Using Human Examples to Teach Evolution to High School Students: Increasing Understanding and Decreasing Cognitive Biases and Misconceptions

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1 Introduction

The science education community broadly accepts that understanding evolution is a critical aspect of scientific literacy, as is evident by the prominence of evolution in the US education system as a 'big idea' or 'core concept' in the Next Generation Science Standards (NGSS, NGSS Lead States, 2013), the Advanced Placement (AP) Biology Curriculum Framework (The College Board, 2011), and AAAS's Vision and Change for Undergraduate Biology (AAAS, 2011) as well as the national curricula in other English-speaking countries (e.g., England (Department of Education, 2014), Australia (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2014). Researchers and educators also broadly recognize that there are many barriers to students learning about evolution, including many teachers avoiding teaching about evolution altogether (e.g., Berkman, Pacheco, & Plutzer, 2008; Pobinerm, 2016). When teachers do teach the content, students often have cognitive biases and misconceptions, especially in the realm of a mechanism of evolution (natural

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selection), common ancestry, deep time, and 'tree-thinking.' The goals of many life science educators are both to bring student understanding more in line with scientific ideas about evolution and to reduce the frequency of student misconceptions and the use of biased ways of thinking about change over time and shared ancestry.

At present, there is no consensus in the evolution education community about the most promising curricular or pedagogical strategies to use to achieve these two goals, especially at the pre-collegiate level. Reviews of the evolution education literature (e.g., Beardsley, Bloom, & Wise, 2012; Pobiner, 2016) suggest that the pedagogical approaches with the most promise are those that use strategies for conceptual change, and attend to the relevance of understanding evolution (e.g., Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2010; Beardsley et al., 2011; Heddy & Sinatra, 2013). Evolution educators are also still exploring the impact of including examples of evolution in humans. Resistance to learning about human evolution is higher than about evolution in other organisms (e.g., Werth, 2009), but recent summaries of different sources of evidence suggest that using human examples holds promise (Pobiner, 2016).

Moreover, there is wide variation in how teachers choose to address student resistance to learning about evolution and tensions between a religious and scientific worldview. Evolution educators generally suggest that the most promising approaches should include acknowledging, respecting, and being sensitive to students' beliefs. Teachers are encouraged to negotiate this conflict, rather than ignoring it or exacerbating it (e.g., Brem, Ranney, & Schindel, 2003; Sinatra, Southerland, Mcconaughy, & Demastes, 2003; Werth, 2012; Bramschreiber, 2013; Pobiner, 2016). At present, however, few studies have quantitatively explored the impact of using teaching strategies that acknowledge the cultural controversy on students' understanding of natural selection below the collegiate level.

In this chapter, we provide evidence for the impact of using a constructivist, guided inquiry pedagogical approach using human evolution case studies to teach AP Biology high school students about natural selection in an attempt to better understand the most promising approaches to support teachers in helping students learn about evolution in general, and natural selection in particular, and overcome common cognitive biases and misconceptions. Importantly, we also report the effect of these curricular materials when used in tandem—or not—with teaching strategies that explicitly acknowledge the cultural controversy around evolution.

1.1 Common Cognitive Biases and Evolution Misconceptions Among Students

There are three major categories of cognitive biases to learning about natural selection that begin in preschoolers which we will outline here.

Essentialism is the belief that individuals and groups have an essential nature that allows them to be placed into categories or kinds with sharp, immutable boundaries (Nehm et al., 2010). In this type of reasoning, membership in a category leads to observable properties which stem from an unobservable, unchangeable core 'essence' that is transmitted from parent to offspring.

Intentionality assumes that events are caused by an intentional mental agent and are purposeful, goal-directed, or progressive, including the idea that evolution is progressing toward an ideal (Evans, 2001; Gregory, 2009; Nettle, 2010).

Teleology assumes that the characteristics and actions of entities or groups have a goal or are inevitable (Nehm et al., 2010) and that aspects of an object's or organism's form are explained by their ultimate purpose. Teleology includes the beliefs that the traits organisms currently possess perform roles or functions that aid survival (that they 'need' these traits) and that natural phenomena are intentionally designed or created for a purposeful goal (Jensen & Finley, 1995; Kelemen, 2012). Such need-based rationales tend to lead to the conclusion that major changes occur within an individual's lifetime and are heritable (Kelemen, 2012).

In addition to cognitive biases, misconceptions, defined as inaccurate ideas that can predate or emerge from instruction (Andrews et al., 2012), and prior beliefs may impede a correct understanding of evolution and the construction of knowledge in the biology classroom (Sinatra, Brem, & Evans, 2008; Smith, 2010). Unfortunately, there is a 'strikingly high prevalence of misconceptions about evolution' among students of all levels (Gregory, 2009: 163). These misconceptions encompass student understanding of a process of evolution, namely natural selection, common ancestry, deep time, and 'tree-thinking' (see Smith, 2010; Werth, 2012; Pobiner, 2016 for more extensive lists of misconceptions about evolution).

The current study focuses on misconceptions associated with students' understanding of natural selection. A prominent assessment for student understanding of natural selection is the open response instrument called Assessing Contextual Reasoning about Natural Selection, or ACORNS (Nehm et al., 2012) (used in this study; see methods) which assesses the three cognitive biases previously described and six misconceptions associated with the following terms: 'pressure,' 'adapt,' 'need,' 'must,' 'use,' and 'energy' (see Table 5 for more details on these terms).

1.2 How Do Different Types of Evolution Instruction Affect Student Understanding of Evolution and the Frequency of Cognitive Biases and Misconceptions?

Evolution educators are still working to build a consensus about the most promising pedagogical approaches to help students overcome cognitive biases and misconceptions. Beardsley et al. (2012) summarized studies of diverse curricular interventions with students, including software-based instruction to problem-based learning, argumentation-eliciting treatments, and targeting-specific misconceptions. Studies published since that review mostly support these conclusions; for example, Andrews, Kalinowski, and Leonard (2011) examined student learning of natural selection in college from 33 instructors at 28 institutions in 22 states in the USA and showed that most learning gains were modest, but two factors associated with misconceptions were positively related to the gains in understanding ('explaining why misconceptions are incorrect' and 'using active-learning exercises to make a substantial effort toward changing misconceptions'), as was student interest in the biology course.

Fewer studies of misconceptions among high school students have been undertaken. In a study with teachers in Maryland and Illinois, all of the six teachers thought individual versus population-level thinking was the main reason for the low understanding of evolution among their students (Hermann, 2013). One recent study of high school students found that they left an introductory biology course with greater numbers of evolution misconceptions than at the beginning of the course, despite an increase in their confidence in their knowledge of evolution (Yates & Marek, 2014). Results of studies conducted with college students are hopeful for identifying effective pedagogical approaches for supporting high school students' understanding of evolution and helping them overcome cognitive biases and misconceptions, but the gap in the research on these and other approaches with high school students indicates that additional work is needed.

Despite potential cultural controversies and a lower acceptance of evolution in humans than non-humans among at least some college students (Ranney & Thanukos, 2011), a growing body of the literature suggests that using human examples may help students learn core evolutionary concepts (summarized in Pobiner, 2016). College students prefer science courses in which human examples are included in evolution instruction along with non-human examples (Paz-y-Miño & Espinosa, 2009) and some studies have found an increase in understanding and/or acceptance of evolution in college students when including human examples (Wilson, 2005; Werth, 2009; Nettle, 2010; Andrews, Leonard, Colgrove, & Kalinowski, 2011; Borgerding et al., 2015). Additionally, student misconceptions may persist because of non-scientific worldviews (Hermann, 2012), and recent studies suggest that explicitly addressing students' beliefs with respect and sensitivity, with the goal of creating a classroom environment conducive to learning about evolution, is the best strategy for students for whom the subject is controversial (Sinatra et al., 2003; Verhey, 2005; Smith, 2010; Hermann, 2012; Bramschreiber, 2013)—with a possible goal of helping students reconcile their personal beliefs with scientific understanding (Anderson, 2007). Therefore, we think a promising approach to engage students with evolution content includes (1) using human examples and (2) explicitly discussing the relationship between evolution and students' beliefs.

2 Methods

2.1 The Teaching Evolution through Human Examples (TEtHE) Project

Teaching Evolution through Human Examples (TEtHE) was a three-year exploratory research and development project funded by the National Science Foundation of the USA. The overall goals of the project were to develop, field-test, and assess the effectiveness of two main components related to the above suggestions about how best to engage students in learning evolution. The first component was four mini-units that use case studies of human evolution to address specific core evolutionary concepts included in the high school AP Biology curriculum. Using a constructivist approach, the units explicitly elicit a range of misconceptions as well as cognitive biases in the broad categories of essentialism, intentionality, and teleology, and then provide opportunities for students to reflect on their prior ideas and gain experience with ways of describing change over time that are scientifically accurate. The second component was two classroom activities that use Cultural and Religious Sensitivity (CRS) Teaching Strategies to create a comfortable classroom environment for learning about human evolution, which also included eliciting possible misconceptions and cognitive biases. This chapter reports on a subset of the results from the national field test for three of the four mini-curriculum units and CRS activities related to addressing core evolution understanding and misconceptions in human and non-human evolution contexts building on two initial publications from the TEtHE project (Pobiner et al., 2018 and Bertka et al., 2019).

TEtHE was primarily a curriculum development project, which led to the decision to identify teachers and students in the 'best-case scenario' for piloting and assessing baseline impact of the mini-units and CRS activities. The sample therefore reflects the intentional selection of well-qualified teachers and their AP Biology students, who are generally more motivated to learn and good at reflecting on their own learning. Overall design for collecting data from the national field test is therefore subject to self-selection bias and the limitations of a non-random and non-systematically selected sample and should be considered exploratory, as our sample did not capture the likely increased variability that would result from a more randomly selected student sample from across the USA. Within these limits of explanatory power, we present the compelling results of our analyses of student understanding of natural selection, cognitive biases, and misconceptions about evolution and encourage additional future research to rigorously test hypotheses that these initial studies elucidate.

2.2 Research Questions

Data from the TEtHE study were analyzed in multiple ways within and between mini-units, using combinations of items with high validity and reliability to address

Table 1 Research questions for the TEtHE project results reported here

Research question 1	Are patterns of changes in student understanding of key concepts, cognitive biases, and misconceptions about natural selection the same between a non-human and human context?
Research question 2	Are there posttest differences in student understanding of key concepts, cognitive biases, and misconceptions about natural selection between a non-human and human context?
Research question 3	Are changes in student understanding of key concepts, cognitive biases, and misconceptions about natural selection the same when teachers use CRS lessons and when they do not?

underlying constructs of understanding, cognitive biases, and misconceptions. Our overall findings indicate that student understanding of evolution increases on a statistically significant level from the pretest to the posttest for two of the three mini-units, *Adaptation to Altitude* and *Malaria*, with effect sizes ranging from 0.26 to 1.32 (Pobiner et al., 2018). For this chapter, we have taken a simpler approach through which we seek to describe patterns in student understanding of critical components of evolution, cognitive biases, and misconceptions about evolution in the two contexts (mouse and human) and between students whose teachers used the CRS and those who did not. Research questions for this subset of the TEtHE project are outlined in Table 1.

2.3 Sample

2.3.1 Participating Teachers

Teachers were selected from a pool of teachers recruited by email and word of mouth by project personnel and their colleagues in the evolution education field. Selected teachers either (a) self-identified as interested in the project or (b) were identified by project staff as teaching in schools with student demographics of interest to the project and the funder, i.e., those traditionally underrepresented in Science, Technology, Engineering, and Technology (STEM) careers. Table 2 includes demographic and socioeconomic information for ten schools in eight states (California, Colorado, Connecticut, Maryland, New Jersey, New York, Utah, and Virginia) at which the teachers implemented these mini-units. More details on implementation can be found in Pobiner et al. (2018).

2.3.2 Participating Students

Participating students were high school juniors and seniors who were qualified by their schools' criteria to participate in an AP Biology class. Attempts were made in

Table 2 Summary of school data and implementation characteristics for students of each teacher who taught using the altitude, malaria, or skin color mini-units

Mini-unit	School type	Low SES (%)	URM (%)	Fidelity: implement	Fidelity: assess	CRS	*n*
Altitude	Public	4	12	High	High	None	51
Altitude	Public	8	8	Low	Low	None	39
Altitude	Private	4	10	High	High	1	18
Altitude	Public	13	11	High	Moderate	1	52
Altitude	Public	20	13	Unknown	Low	2	28
Malaria	Public	11	33	High	Low	1	24
Malaria	Public	30	52	High	High	None	43
Skin color	Public	22	30	High	High	None	23
Skin color	Public	82	81	High	High	1	15
Skin color	Private	3	10	High	High	2	11

Low SES indicates the percentage of students at the school who qualify for free or reduced price lunch
Underrepresented minority (*URM*) indicates the percentage of students at the school who identify as African American or Hispanic
Time frame indicates the teacher-reported month in which the supplement was taught
Fidelity: Implement indicates the extent to which teacher reports indicate that the supplement was taught as intended by the developer
Fidelity: Assess indicates the extent to which the timing of the assessment administration occurred as directed by project staff
CRS indicates whether CRS activity 1 or 2, respectively, was used in the classroom
n indicates the number of students in each class from whom data were collected

the selection of participating teachers to identify a student sample that at minimum is demographically representative of the AP Biology classes taught by highly qualified teachers nationwide, both in STEM careers and in AP Biology classes.

2.4 Interventions

2.4.1 Curriculum Mini-units

The project team developed four curriculum mini-units that focused on using human examples or case studies to teach core evolutionary content. This chapter describes results from the three that focused on natural selection, which are summarized in Table 3. Each unit includes four or five lessons, which were designed to be implemented over five to nine days (depending on whether the full or condensed version is used) and integrated into each teacher's larger instructional sequence for evolution in the AP curriculum. Teachers were asked to implement the lessons 'as intended,' meaning that they were asked to teach all the lessons without modification in the

Table 3 Titles and descriptions of the three mini-units focused on natural selection in modern humans used in the study

Title	Description
Adaptation to altitude	Students learn how to devise an experiment to test the difference between acclimation and adaptation, investigate how scientific arguments show support for natural selection in Tibetans, design an investigation using a simulation based on the Hardy–Weinberg principle to explore mechanisms of evolution, and devise a test to investigate whether or not other populations of people have adapted to living at high altitudes
Evolution of human skin color	Students examine evidence for the relationship between ultraviolet (UV) light and melanin in other animals, investigate the genetic basis for constitutive skin color in humans, learn to test for natural selection in mouse fur color, investigate how interactions between UV and skin color in humans can affect fitness, and explore data on migrations and gene frequency to show convergent evolution of skin color
Malaria	Students examine evidence to compare four different explanations for why many malarial parasites are resistant to antimalarial drugs, investigate how scientific arguments using G6PD data show support for natural selection in humans, and apply their understanding to other genes whose allele frequencies have changed in response to malaria

sequence in which they were provided within recommended time duration, which they did to varying degrees (see Table 3).

2.4.2 Cultural and Religious Sensitivity (CRS) Teaching Strategies Resource

The purpose of the CRS resource is to encourage and equip high school teachers to help students manage any tension they may experience between a scientific study of evolution and their religious and cultural beliefs, and create a classroom environment that supports both an increased understanding of the nature of science and a scientific understanding of evolution. It is not meant to specifically resolve any conflict students may see between their personal worldviews and the scientific account of human evolution, but to help create a nonthreatening classroom environment.

The resource includes background information for teachers on: the nature of science as pertinent to managing a conflict between science and cultural or religious beliefs; the range of creationists' views, from those that are anti-evolution in nature to those that are supportive of a scientific understanding of evolution; the variety of possible relationships between science and religion, including examples of how individuals accommodate evolution and religion; and the historical context and background on legal cases dealing with the teaching of evolution. It also includes two activities to engage students in directed classroom discussions for 50–75 min

Table 4 Titles, timing, classroom setting, and descriptions of the two CRS classroom activities used in the study

	Activity 1	Activity 2
Title	Directed discussions: 'why study evolution?'	A historical role play: 'how do people think about evolutionary theory?'
Timing	Just prior to implementing the mini-unit on evolution	After implementing the mini-unit on evolution (for reinforcement)
Classroom setting	Teachers are aware that many of their students have been exposed to only negative and/or mistaken notions of evolutionary theory	Teachers believe that anti-evolutionism is a minority or a nonexistent viewpoint
Description	Through three in-class exercises that include small group and class discussions, students reflect on how science as a way of knowing differs from other ways of knowing about the world, classify a collection of statements by individuals and religious groups to illustrate a range of possible relations between science and religious or cultural beliefs, and identify the type of data scientists are collecting in example studies of biologists using evolutionary theory as a tool to solve problems and make testable hypothesis. Before the class meets, students complete an assignment that provides insight into their current knowledge and concerns about evolution	Students are assigned one of eight historical characters and work in groups to envision how their character would reply to questions about Darwin's theory of evolution. Paired character groups work together to draft both a historical and a modern-day response to concerns about evolution highlighted by one of their characters

(Table 4). The classroom activities use a procedural neutrality approach (Hermann, 2008) in which information about the cultural controversy surrounding evolution and different points of view about this controversy are elicited from students and from resource material. The teacher does not make a value judgment about these views, but help students come to a correct understanding of the nature of science. Teachers could opt into using either of the two (but not both) classroom activities.

2.5 Assessments

The Assessing Contextual Reasoning about Natural Selection instrument (ACORNS; Nehm et al., 2010, 2012) is intended to assess increased understanding of evolution concepts, specifically natural selection. It is a short-answer diagnostic test that was

Table 5 Key concepts, cognitive biases, and misconceptions scored in the ACORNS questions including brief definitions or descriptions

		Definition/description or phrases used
Key concepts	Variation	Presence of variation caused by mutations, genes, or changes in DNA
	Heritability	Genes are passed on to the next generation, production of offspring with the same traits, inheritance, heritable
	Competition	Competition, struggle
	Hyperfecundity	Overproduction of offspring, more individuals born than can survive
	Resource limitations	Resources, predation (predator or prey)
	Differential survival	Greater or higher survival, others died off, more fit, advantage of a trait, reproduce more, trait/gene selected for or favored, sexual selection
	Frequency/distribution	Generational changes in the distribution or frequency of variation, over time, gene or trait became dominant or more common
Cognitive biases	Essentialism	Change at a level higher than the individual, assumes no within species variability
	Intentionality	Explanation contains mental verb; agent of mental verb is evolving species or nature
	Teleology	Organisms change because they 'need' to
Misconceptions	Pressure	Pressure (by an external force) or lack thereof causes a mutation or trait to occur
	Adapt	Individuals change to adapt to their environment
	Need	Need of an organism causing a mutation or trait to occur so it could survive or reproduce and does not include process
	Must	Desire or preference caused a change
	Use	Traits changed because they were being intensively used or no longer being used
	Energy	Energy/resources were reallocated to another trait for better use

designed with a scoring rubric that standardizes student responses across different contextual variables for evolution (e.g., gain vs. loss of traits, plants vs. animals, within vs. between species differences). The ACORNS scoring instructions and rubrics allow raters to score student responses in seven key features of understanding evolution, three cognitive biases, and six misconceptions (see Table 5, which uses adapted descriptions and examples in Nehm et al., 2010). A score of '1' indicates the presence of a key concept, cognitive bias, or misconception, and a score of '0' indicates the absence of that key concept, cognitive bias, or misconception.

Table 6 Two ACORNS questions used in the TEtHE study

Human evolution question	How would biologists explain how individual people are alive today who can digest lactose originated within a population of people who were all lactose intolerant?
Non-human evolution (mouse) question	How would biologists explain how some individuals of a mouse species that have claws originated within a population of a mouse species that lacked claws?

We used one human-based and one non-human-based question, both of which focused on trait gain (see Table 6). All students answered both questions: first the human context question, which was created by the TEtHE research team, and then the non-human (mouse) context question, which is directly from Nehm et al. (2012). This question was chosen as it also includes gaining a trait and mice is familiar to students. The same versions of the ACORNS instrument were given pre- and post-instruction with the mini-unit. Teachers were asked to distribute the ACORNS as a pretest the day before implementation of the mini-unit and as a posttest the day after implementation.

Each ACORNS instrument was assessed for seven knowledge attributes, three cognitive biases, and six misconceptions (see Table 5), by one of the teams of three raters including two of the authors (Pobiner and Watson) blind to whether or not any assessment was a pretest or a posttest. Inter-rater reliability ranged from 0.71 to 0.99 using a simple comparison of percent agreement across items and raters. The agreement for some items may be skewed by the relatively low percentage of students showing evidence of understanding or misconceptions for those items.

2.6 Analyses

All analyses were conducted using a combined dataset that included students who experienced any of the mini-units for whom we had both pretest and posttest ACORNS data ($n = 320$). No student experienced more than one mini-unit. All students took the same ACORNS assessment, as the target concepts and standards addressed by each mini-unit were identical. Combining students across mini-units also helped to mitigate against the results in any condition being based too heavily on any one teacher's abilities or methods.

Analyses were conducted on an item-by-item basis for each research question, resulting in 80 total comparisons, as described below. We recognize that some of the effects reported therefore may be due to chance rather than to the impact of the interventions. We emphasize that their inclusion here is intended to illuminate potential overall patterns and identify compelling areas for future research.

2.6.1 Research Questions 1 and 2

To identify potential patterns of changes in understanding of key evolution concepts, cognitive biases, and misconceptions about natural selection across mouse and human contexts, we compared the number of scores of 1 for each item at the pretest to the number of scores of 1 at the posttest, for both the mouse and the human contexts. This was done by conducting a series of Wilcoxon nonparametric significance tests for two paired variables.

To identify potential posttest differences in understanding of key evolution concepts, cognitive biases, and misconceptions about natural selection across mouse and human contexts, we compared the number of scores of 1 at posttest for responses in the human context to the number of scores of 1 at posttest for responses in the mouse context. We again conducted a series of Wilcoxon nonparametric significance tests for two paired variables because the data represented different responses from the same students, not assignment to different conditions. For research questions 1 and 2, because each item was rated as either a 1 or a 0, the overall effect was to compare the percentage of correct responses at the pretest to the percentage of correct responses at the posttest.

2.6.2 Research Question 3

To identify potential changes in student understanding of key evolution concepts, cognitive biases, and misconceptions about evolution the same when teachers use CRS lessons and when they do not, we first calculated a pretest–posttest gain score for each item for each student. Resulting scores were either -1 (scored 1 at pretest and 0 at posttest), 0 (no change), or 1 (scored 0 at pretest and 1 at posttest). We then conducted a series of Mann–Whitney nonparametric significance tests for two independent groups, with whether or not a student experienced the CRS as the independent variable.

3 Results

3.1 Research Question 1

Patterns of pretest–posttest gain were found to be similar across the mouse and the human contexts, with significant increases in variation, heritability, differential survival, and frequency/distribution in both contexts and significant decreases in teleology and adapt. Both contexts showed a trend toward decreased presence of cognitive bias and misconceptions at the posttest than at the pretest, with some variation in the specific biases and misconceptions. Table 7 presents the results of the significance tests in the mouse and human contexts, respectively.

Table 7 Pretest–posttest differences by item within the mouse and human contexts; statistically significant differences are in bold

		Mouse context			Human context		
		Pretest	Posttest	Z	Pretest	Posttest	Z
Key concepts	Variation	0.71	0.87	**−5.378****	0.71	0.84	−4.558**
	Heritability	0.49	0.66	**−4.596****	0.45	0.64	**−5.388****
	Competition	0.03	0.03	0.000	0.02	0.01	−0.632
	Hyperfecundity	0.00	0.00	0.000	0.00	0.00	0.000
	Resource limitations	0.16	0.20	−1.434	0.09	0.11	−1.050
	Differential survival	0.58	0.71	**−3.563****	0.34	0.55	**−5.892****
	Frequency/distribution	0.22	0.35	**−3.866****	0.18	0.33	**−5.004****
Cognitive biases	Essentialism	0.12	0.04	**−3.429****	0.08	0.04	−1.667
	Intentionality	0.04	0.03	−0.626	0.03	0.02	−0.535
	Teleology	0.17	0.07	**−4.160****	0.06	0.03	**−2.041***
Misconceptions	Pressure	0.04	0.04	0.000	0.05	0.01	**−3.153***
	Adapt	0.12	0.07	**−2.359***	0.13	0.05	**−3.501****
	Need	0.16	0.10	**−2.496***	0.04	0.03	−0.943
	Must	0.09	0.06	−1.667	0.03	0.02	−1.069
	Use	0.01	0.01	−1.000	0.06	0.03	**−2.041***
	Energy	0.00	0.00	0.000	0.00	0.00	0.000

*$p < 0.05$
**$p < 0.001$

Table 8 Posttest comparisons by item: human context versus mouse context; statistically, significant differences are in bold

		Human	Mouse	*Z*
Key concepts	Variation	0.84	0.87	−1.474
	Heritability	0.64	0.66	−0.577
	Competition	0.01	0.03	−1.265
	Hyperfecundity	0.00	0.00	0.000
	Resource limitations	0.11	0.20	**−3.414****
	Differential survival	0.55	0.71	**−5.392****
	Frequency/distribution	0.33	0.35	−1.068
Cognitive biases	Essentialism	0.04	0.04	0.000
	Intentionality	0.02	0.03	−1.291
	Teleology	0.03	0.07	**−2.985***
Misconceptions	Pressure	0.01	0.04	**−3.317****
	Adapt	0.05	0.07	−1.225
	Need	0.03	0.10	**−4.116****
	Must	0.02	0.06	**−2.982***
	Use	0.03	0.01	−1.897
	Energy	0.00	0.00	0.000

*$p < 0.05$
**$p < 0.001$

3.2 Research Question 2

There were six significant differences between the human and mouse contexts, with students showing evidence of understanding resource limitations and differential survival more frequently in the mouse context than the human context, but greater frequency of teleology cognitive bias and pressure, need, and must misconceptions in the mouse context. Table 8 presents the results of the significance tests comparing the human and mouse contexts for each item.

3.3 Research Question 3

When changes in each variable from pretest to posttest were compared between students who experienced the CRS and those who did not, in the mouse context, students who experienced the CRS appear to have a significantly greater gain in variation, heritability, differential survival, and frequency/distribution than students who did not experience the CRS. They also appear to have significantly larger decreases in the teleology cognitive bias and need misconception.

Table 9 Change, in percentage points, of students answering correctly on each ACORNS component by CRS strategy in the human and mouse contexts; statistically, significant differences are in bold

		Mouse context			Human context		
		CRS	No CRS	*Z*	CRS	No CRS	*Z*
Key concepts	Variation	0.30	0.04	**−4.641****	0.18	0.10	−1.490
	Heritability	0.28	0.08	**−2.885***	0.26	0.13	−1.800
	Competition	−.002	0.02	−1.614	−0.01	−0.01	−0.073
	Hyperfecundity	0.00	0.00	0.000	0.00	0.00	0.000
	Resource limitations	0.06	0.02	−0.713	0.07	−0.01	−1.703
	Differential survival	0.26	0.02	**−3.490****	0.25	0.16	−1.434
	Frequency/distribution	0.23	0.06	**−2.577****	0.15	0.15	−0.079
Cognitive biases	Essentialism	−0.10	−0.05	−1.263	−0.02	−0.04	−0.470
	Intentionality	0.01	−0.02	−0.964	−0.01	−0.01	−0.058
	Teleology	−0.21	−0.01	**−4.651****	−0.04	0.02	−0.650
Misconceptions	Pressure	0.02	−0.02	−1.288	−0.05	−0.03	−0.635
	Adapt	−0.09	−0.02	−1.841	−0.10	−0.06	−0.907
	Need	−0.15	0.02	**−3.776****	−0.02	−0.01	−0.589
	Must	−0.05	−0.02	−0.936	−0.02	−0.01	−0.661
	Use	−0.01	−0.01	−0.131	−0.04	−0.02	−0.663
	Energy	0.00	0.00	0.000	0.00	0.00	0.000

*$p < 0.05$
**$p < 0.001$

In contrast, there were no significant differences in the human context (see Table 9). Although the trend appears to be toward greater increase in frequency of responses that show evidence in understanding key elements of natural selection and greater decrease in misconceptions when the CRS was used, the results are not significant. Table 9 shows the changes in each variable in students who did and did not experience the CRS.

4 Discussion

This is the first study of which we are aware that assessed high school students' understanding of natural selection before and after using curriculum materials that use human examples to teach evolution. It is also the first study in the USA to assess quantitatively high school students' understanding of natural selection before and after using teaching strategies that acknowledge the cultural controversy around teaching and learning evolution that exists in many contexts. The overall increases in understanding of natural selection suggest that combining human examples as the context for evolution instruction with classroom activities that acknowledge the cultural controversy and help manage students' tension around the topic of evolution hold promise as an effective strategy for high school evolution education.

In this study, we saw significant gains in evolution understanding in high school students from pretest to posttest in four aspects of understanding evolution: variation, heritability, differential survival, and frequency/distribution, in both human and mouse contexts. These results are important because variation, heritability, and differential survival are considered by many to be the three main essential components for natural selection. These results suggest that the TEtHE materials may be contributing to changes in understanding of natural selection where it counts the most conceptually. Interestingly, at both pretest and posttest, students were more likely to use resource limitations and differential survival in the mouse context than the human context. Perhaps, these ideas are more difficult realities and/or processes for students to associate with humans.

We also found significant reductions in cognitive biases and misconceptions across both mouse and human contexts, indicating the utility of the TEtHE materials for this purpose as well. Our findings (Tables 6 and 7) agree with previous studies indicating that the idea that individual organisms change in response to 'need' is the most common misconception in secondary and postsecondary students (Gregory, 2009). Interestingly, we saw a higher proportion of students with a teleology cognitive bias and more misconceptions generally in the mouse context than the human context. While this may be the opposite of an intuitive prediction which assumes students will have greater cognitive biases and misconceptions when it comes to humans, it could be interpreted as students still not grasping that evolutionary processes apply to humans at all and are therefore less likely to even have cognitive biases and misconceptions in that context.

We were surprised to find that the CRS activities seemed to pave the way for greater increases in understanding and decreases in cognitive biases and misconceptions in the mouse context, but not the human context. Perhaps, some students who experience the cultural controversy personally and participated in the CRS activities increased their openness to considering natural selection in a non-human context but still have some barriers to learning correct evolution concepts when it comes to humans. It is possible for students to create cognitive walls between things they believe and things they do not believe in order to understand evolution but not 'believe' it or accept it (Coburn, 1996; McKeachie, Lin, & Strayer, 2002; Ingram & Nelson, 2006; Hermann, 2012). Rather than a true lack of conceptual understanding, many students' misconceptions may be the result of this compartmentalizing or dismissal of scientific knowledge, especially if they feel that it contradicts their faith (Coburn, 1996; Hermann, 2012). Overall, the case for the CRS activities attributing to a decrease in some misconceptions and cognitive biases is a compelling finding that is worthy of additional research.

The data reported here support the general findings of educational research on college students in terms of effective pedagogical approaches. Constructivist-learning approaches that elicit student ideas and then give them multiple opportunities and experiences to engage in science practices to build explanations consistent with scientific understandings show promise to achieve the goals of evolution educators. The data also suggest that using examples of evolution in humans, which may be more relevant and interesting to students than examples of evolution in more distantly related organisms (and often ones they have never encountered), also shows important promise (Pobiner et al., 2018). Finally, the data suggest that at least in some contexts, eliciting students' cultural concerns through an explicit discussion of non-scientific views can pave the way to greater correct understanding of evolution (Bertka et al., 2019).

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