanted to see whether the activity described in this paper contributed to an improved understanding of natural selection, not just human evolution. We pre-tested students on the first day of the class and post-tested at the end of the eight-week evolution section of the course. The pretest/posttest design measured learning over a period that included more activities than the discussion presented here. However, the human evolution activity served as the major lesson on natural selection, so we expect that it contributed significantly to student learning gains. We compared the percentage of students who displayed misconceptions on the pretest and posttest of the CINS-II. We used a paired-samples $t$ test (one-tailed) to test the null hypothesis that the difference between posttest and pretest scores was zero and then calculated an effect size using Cohen's $d$. We corrected the pooled standard deviation used to calculate $d$ for the correlation between measures (Dunlap et al. 1996).

Forty-six students (79%) completed both the pretest and posttest CINS-II. They scored significantly better on

**Table 3** Concepts learned during this activity, as reported by students

| Concept learned | No. of students |
|---|---|
| Reproductive success (not just survival) needs to be considered when we think about selection | 2 |
| Individuals do not evolve or change their own genes | 9 |
| Evolution is a continuous process | 1 |
| The environment doesn't directly change DNA sequences | 5 |
| The environment doesn't directly cause evolution | 4 |
| Evolution takes place over a long time period, not one generation | 7 |
| Other students have many different ideas about evolution | 2 |

the ten-question CINS-II after instruction (mean=8.83, SD=1.42) than before instruction (mean=6.57, SD=2.08; $t(45)=6.86$, $p<0.0001$, one-tailed with $\alpha=0.025$), meaning that they displayed fewer misconceptions and instead selected scientifically accepted answers. This corresponds to an effect size of Cohen's $d=1.48$ with a 95% confidence interval from 1.07 to 2.08. This indicates that the class average increased by almost 1.5 standard deviations, which is considered a large positive effect.

For our third measure of how students' misconceptions changed during this activity, students filled out an evaluation of the discussion described in this paper during the class period after this activity. We asked students two open-ended questions, including what they thought the instructor hoped they learned from the activity and what *they* felt was the most important thing they learned from the activity. In response to these questions, students commonly wrote down the non-scientific conceptions they had rejected during this activity. Most often, students reported that they had learned that populations, rather than individuals, evolve. Table 3 provides descriptions of the concepts students reported learning and the number of students who named these concepts. Interestingly, some of the concepts reported by multiple students were not a main focus of the lesson, but are valuable lessons for how evolution proceeds (e.g., evolution takes place over a long time rather than in one generation). In 70% ($n=35$) of student responses to these questions, students reiterated the importance of using the three requirements (i.e., variation, heritability, selection) for natural selection to determine whether a trait is evolving, suggesting that the activity successfully emphasized the importance of considering these requirements.

### Goal 3—To Engage Students in an Activity They Found to be Interesting and Valuable

Some instructors have experienced student resistance when they change from lecturing to more interactive classes that include activities like the one described in this paper (Hestenes 1979), so on the evaluation mentioned above, we asked students to provide their opinions about this activity. The evaluations were anonymous and voluntary, and 93% ($n=54$) of our class completed the evaluations. We asked students to indicate on a six-point Likert scale (strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, and strongly agree) how well the activity held their interest and better helped them understand evolution. We also asked students to use the same scale to provide their opinions about specific parts of this classroom exercise, including how helpful they found writing and reexamining their answers and discussing answers with classmates.

When asked if the activity held their interest, 94.4% agreed and 88.9% agreed that the activity was intellectually challenging (Table 4). Overall, students responded positively to writing and reexamining their answers and discussing questions with classmates (Table 4).

## Discussion

Over 75% of the students in our course who initially displayed misconceptions regarding natural selection recognized and began to change their misconceptions after two hours dedicated to this activity. We could never have achieved this magnitude of learning gains with traditional

**Table 4** Student opinions about the human evolution activity

| Statement | % Agreed[a] | % Disagreed[b] |
|---|---|---|
| This activity held my interest | 94.4 | 5.6 |
| This activity challenged me intellectually | 88.9 | 11.1 |
| This activity helped me better understand evolution | 98.1 | 1.9 |
| Writing down my answers and reexamining them later helped me learn | 88.7 | 11.13 |
| Discussing the questions with my classmates helped me learn | 87.0 | 13.0 |

[a] Answers include "slightly agree," "somewhat agree," and "strongly agree"

[b] Answers include "slightly disagree," "somewhat disagree," and "strongly disagree"

lecture methods. Regrettably, recent research has shown that it is not unusual for introductory science courses to produce negligible student learning gains (Hake 1998a; Andrews et al. 2010). Natural selection is particularly challenging to learn, and some studies show that targeted instruction produces only modest changes in students' conceptions (Bishop and Anderson 1990; Nehm and Reilly 2007). Our students' learning gains compare favorably with other studies that have tested AL and TCC strategies to teach natural selection (Bishop and Anderson 1990; Nehm and Reilly 2007; Jensen and Finley 1996, 1997), and this activity would be relatively easy for an instructor to incorporate into his or her course.

We were interested in how well our students retained what they had learned during this activity, so we included the Human Evolution Question on the final exam, which students took 12 weeks after this activity (8 of those 12 weeks were dedicated to teaching ecology). Only 4% of our students displayed misconceptions on the final exam version of the Human Evolution Question (96% of students who participated in this activity also took the final exam). This is a marked improvement from their answers to the Revision Question (where 32% of student answers failed to completely correct misconceptions). Because this retesting took place three months after the activity, we suspect that rather than simply retaining this information, students continued to build their understanding of natural selection (and thereby their ability to answer this question without displaying misconceptions) in the four additional weeks dedicated to evolution. Throughout the evolution section of this course, we consistently embedded AL and TCC strategies into our instruction, and our results suggest that these methods effectively produce learning gains in undergraduate introductory biology students. In agreement with learning research (Bransford et al. 2000), it also suggests that a holistic and scientifically accepted understanding of natural selection is not built during a single class activity. Rather, these complex conceptual frameworks are built over time as students are forced to question their ideas, incorporate new ideas, and apply these newly integrated ideas (Posner et al. 1982).

As with any classroom activity, instructors will need to carefully incorporate a discussion of contemporary human evolution into their courses. In a previous implementation of this activity, we did not give students enough practice with natural selection before this activity; as a result, the question was too difficult and students became frustrated. To answer the Human Evolution Question, students will need to be able to recall the requirements for natural selection and to apply them to humans. In our course, we used the class period before this activity to illustrate these requirements with examples of selection at work. Specifically, students discussed dog breeding (i.e., artificial selection), selection for coat color in old field mice (see Kalinowski et al. 2010), and neck length in giraffes. Students' misconceptions regarding natural selection are frequently so persistent that students may be unprepared for the human evolution question unless instructors have previously addressed common student misconceptions regarding inheritance. For example, we used the discussion of dog breeding (see the "elaborated example" in Kalinowski et al. 2010) to illustrate to students that evolution does not proceed via the inheritance of acquired traits.

Our human evolution discussion was designed to teach students how natural selection operates. This emphasis does not minimize the importance of other causes of evolution (e.g., mutation, genetic drift, gene flow). Before this exercise, we introduce natural selection as *one* process that causes evolution, and we talk in detail about genetic mutation as a source of variation, but we do not cover other evolutionary processes until after our students understand natural selection. As the class proceeds, we return to the examples in this exercise as we teach gene flow and genetic drift.

Beyond content, the format of this activity (e.g., small group discussions, classroom-wide discussions) may be foreign to students and thus slightly intimidating. First, students accustomed to passively sitting in class may be reluctant to participate in class discussions because they are afraid of providing an incorrect answer. Second, students in the habit of acting as receivers and recorders of facts during class may be uncomfortable allowing for uncertainty while discussing a question. We encourage the incorporation of AL and TCC methods before the human evolution discussion to familiarize students with a more interactive classroom environment.

Formative assessment will be invaluable for incorporating a discussion of human evolution into an introductory biology course. In order to challenge and change students' ideas, it is imperative that an instructor know what his or her students are thinking. To do this, instructors will need to obtain responses from a broad sample of the class. This is important because if only a few students answer the question, their answers may be insufficient to capture the range of misconceptions present in the classroom. This is why we have all students write down an answer and why we randomly call on numerous students. Standardized tests, such as the CINS-II (Anderson et al. 2002; Anderson 2003; Fisher et al., unpublished), are also useful for assessment. As we developed this activity over the course of three years, and tested student learning, we were sometimes surprised to learn that our personal assessment of the effectiveness of a discussion was highly inaccurate. We cannot stress enough the importance of knowing students' initial ideas and assessing learning throughout a course;

without this testing, an instructor cannot know if he or she has successfully taught the students anything.

Alternative hypotheses to explain our students' significant learning gains include an exceptional instructor, exceptional students, or simply an exceptional amount of time in preparation for teaching. We do not believe any of these hypotheses adequately explain why this activity produced impressive learning gains (and misconception rejection). First, our initial implementation of this activity did not produce the sort of learning gains we eventually produced, suggesting that our instruction was not exceptional, but merely practiced. The suggestions for implementation in this section are the lessons we learned. Most students in our course plan to pursue careers in medicine. These aspirations may correspond to increased motivation to succeed, increased past success with school, and higher than average standardized test scores, but also less positive traits such as a highly competitive attitude that hinders cooperative group work and a fear of new classroom methods that they perceive as likely to interfere with their proven ability to succeed in traditional classrooms. We acknowledge that these differences may contribute to the learning gains we found, but other studies have found AL and TCC methods more effective than traditional methods in science classes with non-majors and majors from a broader range of science disciplines than our sample (e.g., Hake 1998a; Bonwell and Eison 1991; Crouch and Mazur 2001; Bishop and Anderson 1990; Jensen and Finley 1996), suggesting that these methods produce learning gains for a wide range of students. Finally, though we have obviously dedicated a substantial amount of time to refining this activity, we also know that instructors who use only lecture methods often devote equal amounts of time to class preparation. Time and dedication alone do not produce significant learning gains.

As we continue to incorporate AL and TCC methods into our course, we envision a course where most of the learning takes place in activities that use TCC and AL strategies, particularly when covering topics about which students hold many misconceptions. As studies showing the inadequacy of using only lectures continue to accumulate, we believe it is ethically questionable and scientifically irresponsible to continue using predominantly lectures to teach college science. This activity is one step toward a course based on research on the effectiveness of teaching methods and, we hope, a step toward a reformed paradigm of how we teach college biology.

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