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Scientifically Adrift: Limited Change in Scientific Literacy, and No Change in Knowledge and Acceptance of Evolution, over Three Years of College

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ABSTRACT

Scientific literacy refers to knowledge of fundamental scientific facts, understanding of the process of science, and appreciation of science's impact on society (Miller, 1989). Evolution literacy is one component of scientific literacy on which U.S. citizens score particularly low (Miller, Scott, & Okamoto, 2006). We conducted a longitudinal study (*N*=200) to explore change in scientific literacy over three years of college, with a particular focus on change in knowledge and acceptance of evolution. We also assessed students' belief in God, moral objections to evolution, young Earth creationist beliefs, and ascription to intelligent design fallacies. Students showed slight and statistically significant growth in scientific literacy overall, but no growth in knowledge and acceptance of evolution. The sample as a whole decreased slightly in belief in God, moral objections to evolution, young Earth creationist beliefs, and acceptance of intelligent design fallacies; but within-person analyses showed that neither incoming beliefs nor change in beliefs consistently coincided with changes in scientific literacy or knowledge and acceptance of evolution. As college seniors, students who had taken more science courses also scored higher in overall scientific literacy and higher in knowledge and acceptance of evolution, but those links were diminished after controlling for their incoming scientific literacy and knowledge and acceptance of evolution. Overall, our findings corroborate previously offered recommendations (Allmon, 2011) that evolution instruction in higher education be multi-faceted and intentional.

KEYWORDS

College Education, Evolution, Longitudinal Research, Acceptance of Evolution, Scientific Literacy

SCIENTIFICALLY ADRIFT

Scientific literacy refers to knowledge of fundamental scientific facts, understanding of the process of science, and appreciation of the impact of science

Note: Tables and figures located in the first appendix of the article, scale items found in appendix II on society (Miller, 1989, 1998, 2002). Scientific literacy is considered essential to function as an informed and active citizen in modern society (Anelli, 2011; Hazen & Trefil, 2009; National Research Council, 1996; Trefil, 2008). Scientific knowledge and reasoning skills help citizens make well-founded decisions about their physical and mental health, community initiatives and educational fads, political and moral debates, and international concerns such as global warming and disease prevention. However, people score quite low on objective measures of their knowledge of scientific facts and understanding of the scientific process (Durant, Evans, & Thomas, 1989; Miller, 1998). For example, in a 1995 assessment (Miller, 1998), fewer than half of United States (U.S.) citizens correctly reported through a pair of closed-ended questions that the Earth goes around the Sun once each year; fewer than half recognized that antibiotics do not kill viruses; and only a small minority (12%) could provide the rationale for conducting an experimental study with a control group to test a drug's effectiveness. Scientific literacy scores in the U.S. have improved somewhat since that 1995 assessment, but only a minority (28%) of adult Americans is considered scientifically literate (Miller, 2007).

Although evolutionary theory is the cornerstone of the life sciences, it is one component of scientific literacy on which U.S. citizens fare particularly poorly (Miller, Scott, & Okamoto, 2006). Compared to Japan and 32 European countries, only Turkey scores lower than the United States in knowledge and acceptance of evolution. On various public polls, only half of U.S. citizens correctly reject the statement that early humans lived on the Earth at the same time as dinosaurs did, and just over a third correctly accept the scientific consensus that human beings, as we know them today, developed from earlier species of animals (Miller et al., 2006). Americans' views seem to be particularly strident in the context of human as opposed to non-human evolution (Keeter & Horowitz, 2009; Miller et al., 2006), which helps to clarify why teaching (and accepting) evolution in the context of human behavior can be quite challenging (O'Brien, Wilson, & Hawley, 2009).

There are a number of factors associated with scoring low in scientific literacy and evolution literacy. Gender, education level, religious belief, and age all relate to scientific literacy (favoring young, educated, non-religious males), but differential exposure to college-level science coursework is the strongest correlate (National Science Board, 2010). In one study of American adults, for example, individual differences in self-reported exposure to college-level science coursework (specifically, having had any Biology, Chemistry, or Physics) explained 39% of the variance in scientific literacy scores (Miller, 1989). That association between exposure to science coursework and scientific literacy has been interpreted to imply that exposure to college-level science coursework *leads* to growth in general scientific literacy (Hobson, 2008; National Science Board, 2010). However, it is possible that scientific literacy and exposure to college-level science coursework are correlated because of self-selection effects, whereby people with strong scientific literacy and interest in science (Durant et al., 1989) are the people who opt to take more coursework in science. In the current study, we use a longitudinal design to test these distinct possibilities: We can investigate (1) whether exposure to science coursework is accompanied by increases in scientific literacy over time, and (2) whether differences among students in incoming scientific literacy predict differential enrollment over subsequent years in college-level science courses. Thus, one objective of the current study is to investigate change in students' overall scientific literacy over three years of college, as a function of their incoming scientific literacy and their reported exposure to college-level science coursework during college.

In contrast to the established link between science coursework and *general* scientific literacy, exposure to advanced education is not consistently associated with increased acceptance of *evolution*. Miller et al. (2006) found no evidence that education level correlated with adult Americans' level of acceptance and knowledge of evolution, and one study that followed Americans from adolescence through early emerging adulthood found no evidence that attending college leads those with creationist views to become more favorable toward evolution (Hill, 2014). Even pre-test post-test studies of students in specific science courses find only a slight increase or no increase at all in acceptance of evolutionary ideas after intentional exposure to material on evolution and natural selection (Chinsamy & Plaganyi, 2007; Rice, Olson, & Colbert, 2011). Thus, non-acceptance of evolution appears to result from more than a mere lack of exposure to accurate information.

Indeed, non-acceptance of evolution is associated with multiple attitudinal and cognitive factors (Allmon, 2011; Hawley, Short, McCune, Osman, & Little, 2011; Hill, 2014). Belief in God is a strong correlate of non-acceptance, as is the view that the Universe, Earth, and all life on Earth were created by direct acts of God over a short period of time approximately 6,000 years ago (Allmon, 2011; Hawley et al., 2011). Moreover, individuals who hold young Earth creationist beliefs and who have friends and family who share those beliefs tend to display consistency over time in their unfavorable attitudes toward evolution (Hill, 2014). Related to holding creationist views, those who ascribe to politically conservative views on social issues (such as abortion) tend to not accept evolution (Miller et al., 2006); and those who ascribe to intelligent design fallacies, hold moral objections to evolution, and distrust science and technology also tend to not accept evolutionary ideas (Hawley et al., 2011).

In summary, individuals' views on evolution appear to be tied to individuals' social attitudes and religious beliefs (Allmon, 2011; Hawley et al., 2011; Hill, 2014). The second objective of the current study is to explore three years of college as a context for change in students' knowledge and acceptance of evolution, and to investigate individual-level attitudes and beliefs that are associated with increased knowledge and acceptance of evolution over those three years. We speculate that students who begin college with attitudes and beliefs that are favorable toward evolution (e.g., less distrust of science and technology, weaker young Earth creationist beliefs) may be more likely to spend time with other students who share those views and in courses that reinforce those views. As such, we predict that students who begin college with beliefs and attitudes that are favorable toward evolution will be more likely than other students to experience increased knowledge and acceptance of evolution during their college years.

METHOD

Participants

In the fall of 2009 ("Time 1"), participants were recruited from introductory psychology courses at a regional public university in the United States. We chose introductory psychology because it serves a variety of majors, is a very popular general education course, and has enrollments comprised mostly of first-year students. We surveyed a total of 377 students (71% female, 29% male); 92% were first- or second-year students, and those who had declared a major represented over 40 different majors or programs across campus. At the initial data collection, all but three participants gave written permission to be contacted in three years for the follow-up assessment.

In the fall of 2012 ("Time 2"), the University Foundation gave us $5,000 to support the longitudinal component of the research. We contacted 242 original participants who were still listed in the university directory and invited them to complete a follow-up assessment in return for $25. Over a three-month period, we collected responses from 200 of the original participants, 99% of whom had been first- or second-year students at Time 1. Those who were still enrolled in the university and who we contacted for follow-up did not differ significantly from those included only in the initial data collection on any potential variables of interest (scientific literacy, attitudes toward science and technology, or religious attitudes and beliefs; p values ranging from .09 - .99). Those we contacted for follow-up were significantly younger at Time 1 compared to those we were unable to contact, $t(372) = 3.79$, $p < .001$, likely because almost all the students whom we contacted later had been first- and second-year students at Time 1.

The final sample of 200 participants consisted of 57 men and 143 women, with a mean age at Time 1 of 18.51 years ($SD = 1.26$). We classified students' reported major at Time 2 into one of four disciplines: Math/Natural Sciences (biology, chemistry, physics, astronomy, geology, materials science, etc.); Social Sciences (psychology, sociology, political science, economics, communication/journalism, etc.); Arts/Humanities (English, religious studies, philosophy, history, theater, art, music, etc.); and Pre-Professional (nursing, kinesiology, business/marketing, education, communication sciences and disorders, etc.).

Our sample closely paralleled student representation university-wide. In the sample, 13% held a major in Math/Natural Sciences (compared to 12% university-wide); 25% in the Social Sciences (compared to 20% university-wide); 5% in the Arts/Humanities (compared to 12% university-wide); and 57% in the Pre-Professional fields (compared to 56% university-wide). One participant did not state their major at either time point. After initial analyses, Pre-Professional and Arts/Humanities majors were combined into one discipline category labelled "other" because their mean scientific literacy composite scores did not differ, $t(198) = 3.11$, $p = .533$. In addition, the sample was 29% male, compared to 41% university-wide.

Materials

We presented the study to students as a general assessment of their "life plans, social attitudes, and general knowledge." Hence, in addition to completing six scientific literacy scales, participants completed various attitude scales pertaining to their views about science, technology, and evolution. They also reported basic demographic information, their relationship attitudes and plans for work and family, and their educational aspirations. Below, we describe only the items that were utilized in the current analysis.

Demographic Characteristics

At both time points, students reported their major, biological sex, current educational level, and number of college-level science classes completed up to that point. At Time 1, students reported the total number of science courses they had completed up to that point (most had either zero or one). We did not ask for names of specific courses or departments, because most students were first-year students at that point and we did not expect them to have completed more than one science course, if any at all.

At Time 2, we asked students to specify how many college-level courses they had taken from each of the following domains: biology, chemistry, geography, geology, physics/astronomy, and materials science. In accord with their general education requirements, the typical student reported a total of 5.32 (*SD* = 4.22) college-level courses from those domains. Unfortunately, we did not include psychology on the list. However, the students in the sample did have introductory psychology because we obtained our sample from introductory psychology classrooms. We did not ask students to list out the specific courses they had taken, nor to describe the degree to which each course focused on various aspects of science (such as scientific reasoning, genetics, evolution, etc.). Given the emphasis that many psychology instructors place on the study of humans as a scientific enterprise, the students may have had as much (or more) exposure to scientific thinking and evolution in their introductory psychology course as they did in their other more “traditional” science courses.

Scientific Literacy Scales

Participants completed scientific literacy scales at both time points. The full list of items is provided in the Appendix. We drew our questions from various scales used in previous research (Hawley et al., 2011; Miller, 1998; Miller et al., 2006). At the time we were crafting our study materials, Hawley et al.’s (2011) paper had not been released and we had access to only some of the items they used. We reviewed Miller’s (1989; 1998; 2002; 2007) work to locate as many items as possible that had been reported in cross-country comparisons. Items were of relatively equivalent difficulty and spanned the topics of genetics (13 items, e.g., *More than half of human genes are identical to those of mice*), biology (9 items, e.g., *Antibiotics kill viruses*), evolution (14 items, e.g., *Natural selection is the only cause of evolution*), inorganic science (10 items, e.g., *Lasers work by focusing sound waves*), scientific reasoning (8 items, e.g., *Good theories give rise to testable predictions*), and probabilistic reasoning (3 items, e.g., *Imagine you are flipping a normal coin, with one side “tails” and one side “heads.” You have flipped the coin nine times so far, and each time it has come up “tails.” What is the chance that on your next flip, it will come up “heads”?*).

For each participant at each of the two time points, we computed subscale scores as well as a total scientific literacy composite score. The composite score was a total percentage correct weighted by the number of items in each subscale. Table 1 displays students' performance at each time point on the Evolution Literacy items.

Attitude Scales

At both time points, students used an 11-point scale to report how much they believe in God or a supreme being (*Not at all* to *Completely*). They completed several attitude subscales pertaining to views on religion and science/technology. The full list of items, which we drew from Hawley et al. (2011) and Miller et al. (2006), is provided in the Appendix. Again, at the time we were crafting our study materials, Hawley et al.'s (2011) paper had not been released and we had access to only some of the items they used. The items we included pertained to moral objections to evolution (2 items, e.g., *People who accept evolution as fact are immoral*); reservations about science and technology (6 items, e.g., *Science and technology have created a world that is full of risks for people*); young Earth creationist beliefs (4 items, e.g., *Adam and Eve from Genesis are the universal ancestors of the entire human race*); and ascription to intelligent design fallacies (6 items, e.g., *There is scientific evidence that humans were created by a supreme being or intelligent designer*). Students responded to these items using an 11-point scale ranging from 0 (*Disagree completely*) to 10 (*Agree completely*).

RESULTS

Descriptive Statistics

Table 1 shows participants' performance on the evolution literacy items, and Table 2 provides descriptive statistics for students' performance on all scientific literacy subscales. Values are presented as percentages of 100. Students varied in their performance on the subscales; they scored highest in inorganic science (M_{T1} = 88%; M_{T2} = 89%) and lowest on knowledge and acceptance of evolution (M_{T1} = 66%; M_{T2} = 67%). Scientific literacy composite scores hovered around 77% at Time 1 and around 80% at Time 2.

Change Over Time

Because we ran various analyses, we adopted an alpha of .01 to control for Type I error. As displayed in Table 2, students' overall scientific literacy showed weak but statistically significant growth from Time 1 to Time 2. Change in composite scores was accounted for primarily by mean-level change in the science reasoning and probabilistic reasoning subscales, and to a lesser degree by growth in biology literacy. The sample as a whole did not show significant change over time in genetic literacy, evolution literacy, or inorganic science literacy. As illustrated by the test-retest stability coefficients in Table 2, students' scores at Time 1 were significantly correlated with their scores at Time 2.

Science Coursework's Relation to Scientific Literacy and Evolution Literacy

There was substantial variability within the sample in growth over time in scientific literacy, with 95% showing a change score between -10 and +15. Although 63% of students experienced growth from Time 1 to Time 2, 37% of the sample showed no change or a decline in their composite science literacy score. Students also varied widely in how much they changed over time in evolution literacy, with 54% of them showing no change or a decline in their evolutionary literacy score from Time 1 to Time 2.

Our first objective was to investigate students' overall scientific literacy over three years of college and test the prediction that exposure to science coursework is correlated with growth over time in scientific literacy. Our first step was to replicate the previously documented association (Miller, 1989) between exposure to science coursework and scientific literacy. As expected, students' scientific literacy scores at the three-year follow-up were positively related to the number of science courses they had taken, $r(198) = .30$, $p < .001$. However, incoming scientific literacy was also associated with the number of science courses taken by Time 2, $r(198) = .37$, $p < .001$. When we conducted a partial correlation analysis to control for students' incoming scientific literacy, students' science coursework no longer predicted their Time 2 scientific literacy scores, partial $r(196) = .09$, $p = .192$.

Analyses revealed the same pattern of associations between science coursework exposure and knowledge of evolution. That is, students' evolution literacy scores at the three-year follow-up were positively related to the number of science courses they had taken, $r(191) = .20$, $p = .004$, but students' incoming evolution literacy was also associated with the number of science courses taken by Time 2, $r(191) = .23$, $p = .001$. When we controlled for students' incoming evolution literacy, students' science coursework no longer predicted their Time 2 evolution literacy scores, partial $r(189) = .13$, $p = .080$.

Belief and Attitudinal Correlates of Scientific Literacy and Evolution Literacy

We pursued other potential correlates of growth in scientific literacy, including students' sex, discipline of study, incoming belief in God, incoming young earth creationist beliefs, incoming ascription to intelligent design fallacies, incoming moral objections to evolution, and incoming reservations about science and technology. Each of these variables was associated with scientific literacy and evolution literacy at one or both time points. For example, independent samples *t*-tests revealed that men's overall scientific literacy exceeded women's at both time points (Men: $M_{T1} = 79.81$, $SD = 7.99$; $M_{T2} = 82.20$, $SD = 6.38$; Women: $M_{T1} = 75.51$, $SD = 7.44$; $M_{T2} = 78.46$, $SD = 7.58$); T1 $t(197) = 3.64$, $p < .001$, $d = 0.52$; T2 $t(128.47) = 3.57$, $p = .001$, $d = 0.63$). On evolution literacy, men did not score higher than women at either time point with the Type I error rate set at .01 (Men: $M_{T1} = 67.46$, $SD = 14.71$; $M_{T2} = 70.34$, $SD = 13.38$; Women: $M_{T1} = 64.80$, $SD = 12.86$; $M_{T2} = 65.70$, $SD = 12.69$); T1 $t(197) = 1.28$, $p = .203$, $d = 0.18$; T2 $t(197) = 2.32$, $p =$

.022, d = 0.29). As displayed in Figure 1, biological sex was not associated with degree of change over the three years. Men and women did not differ in their mean amount of change in science literacy from Time 1 to Time 2, $t(197) = -0.53$, $p = .595$, $d = -0.08$, nor did the sexes differ in their mean amount of change from Time 1 to Time 2 in knowledge and acceptance of evolution, $t(197) = 1.06$, $p = .290$, $d = 0.15$.

With the Type I error rate set at .01, discipline of study (as reported at Time 2) was associated with scientific literacy at both time points, $F_{T1}(2, 192) = 9.77$, $p < .001$, $\eta_p^2 = .09$; $F_{T2}(2, 192) = 13.77$, $p < .001$, $\eta_p^2 = .13$. At Time 1, Math/Natural Science majors scored similarly to Social Science majors ($p = .026$) and higher than Other majors (Pre-Professional and Arts/Humanities; $p < .001$), and Social Science majors scored similarly to Other majors ($p = .172$). At Time 2, Math/Natural Science majors scored similarly to Social Science majors ($p = .055$) and significantly higher than Other majors ($p < .001$), and Social Science majors scored significantly higher than Other majors ($p = .010$). Discipline of study was not associated with evolution literacy at either time point, $F_{T1}(2, 192) = 1.96$, $p = .144$, $\eta_p^2 = .02$; $F_{T2}(2, 192) = 4.15$, $p = .017$, $\eta_p^2 = .04$. As displayed in Figure 2, discipline of study was not associated with magnitude of change in scientific literacy from Time 1 to Time 2, $F(2, 192) = 0.59$, $p = .553$, $\eta_p^2 = .00$, nor was discipline related to the amount of change students showed in their knowledge and acceptance of evolution, $F(2, 192) = 0.31$, $p = .734$, $\eta_p^2 = .00$. As shown in the figure, within each discipline, change in evolution literacy over the three years was negligible.

Table 3 provides correlations among students' literacy scores and their attitudes and beliefs. Students with weaker religious beliefs, weaker moral objections to evolution, and less ascription to intelligent design fallacies had higher evolution literacy and composite scientific literacy at each time point. Students showed substantial stability in these attitudes and beliefs from Time 1 to Time 2, and although the sample as a whole showed an overall reduction in each of these dimensions over the three-year period, at the within-individual level none of the attitude and belief scales predicted change over time in evolution literacy or overall scientific literacy. For example, as displayed in the bottom row of Table 3, students who held weaker belief in God at Time 1 were no more or less likely than other students in the sample to show an increase (or decrease) over the three years in knowledge and acceptance of evolution. Thus, we did not find support for our expectation that students who begin college with attitudes and beliefs that are favorable toward evolution would be more likely than other students to experience increased knowledge and acceptance of evolution during their college years.

We ran a final set of analyses to investigate whether individual change in beliefs over the three years was associated with change in knowledge and acceptance of evolution. The findings were inconsistent. A decreased ascription to intelligent design fallacies, $r(198) = -.14$, $p = .043$, and young Earth beliefs, $r(198) = -.19$, $p = .007$, over three years was weakly associated with an increase in evolution literacy over that time. However, changes in belief in God, moral objections to evolution, and reservations about science and technology were not associated with parallel changes in knowledge and acceptance of evolution (all rs < .09, ps > .180).

DISCUSSION

One objective of the current study was to determine whether individuals show systematic growth in scientific literacy over three years of being in college. We found that, on average, students showed weak but statistically significant growth in overall scientific literacy. However, student growth was seen primarily on the subscales of probabilistic reasoning and scientific reasoning; students showed no growth in evolution literacy (and genetic literacy) despite having plenty of room to improve. Moreover, the links between science coursework and evolution literacy (and scientific literacy overall) at follow-up were diminished after accounting for students' incoming literacy scores, and the link between incoming scientific literacy and follow-up reports of science course-taking suggests that people with pre-existing interests and skills in science and evolution are the people pursuing that coursework. Our findings coincide with what other researchers have documented with much younger samples, namely that those who express interest in science, even in early childhood and early adolescence, are more likely than others to subsequently pursue and achieve in science (Leibham, Alexander, & Johnson, 2013; Lubinski & Benbow, 2006). [It also coincides with Glass, Wilson, and Geher's (2012) finding that many social science researchers who use evolutionary theory initiate their own evolutionary training.] One challenge, then, is to reach students whose initial interest or inclination to accept evolutionary theory is low, thereby making them less likely to enroll in science coursework that might expose them to evolutionary principles and applications. Even among students majoring in the sciences (including psychology), students in most universities can probably avoid classes that mention evolution, such as "Ecology and Evolution," "Human Evolution," and "Evolutionary Psychology," and choose other classes to fulfill their requirements. Because intentional exposure to evolutionary content does not systematically coincide with increased acceptance of evolution (Chinsamy & Plaganyi, 2007; Rice et al., 2011), it may not be enough to require students to take courses with evolution content. University-wide programs that bring evolution into students' general education core (O'Brien & Wilson, 2010), that address both scientific and affective causes of not accepting evolution (Allmon, 2011), and that address students' misconceptions about evolution (Varella, dos Santos, Ferreira, & Bussab, 2013) are likely to be part of the solution.

Our second objective was to investigate individual differences variables as correlates of change over time in knowledge and acceptance of evolution. We found that the small increase in overall scientific literacy was consistent across biological sex and major, suggesting that exposure to general education science courses might be credited for the growth. However, developmental research suggests that traditional-aged college students in general are still maturing cognitively and socio-emotionally during emerging adulthood (Arnett, 2000), so it is possible that the slight growth we observed in science literacy is a manifestation of general maturation processes as opposed to college *per se*.

Students' belief in God, belief in young Earth creationism, belief in intelligent design fallacies, moral objections to evolution, and distrust of science all showed mean-level decreases from Time 1 to Time 2. Contrary to our expectations, however, students' incoming beliefs and attitudes did not predict the degree to which they experienced change over time in their evolution literacy. As noted by one of our reviewers, this null association between incoming religious belief and change in acceptance of evolution suggests that students with stronger religious beliefs do not appear to be any less susceptible to learning about evolution compared to students with weaker religious beliefs.

Students who decreased over the three years in their young Earth beliefs were more likely to show an increase in their knowledge and acceptance of evolution, but we cannot know the causal arrow of those linked changes. That is, did change in young Earth creationist beliefs precede change in knowledge of evolution? Or did increased knowledge of evolution precede change in young Earth creationist beliefs? Regardless, the associations were weak, and individual changes in belief in God, moral objections to evolution, and distrust of science did not coincide with increased knowledge of evolution. We therefore failed to establish consistent evidence that pre-existing attitudes and beliefs predispose individuals toward or away from increased acceptance of evolution during college. Rather, students showed remarkable intra-individual consistency in their attitudes and beliefs over the three years.

Doing Well or Doing Poorly?

Students' composite scientific literacy scores hovered around 77% at Time 1 and 80% at Time 2. On the one hand, their performance is encouraging. For example, compared to the American public in the 1990s, the college students in our sample were more likely to know that antibiotics do not kill viruses (65% correct at Time 1 and 77% correct at Time 2) and that the Earth goes around the Sun once each year (77% correct at Time 1 and 81% correct at Time 2). Moreover, their understanding of probabilistic trends and their scientific reasoning scores showed substantial improvement from Time 1 to Time 2. If people understand that science is rooted in testable predictions and replicable observations of the natural world, and that probabilistic trends are not refuted by personal beliefs and single exceptions, then they have base skills for thinking logically about claims and ideas that they are likely to encounter in daily life (such as psychics, supernatural medical treatments, and conspiracy theories).

On the other hand, students' knowledge of evolution, in particular, was relatively low, and their performance did not improve after three years of college. At both time points, approximately 1 in 5 students failed to recognize that the earliest humans did not live at the same time as the dinosaurs, 1 in 3 failed to acknowledge that humans evolved from earlier species, and 1 in 2 held the false belief that species evolve to be perfectly adapted to their environments. These numbers are discouraging given that evolutionary theory is foundational to the life sciences. However, we do not know whether our students' science instructors explicitly presented evolutionary theory as foundational -- or if they emphasized evolutionary theory at all. Regardless, our findings corroborate other research documenting that in international comparisons U.S. citizens score very low on their knowledge and acceptance of evolution relative to citizens of many other countries (Miller et al., 2006). Students also did not show growth in their basic knowledge of genetics, despite the relevance of genetics to varied social issues such as the safety of genetically modified organisms, cloning and stem cell research, genetic disorders, definitions of race and ancestry, and debates about nature versus nurture.

Our findings of limited change during college coincide with other research on U.S. college students' cognitive development. Using the Collegiate Learning Assessment, an open-ended assessment of students' critical thinking and problem solving skills, Arum and Roksa (2011) reported that nearly half (45%) of college students showed no significant growth in critical thinking skills during the first two years of college. Using the ACT's Collegiate Assessment of Academic Proficiency (CAAP), a standardized, closed-ended assessment of critical thinking, Blaich and Wise (2011) reported that 30% of college students showed no growth or a decline over three years of college; moreover, 58% showed no growth or a decline in political and social involvement, and 79% showed no growth or a decline in their desire to contribute to the sciences. Our study was different in that we assessed scientific literacy as opposed to critical thinking and desire to make intellectual contributions, but our findings were strikingly similar: 37% of students either did not change or declined over the three years in their overall scientific literacy, and 54% either did not change or declined in their knowledge and acceptance of evolution. Given the massive array of scientific knowledge available in today's world, it is possible that our students would have performed differently had we used a different set of questions (e.g., Laugksch & Spargo, 1996). But, in the context of the other longitudinal data on students' intellectual growth, we think it is quite possible that the general pattern of findings would be similar regardless of the actual set of questions we used. Others have already noted (Arum & Roksa, 2011) that some students are "academically adrift" in college; our data suggest that some are "scientifically adrift" as well.

Limitations

One limitation of our study is that our sample was comprised of students from just one American university. However, our university is a public, four-year state university of 10,000 students; we obtained a representative sample of the student body; and our analyses revealed that students who we did not obtain for follow-up did not differ at Time 1 from those we did obtain for follow-up. Hence, our findings likely generalize to students at many other four-year, public universities around the U.S.

Future Research

We recommend that future researchers conduct longitudinal investigations of students from multiple universities from multiple countries, particularly given that many of the items we used have been used in other cross-cultural research on aspects of science literacy (Miller et al., 2006). Another recommendation would be to obtain more specific information on the coursework students take, such as the number of courses that involve evolutionary content or an instructor-provided measure of the proportion of content in each course that involves evolution. We would also recommend multiple assessments of students' progress. Because we assessed students on only two occasions, we cannot say whether the changes occurred at some specific point during college or whether the changes were gradual. Finally, we would measure additional variables that may predict differences in student growth (Pascarella & Terenzini, 2005). For example, perhaps variability in students' growth in scientific literacy is tied to variables such as their intellectual curiosity, peer networks (Hill, 2014), engagement with faculty, or their involvement in research and other high-impact learning experiences. Given the tendency for people to engage in close relationships with like-minded others (Buss, 1985; Rushton, 1989), we might expect that students whose friends and mates are more similar to them in scientific literacy, attitudes, and beliefs are those who are least likely to show change over time on those measures.

CONCLUSION

In conclusion, this three-year study found statistically significant but weak growth during college in probabilistic and science reasoning, but no growth in students' knowledge of evolution and genetics. The growth (and lack of growth) that we observed was consistent across biological sex, discipline of study, and incoming religious attitudes and beliefs; hence, we failed to document systematic predictors of individual differences in direction and magnitude of change over the college years. As we expected, variability in the number of science courses students took was related to students' knowledge as they prepared to leave college; but students' incoming knowledge predicted the number of science courses they proceeded to take. Thus, we found that students who enter college with interest and skill in science and evolution are those most likely to pursue science coursework. Given the combined and increasing relevance of evolution and genetics to both everyday life decisions (such as exercise, diet, and food choices) and larger societal issues (such as ingroup-outgroup biases, educational policy/curricula, genetic modification, disease, and criminal behavior), we encourage explicit attention in higher education towards enhancing students' understanding of genetics and evolutionary theory. We hope that future research will show that individuals' scientific and evolution literacy predict their willingness and ability to use scientific logic and evolutionary principles to inform the decisions they make in everyday life.

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APPENDIX I. TABLES AND FIGURES

Table 1.

Participant Performance on Evolution Literacy Items

	Item	Answer	Time 1 % Correct	Time 2 % Correct
1	The earliest humans lived at the same time as the dinosaurs.	False	76	78
2	Evolution means progression towards perfection.	False	66	70
3	Natural selection is the only cause of evolution.	False	80	81
4	Characteristics acquired during the lifetime of an organism generally cannot be passed down to that organism's offspring.	True	36	34
5	Natural selection is a random process.	False	66	74
6	Human beings, as we know them today, developed from earlier species of animals.	True	64	67
7	Natural selection generally operates for the "good of the group."	False	29	24
8	You can see species of our evolutionary past in human embryos.	True	37	40
9	Over periods of millions of years, some species of plants and animals adjust and survive, while other species die and become extinct.	True	94	94
10	In most populations, more offspring are born than can survive.	True	84	82
11	Increased genetic variability makes a population more resistant to extinction.	True	87	88
12	The more recently two species share a common ancestor, the more closely related they are.	True	85	89
13	Species evolve to be perfectly adapted to their environments.	False	52	54
14	Evolution is a straight progression from primitive to advanced species.	False	58	67

***Note*. Total *N* = 200**

Table 2.
Scientific Literacy Subscale and Composite Scores at Time 1 (T1) and Time 2 (T2)

Literacy Subscale	Time 1 *M (SD)*	Time 2 *M (SD)*	Stability *r*	% Increase T1 to T2 *M (SD)*	Paired *t*	Cohen's *d*
Biology	80.02 (13.86)	83.31 (12.56)	.41***	3.29 (14.38)	3.24**	0.23
Genetic	78.27 (12.63)	79.03 (12.94)	.41***	0.76 (13.95)	0.77	0.05
Evolution	65.62 (13.43)	67.13 (13.03)	.41***	1.52 (14.40)	1.49	0.11
Inorganic Science	87.63 (12.32)	88.58 (12.84)	.42***	0.95 (13.55)	1.00	0.07
Science Reasoning	77.42 (16.37)	84.71 (12.37)	.45***	7.30 (15.40)	6.70***	0.47
Prob. Reasoning	75.83 (19.47)	85.83 (17.50)	.24***	10.00 (22.91)	6.17***	0.44
Scientific. Lit. Composite	76.83 (7.84)	79.62 (7.44)	.65***	2.78 (6.43	6.12***	0.43

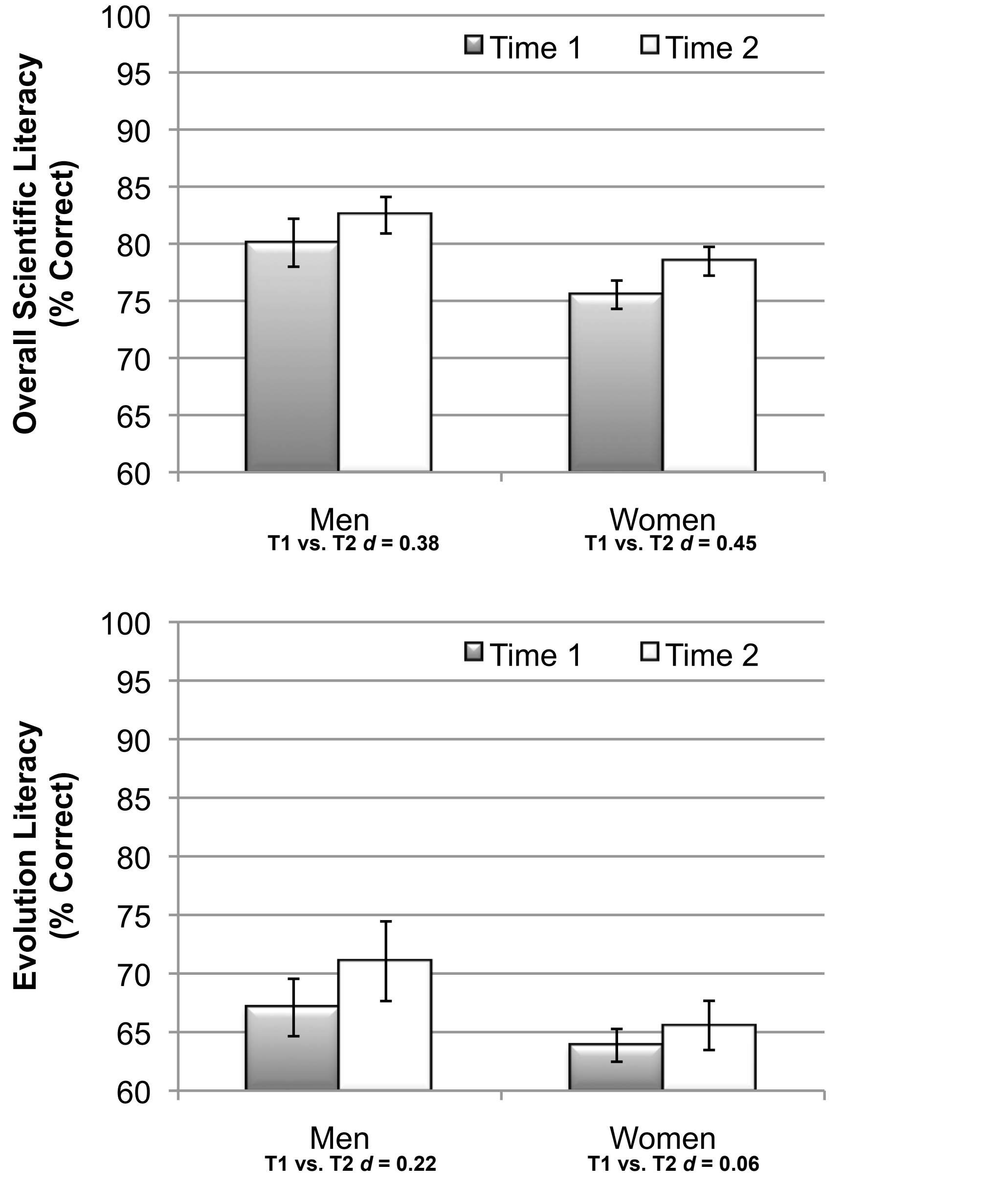
Note. **All mean values are expressed as percentages. For both test-retest stability coefficients (bivariate correlational analyses) and tests of change from Time 1 to Time 2 (paired-samples *t*-tests), ** *p* < .01, *** *p* < .001, *N* = 200. The low stability coefficient for probabilistic reasoning, relative to the others, might be due in part to the limited number of items (3) on that subscale.**

Table 3.
Correlates of Students' Evolution Literacy at Time 1 (T1) and Time 2 (T2)

	Belief in God (1)	Young Earth Creationist Beliefs (2)	Intelligent Design Fallacies (3)	Moral Objections to Evolution (4)	Reservations about Sci. / Technology (5)	Scientific Literacy Composite (6)	Evolution Literacy (7)
1	.76***	.68***	.62***	.33***	.18	-.17	-.23***
2	.68***	.75***	.77***	.63***	.29***	-.30***	-.37***
3	.64***	.83***	.70***	.59***	.24**	-.26***	-.35***
4	.16	.56***	.50***	.55***	.27***	-.32***	-.34***
5	.28***	.40***	.38***	.35***	.56***	-.20***	-.10
6	-.26***	-.38***	-.38***	-.34***	-.28***	.65***	.59***
7	-.28***	-.45***	-.47***	-.33***	-.18**	.65***	.41***
T1 Mean	7.65 (3.03)	4.67 (2.91)	3.96 (1.50)	4.79 (2.12)	2.38 (2.36)		
T2 Mean	7.08 (3.31)	3.93 (3.08)	3.66 (1.71)	3.96 (2.24)	1.94 (2.03)		
T1 vs T2 *p*	< .001	< .001	.005	< .001	.004		
T1 vs T2 *d*	0.25	0.35	0.20	0.49	0.21		
Corr. T1 Score and Δ Evo. Lit. T1 to T2	*r* = .02 *p* = .750	*r* = .04 *p* = .545	*r* = .01 *p* = .933	*r* = .01 *p* = .904	*r* = -.06 *p* = .435		

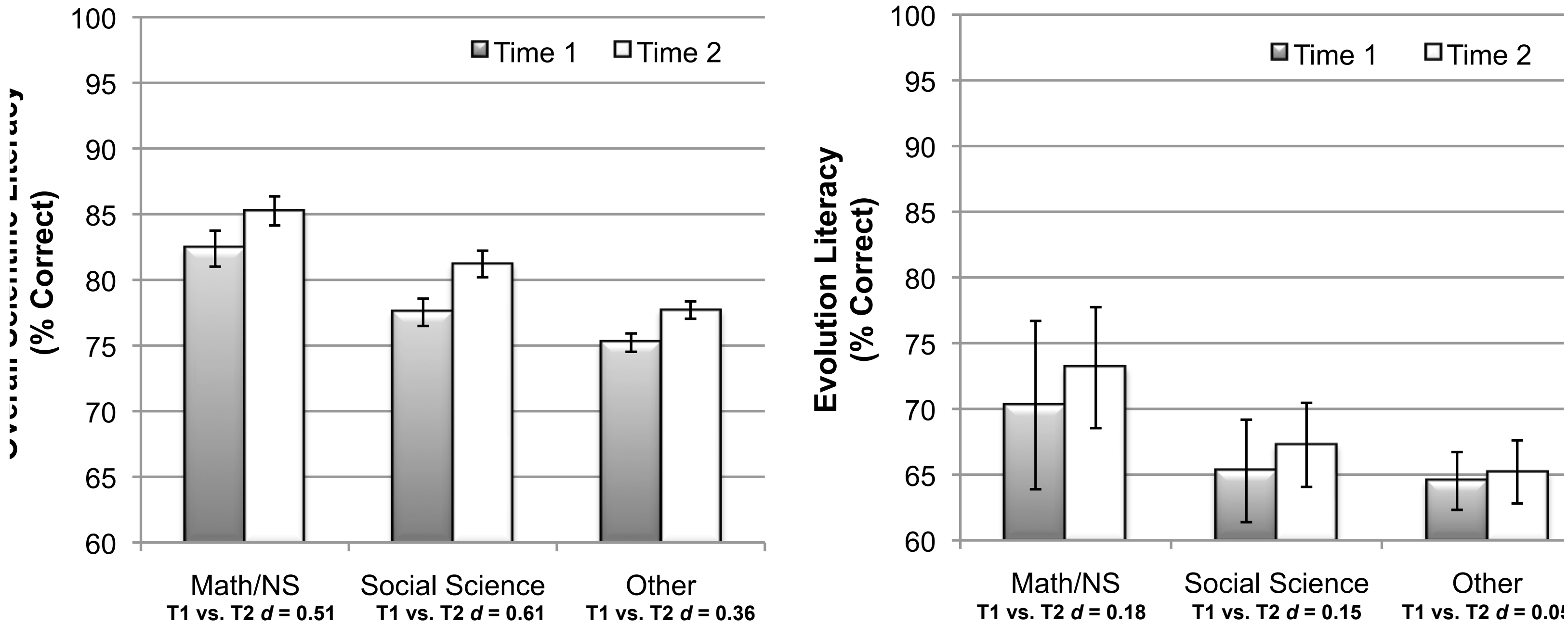
Note. **T1 = Time 1, T2 = Time 2. T1 vs. T2 comparisons were paired samples *t*-tests, with Cohen's *d* as effect size. Time 1-to-Time 2 (intra-individual stability) correlations for each variable are shown along the main diagonal. Associations between different variables at Time 1 are displayed above the main diagonal and associations between different variables at Time 2 are displayed below the main diagonal. The belief and attitude scales were on 11-point scales ranging from 0 to 10. Science literacy composite scores and evolution literacy scores are reported as a percentage out of 100. Standard deviations are shown in parentheses after each mean score. ***p* < .01, ****p* < .001**

Figure 1.
Change in Overall Scientific Literacy for Men and Women



Note. **Bar graph display of men's and women's change in overall scientific literacy (upper panel) and in knowledge and acceptance of evolution (lower panel) from Time 1 to Time 2. Error bars represent 95% confidence intervals of the mean.**

Figure 2.
Change in Overall Scientific Literacy as a Function of Reported First Major



Note. **Bar graph display of change in overall scientific literacy (upper panel) and evolution literacy (lower panel) from Time 1 to Time 2 as a function of reported first major at Time 2 (Total *N* = 199; one person did not state their major). Error bars represent 95% confidence interval of the mean. The two separate disciplines of Pre-Professional and Arts/Humanities were combined for this display because their scores did not differ significantly from each other**

APPENDIX II. SCALE ITEMS

Biology Literacy: 9 Items

True/False:
Almost all food energy for living organisms comes originally from sunlight. (T)
All plants and animals have DNA. (T)
The oxygen we breathe comes from plants. (T)
Antibiotics kill viruses. (F)
Antibiotics kill bacteria. (T)
Human beings, as we know them today, developed from earlier species of animals. (T)
It is possible to extract stem cells from human embryos without destroying the embryos. (F)

What theory serves as the foundation for modern biology?

- Gravity
- **Evolution by selection**
- Plate tectonics
- Intelligent design

"Some variation in heritable characteristics exists in every species. Because of this heritable variation, some individuals have an advantage over others in surviving and reproducing. The advantaged offspring are more likely than others to survive and reproduce. As a result, the proportion of individuals that have advantageous characteristics will increase." What process is being described?

- **Natural selection**
- Photosynthesis
- Transcription
- Acquired inheritance

Genetic Literacy: 13 Items

True/False:
The genetic information encoded in DNA molecules provides instruction for assembling fats and lipids. (T)
Genetic mutations (in some cells) can be passed down to the next generation. (T)
Ordinary tomatoes do not have genes, whereas genetically modified tomatoes do. (F)
Random genetic mutations are never beneficial. (F)
Humans have somewhat less than half of their DNA in common with chimpanzees. (T)
Genetically modified animals are always larger than ordinary animals. (F)
Most cells in the human body have the same genetic information, but different parts of that information are used in different cells. (T)
Today it is not possible to transfer genes from humans to animals. (F)

If someone eats genetically modified fruit, there is a risk that the person's genes might be modified too. (F)
All humans share exactly the same DNA. (F)
More than half of human genes are identical to those of mice. (T)
Genetic mutations occur frequently. (T)
Today it is not possible to transfer genes from animals to plants. (F)

Evolution Literacy: 14 Items

True/False:
The earliest humans lived at the same time as the dinosaurs. (F)
Evolution means progression towards perfection. (F)
Natural selection is the only cause of evolution. (F)
Characteristic acquired during the lifetime of an organism generally cannot be passed down to that organism's offspring. (T)
Natural selection is a random process. (F)
Human beings, as we know them today, developed from earlier species of animals. (T)
Natural selection generally operates for the "good of the group." (F)
You can see species of our evolutionary past in human embryos. (T)
Over periods of millions of years, some species of plants and animals adjust and survive, while other species die and become extinct. (T)
In most populations, more offspring are born than can survive. (T)
Increased genetic variability makes a population more resistant to extinction. (T)
The more recently two species share a common ancestor, the more closely related they are. (T)
Species evolve to be perfectly adapted to their environments. (F)
Evolution is a straight progression from primitive to advanced species. (F)

Inorganic Science Literacy: 10 Items

True/False:
Electrons are smaller than atoms. (T)
All radioactivity is man-made. (F)
The continents on which we live have been moving their location for millions of years and will continue to move in the future. (T)
Radioactive milk can be made safe by boiling it. (F)
Scientists believe that the universe began with a huge explosion. (T)
Lasers work by focusing sound waves. (F)
The center of the Earth is very hot. (T)

Which one is correct?

- **The Earth goes around the Sun**
- The Sun goes around the Earth

How often does the event in the question above happen?

- Once a day

- Once a month
- **Once a year**

Which moves faster, light or sound?
- **Light**
- Sound

Science Reasoning: 8 Items

True/False:
Good theories can be proven by a single experiment. (F)
For scientific evidence to be deemed accurate it must be reproducible by others. (T)
Feelings and beliefs can serve as evidence in support of scientific propositions. (F)
Scientific explanations can be supernatural. (F)
Theories that involve more untested assumptions are generally better than theories that involve fewer untested assumptions. (F)
Good theories give rise to testable predictions. (T)

Now, please think of this situation. Two scientists want to know if a certain drug is effective against high blood pressure. The first scientist wants to give the drug to 1000 people with high blood pressure and see how many experience lower blood pressure levels. The second scientist wants to give the drug to 500 people with high blood pressure, and not give the drug to another 500 people with high blood pressure, and see how many in each group experience lower blood pressure levels. Which method will give you a valid answer?
- The first scientist's method
- **The second scientist's method**

Rate how scientific the following disciplines are, with 1 = *Not at all Scientific* and 5 = *Very Scientific*.
- Biology, Astronomy, History, Physics, Astrology, Economics, Psychology, Medicine all listed
- Only scored item was Astrology: Rating of 1or 2 = correct; 3, 4, or 5 = incorrect

Probabilistic Reasoning: 3 Items

Imagine the following situation. A doctor tells a couple that, because of their genetic makeup, they have a one-in-four chance of having a child with an inherited illness. Which of the following is a real possibility for this couple?
- If they have only three children, none will have the illness.
- If their first child has the illness, the next three children will not.
- **Each of the couple's children has the same risk of having the illness.**
- If their first three children are healthy, then the fourth child will have the illness.

Imagine you are flipping a normal coin, with one side “tails” and one side “heads.” You have flipped the coin nine times so far, and each time it has come up “tails.” What is the chance that on your next flip, it will come up “heads?”

- 0%
- 10%
- **50%**
- 90%

Consider the following research finding, “In children, obesity is positively associated with reading ability.” Which of the following statements CORRECTLY RESTATES this finding?

- Obesity leads children to read more.
- **Obese children are, on average, more able readers than non-obese children are.**
- Laziness leads to obesity and difficulties with reading.
- Spending time reading leads children to gain weight.
- The finding cannot be valid because there are children who are not obese that are also able readers.

Moral Objections to Evolution: 2 items

People who accept evolution as fact are immoral.
If you accept evolution, you really can’t believe in God.

Reservations about Science and Technology: 6 items

Science and technology have created a world that is full of risks for people.
The benefits arising from science and technology are overall much greater than their harmful effects (reverse coded).
Science and technology destroy people’s moral values.
Science and technology make our way of life change too fast.
People would be better off if they lived a simpler life without so much science and technology.
Technological progress is one of the main reasons for the current high levels of unemployment.

Young Earth Creationist Beliefs: 4 items

Adam and Eve from Genesis are the universal ancestors of the entire human race.
All modern species of land vertebrates are descended from the original animals on the ark.
God created humans in their present form.
Humans never could have been related to apes.

Ascription to Intelligent Design Fallacies: 6 items

There is scientific evidence that humans were created by a supreme being or intelligent designer.
Intelligent design should be taught in science classes.
The theory of evolution is a mixture of faith and belief, just like religion.
Humans were specially designed.
There is no evidence that humans evolved from earlier species of animals.
It is statistically impossible that life on Earth arose by chance.