No Missing Link: Knowledge Predicts Acceptance of Evolution in the United States

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Most Americans reject some or all parts of evolutionary theory, contrary to the scientific consensus. Americans' attitudes toward evolution at least partially depend on their religious or political values, and prior work has argued that knowledge of the theory plays a negligible role. But there have been no systematic, large-scale attempts to measure the public's knowledge of evolutionary theory, which means that claims about a lack of significant impact of evolution knowledge on evolution acceptance may be premature. Using a new demographically representative survey (N=1100) that includes a detailed measure of evolution knowledge, we find that knowledge predicts level of acceptance, even after accounting for the effects of religion and politics. These results demonstrate that Americans' views on evolution are significantly influenced by their knowledge about this theory and therefore might be amenable to change.

Keywords: evolution, public understanding of science, acceptance, knowledge, public opinion poll

Americans have a fraught relationship with evolutionary theory. Despite widespread acceptance of this theory in the scientific community (Funk and Rainie 2015), public-opinion surveys have demonstrated that 38% of Americans identify as creationists (Swift 2017) and 52% disagree that human beings developed from earlier species of animals (National Science Board 2016). International comparisons show that these views are extreme, particularly among westernized countries: In a comparison of 34 countries, the United States ranks second to last in public acceptance of evolution (Miller et al. 2006). This large-scale rejection of the scientific consensus has troubling implications for science literacy and for public engagement in science more generally.

The goal of the current study is to expand on work documenting why ordinary Americans hold such views about evolutionary theory. In particular, this study focuses on the role of knowledge of evolutionary theory in supporting acceptance of it.

Researchers examining the public perception of science tend to argue that the public's reported attitudes on evolution are primarily expressions of their political or religious worldviews (Bishop and Anderson 1990, Kahan et al. 2011, Kahan 2016, Snow and Dibner 2016), a type of motivated reasoning sometimes referred to as *identity-protective cognition* (Kunda 1990, Cohen et al. 2000). Rather than genuinely probing individuals' considered views, questions about evolution acceptance trigger people's identification with religious or political groups, leading them to respond consistently with their group's values. These arguments are supported by work finding that acceptance of evolution is either uncorrelated or only weakly correlated with knowledge of it (Bishop and Anderson 1990, Lawson and Worsnop 1992, Demastes et al. 1995, Sinatra et al. 2003, Ingram and Nelson 2006, Shtulman 2006, Nehm et al. 2009). Results such as these have led many researchers in this area to reject the *knowledge-deficit hypothesis* (see Suldovsky 2016), which suggests that evolution acceptance reflects level of knowledge.

However, other work shows that individuals with greater knowledge of evolution are indeed more likely to accept it (Lawson 1983, Johnson and Peeples 1987, Rutledge and Warden 2000, McKeachie et al. 2002, Rutledge and Mitchell 2002, Deniz et al. 2008, Nadelson and Sinatra 2009, Shtulman and Calabi 2012), suggesting that these variables are related. A major contribution of the current work, then, is to clarify the relationship between knowledge and acceptance in the general population, a study that can inform not only the literature on this issue but also educational and political policy.

Crucially, to the best of our knowledge, studies that have investigated the link between knowledge and acceptance have either all recruited nonrepresentative samples—primarily high school and college students—or have not included an extensive or appropriately calibrated measurement of

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the participants' understanding of evolutionary theory. For example, prior work has tended to test students' knowledge after they engaged in specific curricula focused on evolution (Demastes et al. 1995, Ingram and Nelson 2006); these measures are too specifically focused to serve as assessments for the general population. Therefore, the available evidence does not allow us to draw conclusions about relations between acceptance and knowledge in the population as a whole, leaving open the question of how people's reported acceptance may be influenced by their knowledge. The primary goal of the current study was to address this issue (for more details, see preregistration at *https://osf.io/mvg4n*).

Knowledge of evolution

To assess the potential influences of knowledge of evolutionary theory on the acceptance of it, we developed a new evolution knowledge battery specifically designed to capture variance present *in the general public*. We administered this test to a sample that matched the demographics of the overall American population, allowing us to test for the first time whether evolution knowledge and acceptance are related among members of the general public. If so, this would suggest a need to include more than just identity factors in the dialogue about evolution acceptance. Furthermore, such a result could suggest avenues for interventions to increase both knowledge and acceptance.

Our measure tests participants' knowledge of several of the key concepts of evolutionary theory (according to National Research Council 2012), including inheritance, variation, natural selection, and adaptation. Some of these questions were based on previously published tests of these concepts (e.g., Bishop and Anderson 1990, Anderson et al. 2002, Blackwell et al. 2003, Shtulman 2006). In addition to establishing our scale's face validity, we used item response theory (IRT) to analyze pilot data collected from Amazon's Mechanical Turk system (MTurk) and from a demographically representative phone survey conducted by the Annenberg Public Policy Center. We used these analyses to identify and refine or reject items with insufficient discriminatory power. IRT analysis of the data from the current study revealed that our items captured a wide range of difficulty and discrimination, allowing us to discriminate among the participants' levels of knowledge across our demographically representative sample (see figure 1).

The final measure administered in the current survey consisted of 17 multiple-choice or multiple-select items. All of these items were prefaced with "according to scientists" or "scientists would think," which is a technique developed by the National Science Foundation to ensure that participants respond on the basis of their knowledge of the theory rather than on their personal views about it (i.e., construct validity). In other words, this phrasing allows participants who reject evolutionary theory to demonstrate knowledge about it. Cronbach's alpha for the scale was .77.

Scores on this task are the sum of the number of correct responses (maximum of 26). Although most of the questions are multiple choice, two of the questions have multiple correct answers that can be selected (i.e., the participants were asked to "check all that apply"). We treated each item in these questions independently, as if they were true or false items, and counted both the correctly selected and correctly not-selected items. For analysis, we created a score that summed the number of correct answers.

Acceptance of evolution

In addition to administering this new measure of knowledge, we also adjusted the way acceptance of evolutionary theory was measured. As is noted in Miller and colleagues (2006), small changes to the phrasing of the acceptance question can lead to different response patterns. For example, simply asking whether participants believe humans evolved or not yields only 38% who deny evolution (PRRI 2011), whereas asking participants to rate their agreement with a statement such as "evolution is the best explanation for the origins of human life on Earth" on a four-point scale yields 45% disagreement (Pew 2007). Moreover, rephrasing the question to ask about elephants instead of humans leads to only 25% disagreement with the evolutionist option instead of 52% (Maitland et al. 2014; see also Roos 2014). This latter result in particular indicates that asking about acceptance of human evolution is tapping into a different construct from asking about acceptance of evolution in general. Extant surveys thus may not fully capture Americans' views about evolutionary theory.

For the current study, we therefore developed a new measure of acceptance based on one of the most frequently cited polls, Gallup. This poll asks which of three options comes closest to respondents' views on the origin and development of human beings: (1) human beings have developed over millions of years from less advanced forms of life, but God guided this process; (2) human beings have developed over millions of years from less advanced forms of life, but God had no part in this process; and (3) God created human beings pretty much in their current form in the last 10,000 years or so. Because this question offers three possible answers, it is better than most. However, these three options do not allow for any nuance about God's role in evolution; the "guidance" could take many forms. We thus added a fourth answer option, reflecting a deistic view: God set up the laws of nature, which then unfolded on their own. We also chose to ask about the origin of plants and animals rather than of humans (acknowledging that "animals" in colloquial usage is understood to exclude humans). Given the issues identified above, we anticipated that our choice of wording would affect the participants' responses. For example, our use of "plants and animals," which does not mention humans explicitly, might make the evolutionist option more appealing in our survey than in others. On the other hand, our removal of the reference to a young Earth might make more people comfortable with choosing the creationist option. Because any particular framing of the acceptance question cannot yield a full view of Americans'

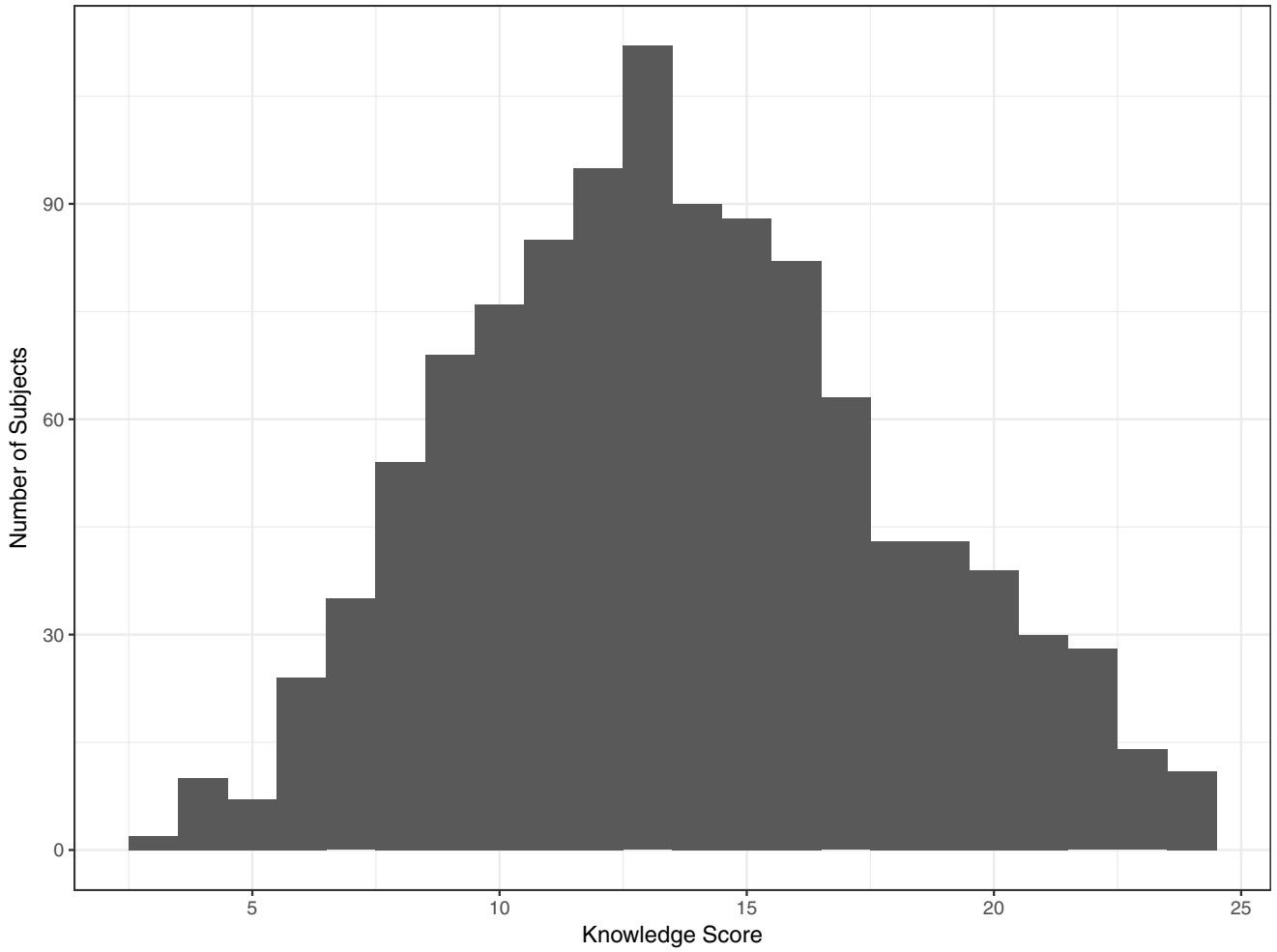

Figure 1. A histogram of our sample's scores on the evolution knowledge scale (N = 1100).

attitudes toward evolutionary theory, we chose the "plants and animals" phrasing to avoid bringing to mind any potential personal consequences of accepting evolution (see Brem et al. 2003) and to provide a more natural comparison with the items in our knowledge battery, which focused on nonhuman animals.

Specifically, we asked people to choose which of the following options best described how they think animals and plants came to exist on Earth: (a) animals and plants were created by God in more or less their current form (*creationism*); (b) animals and plants developed through natural processes, which were guided by God the entire time (*theistic evolution*); (c) animals and plants developed through natural processes, which were set up by God but continued on their own (*deistic evolution*); and (d) animals and plants developed entirely through natural processes (*naturalistic evolution*). Each level of acceptance varies the extent of God's involvement.

After answering this acceptance question, the participants rated the extent to which various factors influenced their views on this topic: the quality of the scientific evidence, the theory's conflict or consistency with their religious beliefs, their education, and their family's beliefs.

Other measures

In addition to assessing whether Americans' knowledge of evolutionary theory plays any role in their degree of acceptance, we tested the impact of several other factors on evolution acceptance, such as general science knowledge and authoritarian tendencies. Prior work suggests that these either directly predict acceptance (e.g., Lombrozo et al. 2008) or relate to religious or political beliefs, which in turn predict acceptance (e.g., Jost et al. 2003).

Science knowledge and reasoning skills (OSI2). We included the 18-item ordinary science intelligence scale (OSI version 2; Kahan 2016), which measures general knowledge of science and the scientific method (drawn from the National Science Foundation Science and Engineering Indicators), basic numeracy, and cognitive reflection (Frederick 2005).

Some of our participants had responded to these items in a previous survey, so instead of repeating the test and possibly biasing their responses, we used their responses from the earlier survey.

Questions on this task are a combination of multiple choice (e.g., "Which gas makes up most of the Earth's atmosphere?" with answer choices *hydrogen*, *nitrogen*, *carbon dioxide*, and *oxygen*) and open response (e.g., "Imagine that we roll a fair, six-sided die 1000 times. Out of 1000 rolls, how many times do you think the die would come up as an even number?"). We constructed a scale by summing the correct scores (maximum of 18).

Understanding the nature of theories. The participants saw two items asking them to rate their agreement with statements about the nature of scientific theories (adapted from Lombrozo et al. 2008). The statements were, "Once a scientific theory has been established, it is never changed" and "Scientific theories are just scientists' guesses." Ratings were made on a five-point scale (1, *strongly agree*; 3, *unsure*; 5, *strongly disagree*). We averaged together the participants' responses to these two items. Final scores thus fell between 1 (*strongly agree*) and 5 (*strongly disagree*), with higher numbers indicating more correct responding.

Criteria for belief. The participants reported the extent to which they think that two candidate criteria are good reasons for belief. Specifically, the participants were asked to consider the statements, "There is good scientific evidence for it" and "I feel it is true in my gut" and to indicate whether each is an *excellent* (coded 5), *good* (coded 4), *okay* (coded 3), *bad* (coded 2), or *terrible* (coded 1) reason to believe something. These measures are based on prior work finding that evolutionists and creationists accept different warrants for belief (Metz et al. 2018). In our analyses, we considered these two items separately because they measure two different types of criteria that could be accepted independently.

Need for closure. We presented two subscales from the brief need for closure scale (Roets and Van Hiel 2011). Three items asked about tolerance of ambiguity (e.g., "I don't like situations that are uncertain"), and three items asked about closed-mindedness (e.g., "I do not usually consult many different opinions before forming my view"). The participants rated their agreement with these statements on a scale from 1 (*completely disagree*) to 6 (*completely agree*). Their scores for these six items were averaged to create a single measure, with higher numbers indicating higher need for closure.

Authoritarianism. We asked about 4 pairs of qualities that children could have (e.g., independent versus respectful of their elders). The participants chose which item in each pair they thought was more important for children to display (Feldman and Stenner 1997). The item that corresponded to the authoritarian option was coded 1, and the other option was coded 0. We took the average of how many authoritarian choices each participant made, with scores ranging between 0 and 1.

Participants and procedures

We contracted with the survey firm YouGov to conduct a nationally representative survey of Americans (N = 1100) in July 2016. These individuals were drawn from standing panels maintained by YouGov. The survey firm administered online surveys to a total of 1268 respondents . YouGov (blind to our hypotheses) pared down this sample to a final sample of 1100 to match the demographic makeup of the United States in terms of the dimensions of gender, age, race, education, party identification, ideology, and political interest, based on the 2010 American Community Survey and the Current Population Survey.

Although our sample already matched the demographics of the United States well, it was not possible for it to precisely match the demographic breakdown of the entire US population on every dimension of interest. As is standard in surveys of this kind, YouGov also provided sample weights to obtain an even closer fit between our data and the true demographic makeup of the country. Following accepted practices in public opinion research, we use the weighted data when reporting "top lines" or descriptive statistics (here, the percentages of individuals who agreed with each acceptance category), and we used the raw data for all inferential analyses.

In the survey, the participants completed seven measures (see the supplemental material and *https://osf.io/mvg4n*): evolution knowledge, evolution acceptance, basic scientific literacy (OSI2), understanding the nature of scientific theories, criteria for belief, need for closure, and authoritarianism. These measures were split into three blocks: the *knowledge* block, which contained our evolution knowledge test and the OSI2; the *acceptance* block, which contained only the acceptance question and its accompanying questions about influences on these views; and the *opinion* block, which contained the remaining measures (nature of theories, criteria for belief, need for closure, and authoritarianism).

The participants first saw the knowledge and opinion blocks, order counterbalanced between participants. The acceptance block was always presented at the end of the survey to avoid priming participants' responses to the other measures by asking them to consider their personal beliefs about evolutionary theory. Within the knowledge block, the order of all of the questions from both of the measures was randomized. Within the opinion block, we randomized the order of each of the two questions about nature of theories, each of the two questions about criteria for belief, the set of need-for-closure questions, and the set of authoritarianism questions. The order of the questions within the need-for-closure measure and the authoritarianism measure was randomized, but these questions were always presented as a unit. Within the acceptance block, the order of questions was fixed: The participants always responded to the main acceptance question first and then the question about influences on their view.

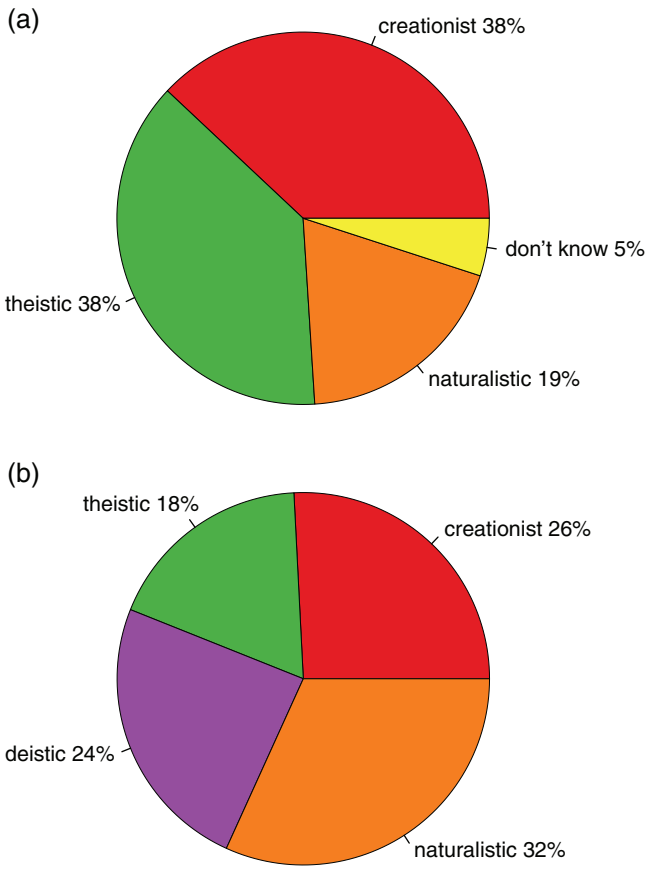

Figure 2. Views of the American public on the origins of species from the Gallup poll (panel a) and our survey (panel b).

Demographic variables. Because the participants were part of an online panel, demographic data including political-party affiliation, political ideology, religion, degree of religiosity, age, and level of education were previously collected by YouGov in a separate testing session and shared with us. We relied on the three-question Pew Religious Life battery to determine degree of religiosity, which more richly captures the participants' degree of religiosity rather than simply the religion with which they identify. Although this is a standard battery, we acknowledge that these three questions may not fully capture all of the complex dimensions of religiosity (see Cornwall et al. 1986). These three questions ask about attendance at religious services aside from weddings and funerals (*more than once a week*, *once a week*, *once or twice a month*, *a few times a year*, *seldom*, and *never*), the importance of religion (*very important*, *somewhat important*, *not too important*, *not at all important*), and frequency of prayer (*several times a day*, *once a day*, *a few times a week*, *once a week*, *a few times a month*, *seldom*, or *never*). Because responses to these three items were made on different scales, the scale for each item was normalized, and then the normalized scores were averaged and normalized again to yield a total religiosity score. We divided our respondents into high (more than 1 standard deviation [SD] above the mean), average (between 1 SD above the mean and 1 SD below the mean), and low religiosity (more than 1 SD below the mean).

Results

Our primary aims in this study were to determine Americans' levels of acceptance of and knowledge about the theory of evolution and to explore the relationship between these factors. A full report of all of our preregistered hypotheses and tests is available in the supplemental material and at our OSF site; here, we focus only on the tests that address these primary goals.

What are Americans' views about evolutionary theory? As we predicted, our acceptance question yielded strikingly different results from those of Gallup, which asked about human evolution and offered only three response options. Only 26% of our respondents held creationist views (rather than Gallup's 38%), whereas 32% accepted naturalistic evolution (rather than Gallup's 19%; figure 2).

In addition, as we predicted and as we expected from prior work, each participant's level of evolution acceptance related to various identity factors. In regressions predicting level of acceptance from each factor individually, the participants who had higher levels of religiosity were more likely to reject evolution ($\beta = -1.12$, $p < .001$), as were those with more conservative political ideology ($\beta = -0.35$, $p < .001$).

What do Americans know about evolutionary theory? We predicted that people's scores on our evolution knowledge battery would be generally low. To test this prediction, we counted the total number of participants who "failed" each test (i.e., scored less than 60%, using a standard academic measure of failing) and found that 68% of our participants fell below this threshold. Although it is not possible to compare our test directly with tests used in prior work because both the questions and the sample populations are different, other studies of evolutionary knowledge find similarly low performance. For example, about half of the students in Shtulman (2006) responded incorrectly to questions about variation and inheritance, and only 31% of the students studied by Bishop and Anderson (1990) demonstrated understanding of topics in natural selection.

Is there a relation between acceptance and knowledge? Our data show meaningful, statistically significant differences in understanding based on degree of acceptance ($F(3) = 44.8$, $p < .001$, $\eta^2 = 0.11$; figure 3). T-tests show that scores for creationists (mean [M] = 11.8, SD = 3.4) and theistic evolutionists ($M = 12.3$, SD = 4.3) did not differ significantly ($t(468) = 1.39$, $p = .17$, Cohen's $d = 0.13$). Theistic evolutionists scored lower than deistic evolutionists ($M = 14.3$, SD = 4.1, $t(446) = 5.06$, $p < .001$, Cohen's $d = 0.48$), who in turn scored lower than naturalistic evolutionists ($M = 15.2$, SD = 4.5, $t(628) = 2.3$, $p = .02$, Cohen's $d = 0.19$). A multinomial logistic regression predicting level of acceptance from scores on the knowledge test shows that for each one-point

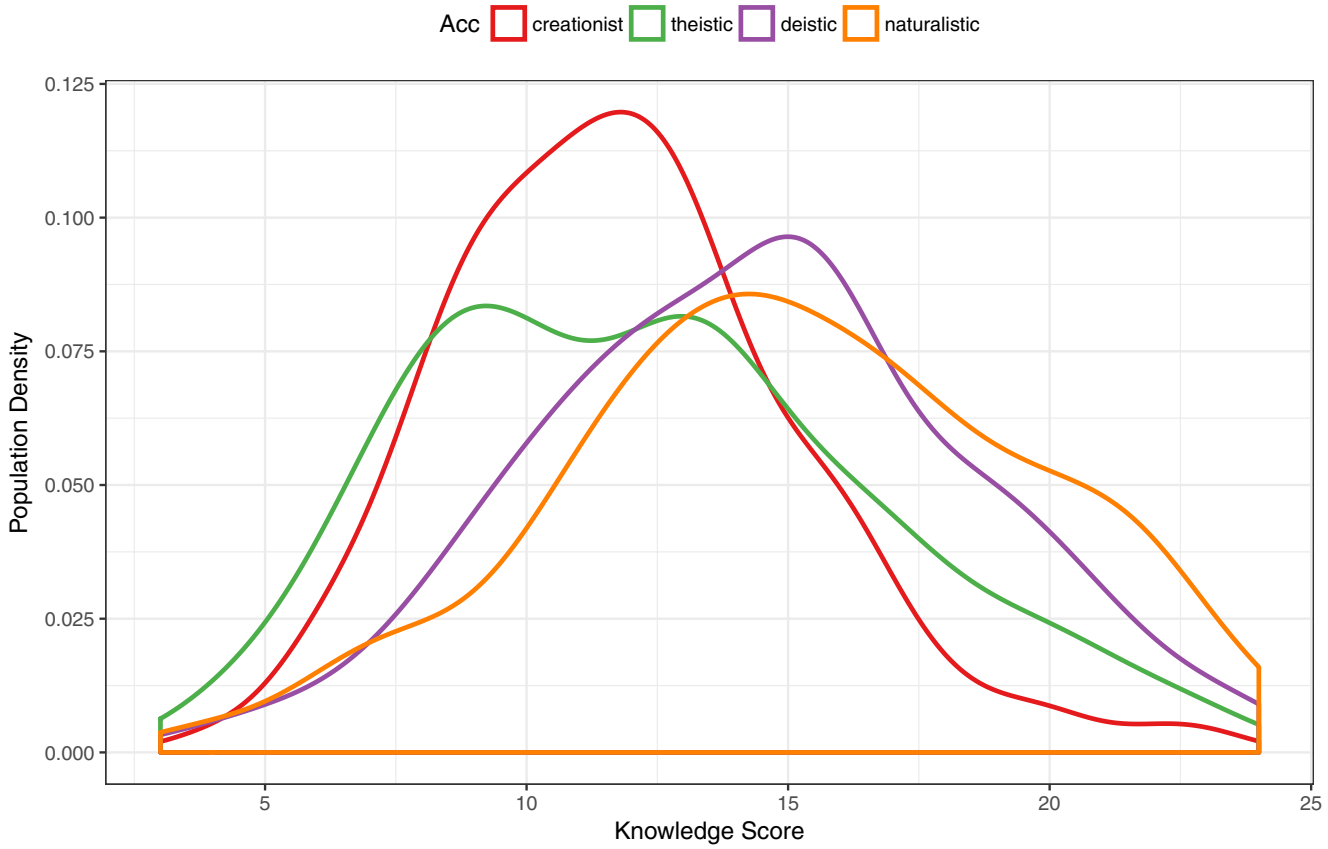

Figure 3. The distribution of the participants' scores on the evolution knowledge battery, split by their acceptance level.

increase in knowledge score, individuals are 1.16 times more likely to choose the deist option versus the creationist one and 1.22 times more likely to choose the naturalistic evolutionist option versus the creationist one. That is, as was predicted, understanding evolutionary theory is related to accepting it.

However, as we noted above, the tendency to accept evolutionary theory is predicted by affiliations and prior beliefs, such as religiosity. It is thus possible that those factors fully explain levels of acceptance, leaving no role for understanding. To test this possibility, we conducted a logistic regression predicting whether one leans evolutionist (i.e., accepts deistic or naturalistic evolution) from performance on the knowledge battery, religiosity, having a conservative ideology, age, gender, and level of education (table 1). This test showed that the participants' knowledge of evolution remained predictive of their level of acceptance even after taking into account the effect of demographic factors and the interaction for knowledge and religion (although it is important to note that the effect of religion loses significance when the interaction term is included). Crucially, this model fits the data significantly better than the same model that does not include the participants' knowledge scores ($\chi^2(972) = 51.31$, $p < .001$), and this model explains more of the variance (pseudo $R^2 = .43$ compared with .38). This result provides the first key piece of evidence that knowledge about the theory of evolution plays a significant role in whether or not members of the public accept this theory as the correct explanation for the origin and development of life.

This result can be seen in figures 4 and 5, which show the relationship between knowledge of evolution and level of acceptance for three categories of religiosity (*below average*, *average*, and *above average*) and five levels of political ideology (*very liberal*, *liberal*, *moderate*, *conservative*, and *very conservative*): Increasing knowledge is related to increasing likelihood of acceptance of evolution. Crucially, this is the case for each level of religiosity and each level of political ideology, indicating that there is little polarizing effect of increased knowledge.

What is the impact of the auxiliary measures? As was predicted, we found positive relationships between acceptance of evolution and performance on the OSI2 (β =0.18, $p < .001$), understanding the nature of theories ($\beta = 0.80$, $p < .001$), acceptance of scientific evidence as a criterion for belief ($\beta = 0.66$, $p < .001$), and education ($\beta = 0.22$, $p < .001$). We also found negative relationships between acceptance of evolution and political conservatism ($\beta = -0.35$, $p < .001$), acceptance of gut feelings as a criterion for belief ($\beta = -0.25$, $p < .001$), need for closure ($\beta = -0.29$, $p < .001$), religiosity ($\beta = -1.12$, $p < .001$), and authoritarianism ($\beta = -1.68$, $p < .001$). Contrary to our

Table 1. The results of a logistic regression predicting level of acceptance from performance on the knowledge battery, religiosity, having a conservative ideology, age, gender, and level of education.

	B	Standard error	*p* value	exp(B)	2.5% CI	97.5% CI
(Intercept)	–2.389	0.471	<.001**	0.092	0.036	0.229
Knowledge	0.160	0.024	<.001**	1.174	1.121	1.232
Religiosity	–0.226	0.336	.500	0.797	0.413	1.543
Conservative Ideology	–0.152	0.076	.046*	0.859	0.740	0.997
Age	0.011	0.005	.031*	1.011	1.001	1.020
Female	–0.046	0.161	.776	0.955	0.697	1.310
Education	0.226	0.059	<.001**	1.253	1.118	1.408
Knowledge x Religion	–0.077	0.025	.002**	0.926	0.881	0.972

*$p < .05$. **$p < .01$.

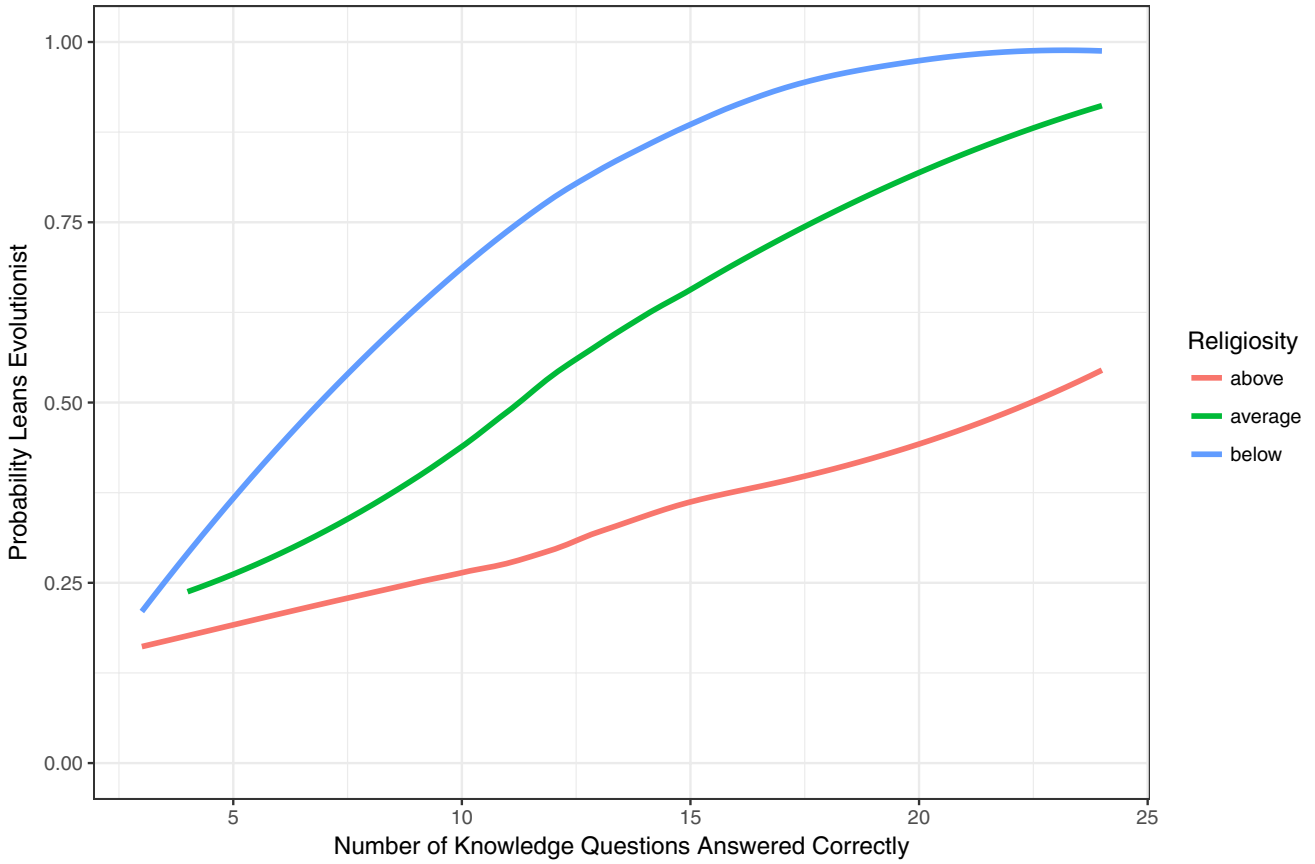

Figure 4. The participants' probability of leaning evolutionist as a function of their scores on the evolution knowledge battery, split by their degree of religiosity.

predictions, there was no relationship with age ($\beta = -0.002$, $p = .62$).

Finally, we explored the contributions of domain-specific knowledge about evolution (as was measured by our knowledge battery) compared with those of domain-general knowledge about science and scientific reasoning skills (as was measured by the OSI2) to determine whether specific or general knowledge might be more important to an individual's level of acceptance. We conducted a logistic regression predicting whether one leans evolutionist from performance on the knowledge battery, performance on the OSI2, religiosity, having a conservative ideology, age, gender, and level of education (table 2). We found that both domain-specific evolution knowledge and OSI2

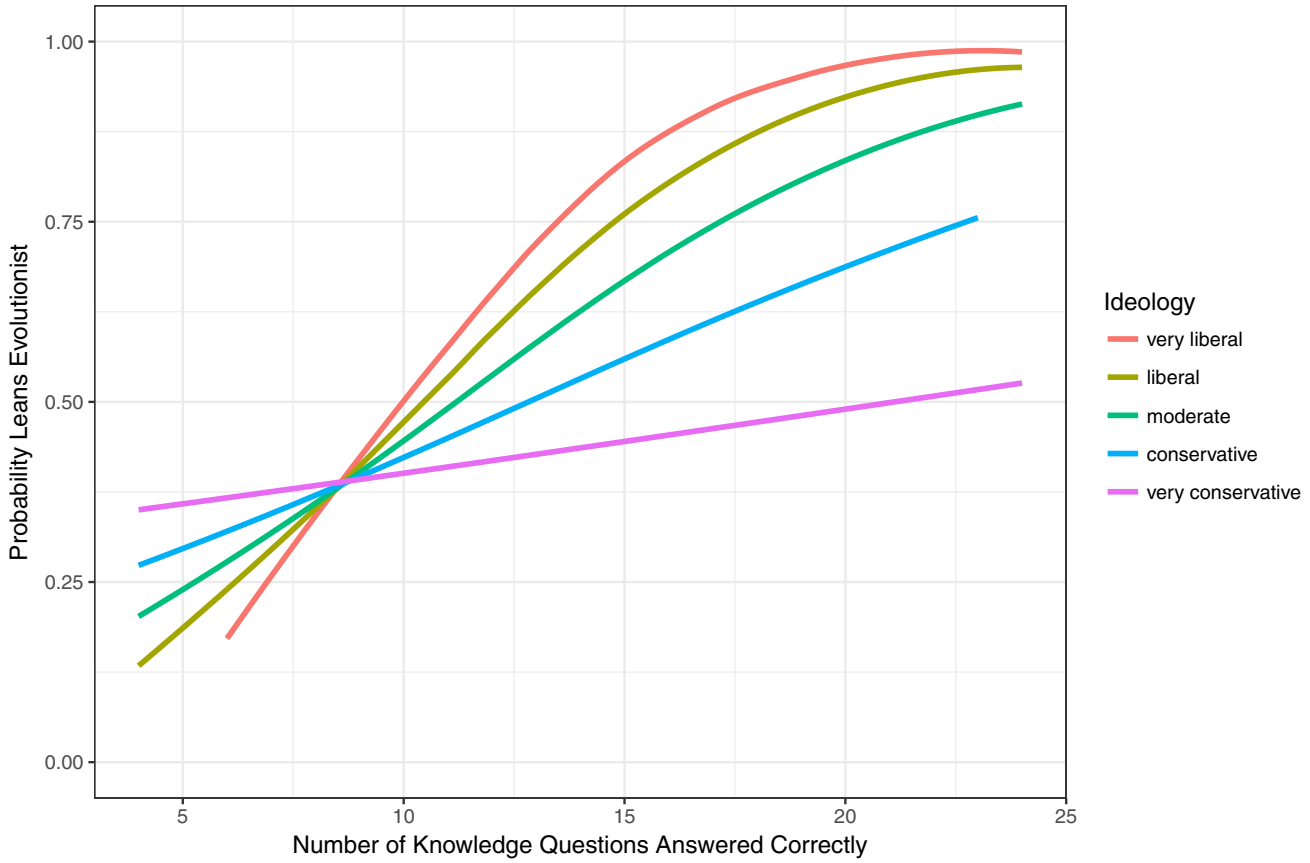

Figure 5. The participants' probability of leaning evolutionist as a function of their scores on the evolution knowledge battery, split by their political ideology.

performance were independently predictive of evolution acceptance and at approximately the same level (β = 0.082 and 0.087, respectively).

Conclusions

The current study was designed to gain a more accurate view of how Americans think about evolutionary theory, with the particular goal of investigating whether individuals' knowledge about the theory plays a significant role in their acceptance of it. To our knowledge, this is the first attempt to explore these questions using a sample that reflects the demographics of the entire country, as well as the first time that such a sample has been tested on its knowledge of a comprehensive set of topics within evolutionary theory. We predicted that we would find a higher degree of acceptance in our survey than in previous work and that knowledge would predict acceptance. Both predictions were supported.

With respect to overall levels of acceptance, our data paint a more optimistic picture of Americans' attitudes toward evolution than previous polls: Only a quarter of our respondents were creationist, and more than half of our sample accepted that evolution happened without specific divine intervention. Although the current design does not allow us to determine exactly why our results differ from those of prior surveys, the fact that we found significantly fewer creationists with these small wording changes suggests that Americans may not be as resistant to evolutionary theory as previously thought. In our future work, we intend to directly compare levels of evolution acceptance when the question is about humans as opposed to plants and animals, which will provide greater insight into the role that perceived human uniqueness plays in people's beliefs.

In line with previous work in this area, our data show that participants with high levels of religiosity and conservative views are more likely to reject evolutionary theory. On the basis of results such as these, some have argued that people's responses to evolution-acceptance questions can be explained primarily by people expressing or protecting their identities ("identity-protective cognition"; Kahan et al. 2007). Importantly, however, we found that level of acceptance is not solely a result of these identity factors; knowledge of evolutionary theory also plays a significant role. Even when taking into account the participants' level of religiosity and political conservatism, as well as their age, gender, and level of education, performance on our knowledge battery was still a significant predictor of their level of acceptance. Crucially, and contrary to some similar work on climate change (Kahan et al. 2012), we found a

Table 2. The results of a logistic regression predicting level of acceptance from performance on the knowledge battery, performance on the OSI2, religiosity, having a conservative ideology, age, gender, and level of education.

	B	SE	*p* value	exp(B)	2.5% CI	97.5% CI
(Intercept)	–2.054	0.461	<.001**	0.128	0.051	0.313
Knowledge	0.082	0.027	.002**	1.086	1.030	1.145
OSI2	0.087	0.030	.003**	1.091	1.030	1.157
Religiosity	–1.236	0.102	<.001**	0.291	0.237	0.353
Conservative ideology	–0.199	0.077	.010**	0.820	0.705	0.953
Age	0.011	0.005	.024*	1.011	1.001	1.021
Female	–0.064	0.164	.697	1.066	0.773	1.474
Education	0.199	0.060	<.001**	1.220	1.086	1.373

*$p < .05$. **$p < .01$.

relationship between increasing knowledge and increasing acceptance at all levels of religiosity and political ideology. We believe that we were able to find these relationships, which have not been seen in previous work, because our test was appropriately calibrated to capture the large variance in knowledge in the general population, because we asked about evolution in a context not involving humans, and because we provided more options for categorizing people's views on evolution.

Indeed, our inclusion of four options in our acceptance question allows us to construct a more nuanced view of relations between Americans' attitudes toward evolutionary theory, their knowledge of the theory, and identity factors. For example, highly religious participants and politically conservative participants with high degrees of knowledge tend to accept evolution, but they believe that God was the prime mover. Specifically, for those with a high degree of understanding of evolution (1 SD above the mean), 79% of the most religious subjects and 41% of the political conservatives are deistic evolutionists, as opposed to 24% of the total population.

Our inclusion of several auxiliary measures can also begin to tease out reasons for individuals' stated level of acceptance. The participants were more likely to accept evolution if they scored higher on a test of general science knowledge and reasoning skills, if they understood to a greater extent the role of theories in science, and if they believed that "it feels true in my gut" was a poor criterion for belief. The participants were more likely to reject evolution if they reported higher levels of authoritarianism and need for closure.

Because this study is correlational, it does not provide definitive evidence about potential causal links among these factors: Greater knowledge of evolution might lead to views that more closely resemble the scientific consensus, but it is also possible that individuals who accept evolutionary theory are more likely to learn about it. Some evidence for the former direction of causation comes from interventions that aim to increase knowledge, which have shown that developing a greater understanding of evolution in the classroom can increase acceptance, at least among college students (Lawson and Weser 1990, Matthews 2001, Ingram and Nelson 2006, Shtulman and Calabi 2012—but see Bishop and Anderson 1990, Lawson and Worsnop 1992). Similar effects have been reported for a brief educational intervention about climate change, another publicly controversial scientific topic (Ranney and Clark 2016). Optimistically, this suggests sustained attention to education might be able to improve the public's attitudes about evolutionary theory.

Although our data cannot currently determine whether increasing knowledge may increase acceptance, we can offer some suggestions on how to proceed should this be the case. First and foremost, we believe that any efforts to bolster people's knowledge should be targeted not only toward improving general knowledge about evolutionary theory but also toward teaching a more realistic view of modern scientific methods and how science creates knowledge. Research in our labs and elsewhere suggests that the kind of scientific and ecological literacy required for accepting evolutionary theory crucially involves an appreciation of the nature of scientific research (Lombrozo et al. 2006, 2008). In addition, we believe that teaching evolution should not be the sole province of the formal education system, especially given that even biology teachers have many misconceptions about this topic (Rutledge and Mitchell 2002, Cotner et al. 2016). Informal educational experiences, such as television shows or science museums, could help to bridge this gap by providing enriching and effective tools for conveying topics in evolutionary theory. Indeed, recent work in developmental psychology reveals that young children can learn the principles of natural selection from storybooks (Kelemen et al. 2014, Shtulman et al. 2016). Finally, whether based in formal or informal educational settings, any such effort should be sensitive to our best science of science communication, aiming to improve understanding without entrenching existing biases (Jamieson 2017).

These recommendations underscore the fact that many factors can play a role in shaping individuals' particular

views on evolutionary theory. The most important contribution of our data is to emphasize that a crucial part of this complexity is due to individuals' knowledge of evolution, the importance of which has previously been underestimated.

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Supplemental material

Supplementary data are available at *BIOSCI* online.

References cited

Anderson DL, Fisher KM, Norman GJ. 2002. Development and evaluation of the conceptual inventory of natural selection. Journal of Research in Science Teaching 39: 952–978. doi:10.1002/tea.10053

Bishop BA, Anderson CW. 1990. Student conceptions of natural selection and its role in evolution. Journal of Research in Science Teaching 27: 415–427. doi:10.1002/tea.3660270503

Blackwell WH, Powell MJ, Dukes GH. 2003. The problem of student acceptance of evolution. Journal of Biological Education 37: 58–67. doi:10.1080/00219266.2003.9655852

Brem SK, Ranney MA, Schindel J. 2003. Perceived consequences of evolution: College students perceive negative personal and social impact in evolutionary theory. Science Education 87: 181–206. doi:10.1002/sce.10105

Cohen GL, Aronson J, Steele CM. 2000. When beliefs yield to evidence: Reducing biased evaluation by affirming the self. Personality and Social Psychology Bulletin 26: 1151–1164. doi:10.1177/01461672002611011

Cornwall M, Albrecht SL, Cunningham PH, Pitcher, BL. 1986. The dimensions of religiosity: A conceptual model with an empirical test. Review of Religious Research 27: 226–244. doi:10.2307/3511418

Cotner S, Graczyk H, Rodríguez Garcia JL, Moore R. 2016. In Galápagos… and uncomfortable with evolution. Journal of Biological Education 50: 115–119. doi:10.1080/00219266.2016.1175758

Demastes SS, Settlage J, Good R. 1995. Students' conceptions of natural selection and its role in evolution: Cases of replication and comparison. Journal of Research in Science Teaching 32: 535–550. doi:10.1002/tea.3660320509

Deniz H, Donnelly LA, Yilmaz I. 2008. Exploring the factors related to acceptance of evolutionary theory among Turkish preservice biology teachers: Toward a more informative conceptual ecology for biological evolution. Journal of Research in Science Teaching 45: 420–443. doi:10.1002/tea.20223

Feldman S, Stenner K. 1997. Perceived threat and authoritarianism. Political Psychology 18: 741–770. doi:10.1111/0162-895X.00077

Frederick S. 2005. Cognitive reflection and decision making. Journal of Economic Perspectives 19: 25–42. doi:10.1257/089533005775196732

Funk C, Rainie L. 2015. Public and scientists' views on science and society. Pew Research Center. (18 December 2017; *www.pewinternet.org/2015/01/29/public-and-scientists-views-on-science-and-society*)

Ingram EL, Nelson CE. 2006. Relationship between achievement and students' acceptance of evolution or creation in an upper-level evolution course. Journal of Research in Science Teaching 43: 7–24. doi:10.1002/tea.20093

Jamieson KH. 2017. The need for a science of science communication: Communicating science's values and norms. Pages 15–23 in Jamieson KH, Kahan DM, Scheufele DA, eds. Oxford Handbook of the Science of Science Communication. Oxford University Press.

Johnson RL, Peeples EE. 1987. The role of scientific understanding in college: Student acceptance of evolution. American Biology Teacher 49: 93–98.

Jost JT, Glaser J, Kruglanski AW, Sulloway FJ. 2003. Political conservatism as motivated social cognition. Psychological Bulletin 129: 339–375. doi:10.1037/0033-2909.129.3.339

Kahan DM. 2016. "Ordinary science intelligence": A science-comprehension measure for study of risk and science communication, with notes on evolution and climate change. Journal of Risk Research 20: 995–1016. doi:10.1080/13669877.2016.1148067

Kahan DM, Braman D, Gastil J, Slovic P, Mertz CK. 2007. Culture and identity-protective cognition: Explaining the white-male effect in risk perception. Journal of Empirical Legal Studies 4: 465–505. doi:10.1111/j.1740-1461.2007.00097.x

Kahan DM, Jenkins-Smith H, Braman D. 2011. Cultural cognition of scientific consensus. Journal of Risk Research 14: 147–174. doi:10.1080/13669877.2010.511246

Kahan DM, Peters E, Wittlin M, Slovic P, Ouellette LL, Braman D, Mandel G. 2012. The polarizing impact of science literacy and numeracy on perceived climate change risks. Nature Climate Change 2: 732–735. doi:10.1038/nclimate1547

Kelemen D, Emmons NA, Seston Schillaci R, Ganea PA. 2014. Young children can be taught basic natural selection using a picture-storybook intervention. Psychological Science 25: 893–902. doi:10.1177/0956797613516009

Kunda Z. 1990. The case for motivated reasoning. Psychological Bulletin 108: 480–498. doi:10.1037/0033-2909.108.3.480

Lawson AE. 1983. Predicting science achievement: The role of developmental level, disembedding ability, mental capacity, prior knowledge, and beliefs. Journal of Research in Science Teaching 20: 117–129. doi:10.1002/tea.3660200204

Lawson AE, Weser J. 1990. The rejection of nonscientific beliefs about life: Effects of instruction and reasoning skills. Journal of Research in Science Teaching 27: 589–606.

Lawson AE, Worsnop WA. 1992. Learning about evolution and rejecting a belief in special creation: Effects of reflective reasoning skill, prior knowledge, prior belief and religious commitment. Journal of Research in Science Teaching 29: 143–166. doi:10.1002/tea.3660290205

Lombrozo T, Thanukos A, Weisberg M. 2008. The importance of understanding the nature of science for accepting evolution. Evolution: Education and Outreach 1: 290–298. doi:10.1007/s12052-008-0061-8

Maitland A, Tourangeau R, Yan Y, Bell R, Muhlberger P. 2014. The effect of question wording on measurement of knowledge about evolution: An examination of survey experiment data collected for the National Center for Science and Engineering Statistics. National Center for Science and Engineering Statistics. Washington, DC.

Matthews D. 2001. Effect of a curriculum containing creation stories on attitudes about evolution. American Biology Teacher 63: 404–409. doi:10.1662/0002-7685(2001)063[0404:EOACCC]2.0.CO;2

McKeachie WJ, Lin Y-G, Strayer J. 2002. Creationist vs. evolutionary beliefs: Effects on learning biology. American Biology Teacher 64: 189–192. doi:10.1662/0002-7685(2002)064[0189:CVEBEO]2.0.CO;2

Metz SE, Weisberg DS, Weisberg M. 2018. Non-scientific epistemic criteria sustain counter-scientific beliefs. Cognitive Science. Manuscript in press.

Miller JD, Scott EC, Okamoto S. 2006. Public acceptance of evolution. Science 313: 765–766. doi:10.1126/science.1126746

Nadelson LS, Sinatra GM. 2009. Educational professionals' knowledge and acceptance of evolution. Evolutionary Psychology 7: 490–516.

National Research Council. 2012. A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. National Academies Press.

National Science Board. 2016. Science and Engineering Indicators. National Science Foundation.

Nehm RH, Kim SY, Sheppard K. 2009. Academic preparation in biology and advocacy for teaching evolution: Biology versus non-biology teachers. Science Education 93: 1122–1146. doi:10.1002/sce.20340

[Pew] Pew Forum on Religion and Public Life. 2007. Pew Research Center for the People and the Press Poll. Pew Research Center.

[PRRI] Public Religion Research Institute. 2011. PRRI/RNS Religion News Survey, September. Association of Religion Data Archives. (18 December 2017; *www.thearda.com/Archive/Files/Descriptions/PRRIRNSP.asp*)

Ranney MA, Clark D. 2016. Climate change conceptual change: Scientific information can transform attitudes. Topics in Cognitive Science 8: 49–75. doi:10.1111/tops.12187

Roets A, Van Hiel A. 2011. Item selection and validation of a brief, 15-item version of the need for closure scale. Personality and Individual Differences 50: 90–94. doi:10.1016/j.paid.2010.09.004

Roos JM. 2014. Measuring science or religion? A measurement analysis of the National Science Foundation sponsored science literacy scale 2006–2010. Public Understanding of Science 23: 797–813. doi:10.1177/0963662512464318

Rutledge ML, Mitchell MA. 2002. High school biology teachers' knowledge structure, acceptance and teaching of evolution. American Biology Teacher 64: 21–28. doi:10.1662/0002-7685(2002)064

Rutledge ML, Warden MA. 2000. Evolutionary theory, the nature of science and high school biology teachers: Critical relationships. American Biology Teacher 62: 23–31.

Shtulman A. 2006. Qualitative differences between naïve and scientific theories of evolution. Cognitive Psychology 52: 170–194. doi:10.1016/j.cogpsych.2005.10.001

Shtulman A, Calabi P. 2012. Cognitive constraints on the understanding and acceptance of evolution. Pages 47–65 in Rosengren KS, ed. Evolution Challenges: Integrating Research and Practice in Teaching and Learning about Evolution. Oxford University Press.

Shtulman A, Neal C, Lindquist G. 2016. Children's ability to learn evolutionary explanations for biological adaptation. Early Education and Development 27: 1222–1236. doi:10.1080/10409289.2016.1154418

Sinatra GM, Southerland SA, McConaughy F, Demastes JW. 2003. Intentions and beliefs in students' understanding and acceptance of biological evolution. Journal of Research in Science Teaching 40: 510–528. doi:10.1002/tea.10087

Snow CE, Dibner KA, eds. 2016. Science Literacy: Concepts, Contexts, and Consequences. National Academies Press. doi:10.17226/23595

Suldovsky B. 2016. In science communication, why does the idea of the public deficit always return? Exploring key influences. Public Understanding of Science 25: 415–426. doi:10.1177/0963662516629750

Swift A. 2017. In US, belief in creationist view of humans at new low. Gallup News. (18 December 2017; *www.gallup.com/poll/210956/belief-creationist-view-humans-new-low.aspx*)

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