Learning, Understanding, and Acceptance: The Case of Evolution

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Abstract

The relationship between understanding an idea and accepting it as true has been little studied, yet this relationship is key to science education. The present study explored this relationship in the context of evolution by natural selection, which just 40% of Americans accept as true. US undergraduates' understanding of evolution was assessed before and after a one-semester class on evolution and behavior and was compared to their acceptance of evolution. Participants who initially held inaccurate, need-based theories of evolution were less likely to accept evolution – both microevolution and macroevolution – than participants who held accurate, selection-based theories. After instruction, however, participants who had increased their understanding of evolution had increased their acceptance of evolution as well. These findings suggest that understanding evolution is essential to accepting it, and that teaching evolution is a necessary step to increasing its public acceptance.

Keywords: conceptual development; intuitive theories; naïve biology; science education

Introduction

Theories are the ultimate desiderata of science. While many scientists have devoted their lives to the pursuit of theoretical knowledge, very few have elucidated theories sufficiently comprehensive to survive the test of time. Those theories that have survived – e.g., Newton's theory of universal gravitation, Maxwell's theory of electromagnetic radiation, Wegener's theory of continental drift – share several common attributes, including parsimony, coherence, and vast explanatory scope (see Kuhn, 1977; Thagard, 2007). Appreciation of these attributes presumably requires an understanding of how the theory works – i.e., how it answers the questions it purports to answer and how it solves the problems it purports to solve – yet there is little evidence to support this contention. The present study attempts to provide such evidence by exploring the relationship between understanding and accepting biology's most fundamental theory: Darwin's theory of evolution by natural selection.

First published in 1859, Darwin's theory sought to answer the age-old questions of where species had come from and why species match (i.e., are adapted to) their environment. Despite initial resistance among biologists skeptical of Darwin's inability to explain the source of heritable variation, evolution by natural selection eventually came to be recognized as the unifying paradigm of the life sciences (Bowler, 1983). As the biologist Dobzhansky (1973) has succinctly stated, "Nothing in biology makes sense except in the light of evolution." Scientific consensus aside, many outside the scientific community still doubt that evolution occurs. In a recent survey of 34 countries, only 40% of Americans agreed with the statement "Human beings, as we know them, developed from earlier species of animals," placing the United States second to last in its overall acceptance of evolution (Miller, Scott, & Okamoto, 2006).

Do Americans who reject evolution actually understand what evolution is? One reason to think not is that the literature on evolution education has documented numerous evolutionary misconceptions in numerous populations, including middle school students (Lawson & Thompson, 1988), high school students (Banet & Ayuso, 2003; Settlage, 1994), college undergraduates (Anderson, Fisher, & Norman, 2002; Asterhan & Schwarz, 2007; Bishop & Anderson, 1990; Demastes, Settlage, & Good, 1995; Ferrari & Chi, 1998; Greene, 1990; Jensen & Finley, 1995), medical school students (Brumby, 1984), and even pre-service teachers (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005). These misconceptions include conflating mutation with adaptation, conflating species adaptation with individual adaptation, and preferring teleological explanations of adaptation to mechanistic ones. Recent research by Shtulman (2006) and Shtulman and Schulz (in press) has shown that these misconceptions stem from an essentialist construal of biological kinds, on which species are viewed as the physical manifestation of an underlying "essence" rather than as continuums of randomly occurring variation. This construal leads individuals to devalue the prevalence and persistence of within-species variation, and, consequently, to fail to understand any mechanism of evolution that operates over such variation – i.e., natural selection.

Despite these considerations, the claim that disbelief in evolution stems from a misunderstanding of evolution has yet to receive empirical support. No study testing for correlations between understanding and acceptance has found them (Bishop & Anderson, 1990; Brem, Ranney, & Schindel, 2003; Demastes et al., 1995; Lawson & Worsnop, 1992; Sinatra, Southerland, McConaughy, & Desmastes, 2003).

It is possible that these null results reflect a genuine dissociation between understanding and acceptance. It also possible, however, that they reflect an inadequacy in the studies' methodological power, particularly their power to differentiate accurate conceptions of evolution from inaccurate ones. To address this latter possibility, we sought correlations between understanding and acceptance with an assessment tool designed in light of the history and philosophy of biology (e.g., Gould, 1996; Hull, 1965; Mayr, 1982; 2001) to uncover naïve theories of evolution incompatible with natural selection. Previous research using this assessment tool (Shtulman, 2006; Shtulman & Schulz, in press) has shown that, parallel to early evolutionary theorists, most contemporary students of evolution construe evolution as the uniform (non-genetic) transformation of a species' underlying essence, resulting in the gradual adaptation of all species members. Although many students retain this "transformational" understanding of evolution throughout their biology education, some do achieve a correct, "variational" understanding of evolution, in which evolution is construed as the selective propagation of within-species variation.

In addition to seeking correlations between understanding and acceptance, we also sought correlations between *learning* and acceptance, as such correlations would speak to the question of whether understanding and acceptance are causally related. To that end, we measured participants' acceptance of evolution both before and after a teaching intervention designed to increase their understanding of evolution.

Method

Participants

The participants were 45 undergraduates enrolled in a one-semester course on evolution and behavior at a public northeastern university with similar demographics to the United States as a whole. All had taken at least one high school or college-level biology course prior to the course in which they were currently enrolled, and some had taken as many as three.

The Teaching Intervention

The main objective of the teaching intervention was to help participants derive, for themselves, the concepts of evolution and natural selection from basic principles of biology, natural history, and population dynamics. The intervention was based on Mayr's (1982) analysis of how Darwin initially derived the concepts of evolution and natural selection from four basic phenomena (superfecundity, resource limitation, trait variation, trait hereditability) and two intermediate inferences (differential survival, differential reproduction). Five clusters of activities produced opportunities for participants to reproduce this chain of inferences, either by generating their own data or by analyzing preexistent data from real populations of organisms. These activities also produced opportunities for participants to confront, articulate, and question their non-genetic, non-variational assumptions about species adaptation.

The opening activity was designed to introduce the concept of superfecundity (the potential inherent in all species to grow exponentially) and to set the stage for the other three phenomena. That activity began with the instructor posing the question, "Why is the earth not covered in dogs?" Participants were asked to estimate the number of offspring a single pair of dogs would produce over six generations of breeding if each pair of each generation produced just ten offspring each year (the so-called "overlapping generations model"). After making an estimation, participants calculated and graphed the actual number of offspring produced. This value typically exceeded their estimates by several orders of magnitude, and raised powerful questions that served as entry points for discussing the other phenomena and inferences. For instance, the frequently asked question "Why do so few individuals survive?" raised issues of limited resources (e.g. food, nests, mates), competition, predation, disease, and bad weather. The question "Who dies?" set up issues of trait variation, differential heritability, and chance. And the question "Who survives?" raised issues of differential reproduction, trait variability, chance. (For more on the intervention, see Calabi, 1998, 2005.)

This way of teaching evolution contrasts with typical instruction in that it allows students to derive relevant outcomes from first principles and real data, while also accounting for their pre-instructional misconceptions. (For similar approaches in other domains, see Smith & Unger, 1997; Slotta & Chi, 2006). Because students had derived and constructed the relevant concepts themselves, we hypothesized that they were more likely to accept those concepts as true, thereby side-stepping the typical "dualistic" outcome of science education, in which students maintain their intuitive beliefs alongside those explicitly required by the instructor (e.g., Bloom & Wiseberg, 2007).

The Comprehension Assessment

At the beginning and end of the 15-week semester, participants' understanding of evolution was assessed with a 30-question survey covering six evolutionary phenomena: variation, inheritance, adaptation, domestication, speciation, and extinction. Each question was designed to differentiate inaccurate, transformational interpretations of the phenomenon at hand from accurate, variational ones. As an illustration, consider the following task from the section on variation:

> During the 19th century, England underwent an Industrial Revolution that resulted in the unfortunate side effect of covering the English countryside in soot and ash. During this same period of time, England's native moth species *Biston betularia* became, on average, darker in color. If you had gathered a random sample of *Biston betularia* every 25 years over the course of the nineteenth century, what range of colorations would you have expected to find at each point in time?

Participants responded to this question by shading each moth in a 5 x 5 matrix representing five samples of five moths each. The two most common response patterns are depicted in Figure 1. The pattern on the left depicts an adaptive variation (i.e., dark coloration) spreading through a population over time and was classified as an instance of (correct) variational reasoning. The pattern on the right depicts a population uniformly acquiring the same adaptation and was classified as an instance of (incorrect) transformational reasoning. Note that the main difference between these two response patterns is the inclusion/exclusion of within-species variation. Whereas the pattern on the left depicts variation occurring both within and across generations, the pattern on the right depicts variation occurring only across generations.

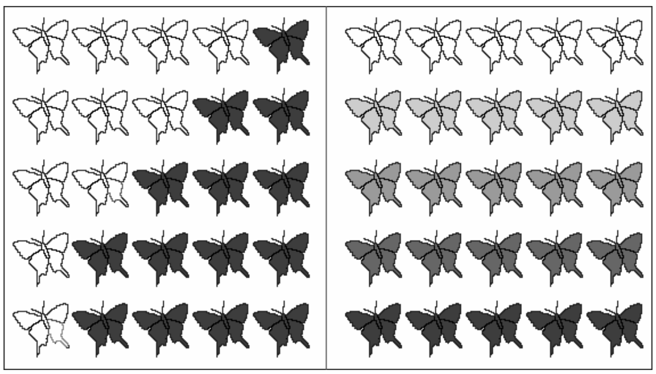

Figure 1: The variational response pattern (left panel) and the transformational response pattern (right panel) on the moth-shading task of the comprehension assessment.

The entire comprehension assessment and scoring rubric can be found in Shtulman (2006). In brief, participants responses were scored along a three-point scale. Responses consistent with variationism were scored +1; responses consistent with transformationism were scored –1; and responses consistent with both (i.e., ambiguous responses) were scored 0. Summed across 30 questions, participants' assessment scores could range anywhere from -30 to +30. In actuality, they ranged from -24 to +28.

Half of the questions on the comprehension assessment were open-ended in nature. Participants' responses to these questions (n = 1350) were scored by a single coder blind to the identity of the participant who had provided them. A subset of the responses (n = 420) were scored by a second coder, who agreed with the first coder 92% of the time. This percentage was considered sufficiently high to retain the first coder's scorings.

Measures of Acceptance

Following the comprehension assessment, participants were asked to rate their agreement with five statements of belief on a scale from 1 ("strongly disagree") to 5 ("strongly agree"). Those statements were (1) "Species have changed over time;" (2) "The species in existence today have not always existed;" (3) "Natural selection is the best explanation for how species adapt to their environment;" (4) "Natural selection is the best explanation for the origin of new species;" and (5) "The origin of human beings does not require a different explanation than the origin of other species." The ordering of these statements was determined by their hypothesized controversiality, as public opinion polls have shown that Americans are more accepting of microevolution than macroevolution and more accepting of nonhuman evolution than human evolution (Scott, 2005).

Following the five statements about evolution were two statements about religion: "I believe in the existence of God" and "I believe in the existence of souls." Participants' agreement ratings for these two statements were analyzed separately from their agreement ratings for the preceding five, as they do not directly bear on participants' acceptance of evolution.

It is worth noting that previous research using the same comprehension assessment, the same measures of acceptance, and the same sample size (i.e., Shtulman, 2006) found a positive, but nonsignificant, correlation between understanding and acceptance. Re-inspection of those data revealed the presence of two outliers – i.e., two participants whose agreement ratings that were more than two standard deviations below the mean (perhaps because they had misinterpreted the rating scale). Removing those participants from the dataset yielded correlations between understanding and acceptance of a comparable magnitude to those reported below.

Results

Assessment Scores

As expected, participants in the present study demonstrated pervasive, pre-instructional misconceptions of a transformational nature. Some of these misconceptions were corrected by instruction, and some were not. The effect of instruction on participants' overall understanding of evolution can be seen in Table 1, which displays frequency distributions of participants pre- and post-instructional assessment scores. Before instruction, nearly half of all participants scored below -10, resulting in a mean score of -4.0 (SD = 15.0). After instruction, only a quarter did so, resulting in a mean score of 1.1 (SD = 13.8). A paired-samples t-test confirmed that this difference was statistically significant ($t(45) = 4.39$, $p < 0.001$).

Although pre-post gains in assessment scores were modest in size, they were frequent in occurence. A full 71% of participants increased their score by one or more points, 47% increased their score by five or more points, and 27% increased their score by ten or more points. This rate of change is unprecedented in the evolution education literature (e.g., Bishop & Anderson, 1990; Demastes et al., 1995; Jensen & Finley, 1995).

Table 1: Frequency distributions of participants' pre- and post-instructional assessment scores (n = 45).

Range of scores	Pre-instruction	Post-instruction
-30 to -21	4	2
-20 to -11	18	10
-10 to 0	6	12
1 to 10	7	10
11 to 20	6	7
21 to 30	4	4

Acceptance Ratings

Just as participants assessment scores increased as a function of instruction, their agreement ratings for the five statements of belief increased as well. Before instruction, participants' ratings averaged 4.2 across the five statements of belief (SD = 0.7); after instruction, they averaged 4.4 (SD = 0.6). A paired-samples t-test confirmed that this difference was statistically significant ($t(45) = 4.39$, $p < 0.001$).

To determine whether participants' understanding of evolution was correlated with their acceptance of evolution, participants' agreement ratings for the five statements of belief listed above were averaged together and compared to their overall assessment score. This analysis revealed that the higher a participant scored on the comprehension assessment, the more he or she tended to accept the occurrence of evolution, both before instruction ($r = 0.56$, $p < 0.001$) and after ($r = 0.50$, $p < 0.001$). Thus, even though participants' assessment scores tended to increase from pretest to posttest, the relationship between assessment scores and agreement ratings remained constant.

This finding was further explored by regressing participants' assessment scores against their agreement ratings for the five statements of belief treated as independent measures. In other words, agreement ratings for each statement of belief were entered into the regression as separate variables. This analysis revealed that participants' agreement ratings explained a significant amount of the variance in their assessment scores both before instruction ($R^2 = 0.40$, $F(5,39) = 5.20$, $p < 0.01$) and after ($R^2 = 0.29$, $F(5,39) = 3.19$, $p < 0.05$), though none of the individual ratings were significant predictors on their own (possibly because of the limited range of variability associated with each).

Participants' agreement ratings are broken down by statement type (S1, S2, S3, S4, S5) and assessment period (pre-instruction, post-instruction) in Figure 2. Two effects are observable from this figure. First, agreement ratings decreased from statement 1 (about species change) to statement 5 (about human evolution), as predicted by the controversiality of their content. Second, agreement ratings increased as a function of instruction. The reliability of these effects was assessed with a 5 x 2 repeated-measures ANOVA, which revealed main effects of both statement type ($F(4,176) = 17.34$, $p < 0.001$) and assessment period ($F(1,44) = 9.48$, $p < 0.01$) but no interaction between them.

The main effect of statement type was explored with a linear contrast analysis. This analysis confirmed that participants' agreement ratings decreased linearly from statement 1 to statement 5 ($F(1,44) = 36.59$, $p < 0.001$). The main effect of assessment period was explored with paired-samples t tests comparing participants' pre-instructional agreements ratings to their post-instructional ones for each statement of belief. These analyses revealed significant increases for three of the five statements: statement 2 (about speciation), $t(44) = 2.30$, $p < 0.05$; statement 3 (about adaptation), $t(44) = 2.93$, $p < 0.01$; and statement 5 (about human evolution), $t(44) = 2.15$, $p < 0.05$.

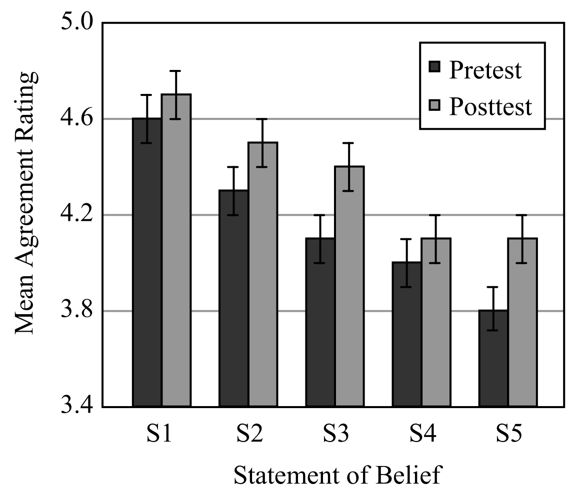

Figure 2: Mean agreement ratings (+ SE) for the five statements of belief, both before and after instruction; 1 = "strongly disagree," 5 = "strongly agree."

The data displayed in Figure 2 were averaged over agreement ratings ranging from "strongly agree" to "strongly disagree." To assess the effect of instruction on participants' sheer acceptance of evolutionary claims, we calculated the percentage of participants who agreed (or strongly agreed) with each statement of belief and compared those percentages across assessment periods. Before instruction, the percentage of participants who agreed with statements 1 through 5 were 93%, 76%, 76%, 62%, and 58%, respectively. After instruction, those percentages were 100%, 89%, 91%, 69%, and 76%, respectively.

Parallel to the paired-samples t tests reported above, chi-square analyses revealed a significant association between instruction and acceptance for three of the five statements: statement 2 ($\chi^2 = 3.85$, $p < 0.05$), statement 3 ($\chi^2 = 6.08$, $p < 0.05$) and statement 5 ($\chi^2 = 9.36$, $p < 0.01$). The fact that instruction increased participants' acceptance of statement 5 (i.e., "The origin of human beings does not require a different explanation than the origin of other species") is particularly noteworthy, as it is this claim that Americans are least likely to endorse (e.g., Miller, Scott, & Okamoto, 2006; Newport, 2004).

Although most participants (71%) increased their assessment score following instruction, some (29%) did not. To determine whether those who increased their score (the "learners") increased their acceptance of evolution more than those who did not increase their score (the "nonlearners"), we subtracted participants' pre-instructional agreement ratings from their post-instructional agreement ratings and compared those differences across groups. The results of this analysis, displayed in Table 2, show that the effect of instruction on participants' agreement ratings was restricted mainly to the learners. In other words, only participants who increased their understanding of evolution tended to increase their acceptance of evolution as well.

Table 2: Mean differences between pre- and post-instructional agreement ratings (+ *SE*) for both learners and nonlearners.

Statement	Learners	Nonlearners
S1	+.28 (.11)	-.15 (.10)
S2	+.31 (.13)	+.08 (.18)
S3	+.44 (.11)	-.08 (.18)
S4	+.28 (.71)	-.23 (.17)
S5	+.34 (.13)	+.38 (.27)

To assess the reliability of this effect, we submitted the difference scores displayed in Table 2 to a 2 x 5 repeated-measures ANOVA in which participant group (learners, nonlearners) was treated as between-participant factor and statement type (S1, S2, S3, S4, S5) was treated as a within-participant factor. This analysis revealed a significant effect of participant group ($F(1,43) = 5.02$, $p < 0.05$) but no other significant effects, implying that it was a change in understanding, not merely a change in exposure, that increased participants' overall acceptance of evolution.

Discussion

Many investigators (e.g., Bishop & Anderson, 1990; Demastes et al., 1995; Lawson & Worsnop, 1992; Sinatra et al., 2003) have pursued the intuition that understanding evolution leads to an acceptance of evolution, yet none have found evidence to support it. Here, we document such evidence for the first time using a comprehension assessment sufficiently sensitive to differentiate transformational conceptions of evolution (consistent with pre-Darwinian biology) from variational ones (consistent with post-Darwinian biology). We found not only that participants' acceptance of evolution was correlated with their understanding of evolution but also that their acceptance of evolution increased in strength as their understanding of evolution increased in accuracy.

Taken together, these findings suggest that Americans' disbelief in evolution is fostered, at least in part, by a misunderstanding of what evolution is. Rather than construe evolution as the selective propagation of within-species variation, many appear to construe evolution as the uniform, cross-generational transformation of all species members. This construal is not only incorrect but is also problematic for appreciating how biological phenomena bear on evolutionary claims and how evolutionary claims make sense of biological phenomena.

As an illustration, consider the recent discovery that humans share over 80% of their genes with mice (Waterston et al., 2002). This discovery is easily assimilated by a variationist, who sees species as continuums of variation related by common ancestry, but is not easily assimilated by a transformationist, who sees species as discrete entities characterized by unique, nonoverlapping essences. A transformationist must either recast mice as the evolutionary forbearers of humans (e.g., the *San Franscisco Chronicle* reporter who asserted that "scientists have found a wealth of common chemistry between human beings and our tiny, four-legged ancestors") or downplay the importance of genes in determining a species' identity (e.g., the *London Observer* reporter who asserted that "environmental influences are vastly more powerful [than genetic influences] in shaping the way humans act").

It should be noted that our findings, while implicating understanding as an important influence on acceptance, do not implicate understanding as the *only* influence on acceptance. One's religious commitments are presumably an important influence as well. In this study such influence was seen in participants' agreement ratings for the statements "I believe in the existence of God" and "I believe in the existence of souls." These ratings did not change as a function of instruction and were negatively correlated with participants' assessment scores at both pretest and posttest.

Interestingly, adding participants' agreement ratings for the religious statements to the regression models of their pre- and post-instructional assessment scores (described above) yielded no significant change to the pre-instructional model but *did* yield a significant change to the post-instructional model, increasing the amount of variance that model could explain by 16% (*F-change*$(2,37) = 5.46$, $p < 0.01$). This pattern of results indicates that, although religious individuals were no less likely to understand evolution than nonreligious individuals before instruction, they were significantly less likely to do so after instruction, perhaps because of a lack of attentiveness to instruction.

Clearly, multiple factors influence an individual's acceptance of evolution. An understanding of evolution is, however, the only factor that science educators can hope to change. Lest the work of such individuals be in jest, the present study demonstrates that effective instruction can, indeed, foster an increased acceptance of evolution. Improving evolution education in the United States, as a whole, might therefore increase public acceptance of evolution to a level more typical of other first-world nations.

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