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What's effective and ineffective in preparing high school biology educators to teach evolution? Evidence from a representative national U.S. survey

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Abstract

Background What types of coursework prepare biology teachers to teach evolution effectively? The present study provides answers to that question based on evidence from a nationally representative sample of public high school biology teachers in the U.S. Data about their pre-service coursework (in seven categories) and their attitudes and practices relevant to teaching evolution (in five categories relating to personal acceptance of evolution, perception of scientific consensus on evolution, instructional time devoted to evolution, classroom characterization of evolution and creationism, and emphasis on specific topics in teaching evolution) were collected.

Results Coursework focused on evolution was significantly associated with positive outcomes: more class hours devoted to evolution, not presenting creationism as scientifically credible, and prioritizing common ancestry, human evolution, and the origin of life as topics of instruction, while shunning Biblical perspectives on the history of life. Similarly, coursework with some evolution content was significantly associated with positive outcomes: awareness of the scientific consensus on evolution, presenting evolution but not creationism as scientifically credible, and prioritizing common ancestry as a topic of instruction. But surprisingly, methods coursework on problem-based learning was significantly associated with negative outcomes: presenting creationism as well as evolution as scientifically credible and prioritizing Biblical perspectives on the history of life as a topic of instruction. Similarly, and likewise surprisingly, methods coursework on teaching controversial topics was associated with a negative outcome: presenting creationism as scientifically credible.

Conclusion Consistent with previous work, the results of the present study suggest that pre-service coursework in evolution is important in preparing educators to teach evolution effectively. But they also suggest, surprisingly, that pre-service methods coursework aimed at preparing educators to teach evolution effectively tends, at present, to be counterproductive, leading to the presentation of creationism as scientifically credible.

Background

It is generally acknowledged that evolution is a vital part of science education: in the Next Generation Science Standards (NGSS Lead State Partners 2013), for example, evolution is treated as a disciplinary core idea of the life sciences. It is also generally acknowledged that evolution is a particularly difficult topic for educators to teach, owing in part to the counterintuitive concepts involved

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(Kampourakis 2014; Shtulman 2017) and, especially in the U.S., religiously based doubt and denial (Branch et al. 2010; Laats 2020). The question of how best to prepare science teachers to teach evolution effectively in the face of such challenges is therefore urgent.

A large body of literature addresses the preparation of science educators to teach evolution effectively (helpfully reviewed by Sickel and Friedrichsen 2013). However, the bulk of it is theoretical, anecdotal, or based on case studies. Only a fraction of it involves survey research, and most of that research is based on small non-representative samples of educators. Many are studies of pre-service teachers or otherwise based on non-representative captive populations, such as in-service teachers attending a particular professional development session. Only a handful of articles and dissertations (discussed below) utilize surveys of in-service teachers that can link their pre-service coursework to their classroom performance.

Here we report on a nationally representative probability survey of public high school biology teachers in the U.S., examining associations between their pre-service coursework and their current attitudes and practices regarding the teaching of evolution. (Henceforth "teachers" should be understood as referring to public high school biology teachers in the U.S.). In relying on a nationally representative survey, the present study has only one precedent (described in Berkman et al. 2008), and it is broader than any of its predecessors, examining seven aspects of pre-service coursework (considered as the independent variables) and five aspects of attitudes and practices regarding the teaching of evolution (considered as the dependent variables).

The dependent variables measure three different kinds of outcomes. Two measure teachers' personal knowledge and beliefs: whether they personally accept evolution and whether they are aware of the scientific consensus on it. Two measure global properties of their general approach to teaching evolution: how much instructional time they devote to it and how they characterize the scientific status of evolution and creationism in their lessons. The remaining outcome involves teachers' approaches to developing an effective lesson plan, as reflected in their responses to a question about which topics they would prioritize if asked to create a two-week unit on evolution. These, in our view, capture many key elements relevant to the effective teaching of evolutionary science and, taken together, they allow us to create a detailed portrait of how evolution is being taught in U.S. public high schools. For each kind of outcome, we will seek to determine whether and to what extent each of the seven kinds of preparation is associated with their prevalence.

We proceed as follows. First, after documenting and summarizing the relevant research that we could identify, we describe the independent and dependent variables of the present study. Second, we explain our methodology (with further details provided in Plutzer et al. 2020 and in the Appendix) and dataset. Third, we report on a series of regression analyses, which seek to isolate the effects of coursework preparation on teaching outcomes, controlling for teacher seniority, gender, and the nature of their state's science education standards. Finally, we discuss the results, offering recommendations for researchers and policymakers.

Prior research on predictors of our outcomes

We will briefly describe the prior research (limited to studies using samples of U.S. in-service high school biology teachers) relevant to the five classes of dependent variables that we examined in our survey.

Personal acceptance of evolution

Previous work tended to find positive associations between acceptance of evolution and pre-service coursework on biology, evolution, and the philosophy of science. Rutledge and Mitchell (2002) found that high school biology teachers in Indiana were more likely to accept evolution "as a scientifically valid explanation of the state of living organisms of the present and past" if they took more credit hours in biology, completed a class in evolution, or completed a class on "the nature/philosophy of science." Toro found that in a national sample of secondary science teachers in the United States, "having both science content and science pedagogy degrees leads to a higher acceptance rating of evolution theory over just an education degree" (2018, p. 84), where acceptance was assessed by the MATE instrument (Rutledge and Warden 2000).

Perception of scientific consensus on evolution

There is apparently no previous work investigating association between pre-service coursework and perception of scientific consensus on evolution, except insofar as studies such as Rutledge and Mitchell (2002) and Toro (2018) are regarded as doing so: as Sickel and Friedrichsen (2013) note, instruments purported to assess personal acceptance of evolution often seem to be assessing perception of scientific acceptance of evolution (see also Tourangeau et al. 2016). A substantial body of work on scientific consensus on climate change suggests that awareness of scientific consensus is significantly associated with acceptance and thus predictive of appropriate action (see, e.g., Sloane and Wiles 2020; van der Linden et al. 2015; van der Linden 2021). In the case of high school biology teachers, it might be expected that awareness of the scientific consensus on evolution would similarly be predictive of desirable classroom outcomes, so the association between pre-service coursework and awareness of the scientific consensus is of interest.

Instructional time devoted to evolution

Previous work investigating associations between pre-service coursework and class time devoted to evolution provides mixed results. Aguillard (1999) found that among Louisiana public high school biology teachers there was a significant association between instructional time devoted to evolution and coursework in biology and evolution. But Donnelly and Boone (2007) found that among Indiana public high school biology teachers the number of days spent teaching evolution did not differ among groups based on number of biology classes taken, completion of an evolution class, or completion of a history and philosophy of science class. Yet Berkman et al. (2008), discussing a 2007 survey of which the 2019 survey underlying the present study is a partial replication, found that in a national sample of public high school biology teachers there was a significant association between instructional time devoted to evolution and completion of a class devoted to evolution.

Classroom characterization of evolution and creationism

Ideally, teachers explicitly endorse evolution in their classrooms as a central, unifying, and unrivaled principle of science, consistent with the recommendations of authorities such as the National Academy of Sciences (1998). Unfortunately, not all do so. Previous work investigating associations between pre-service coursework and classroom characterization of evolution generally suggests that pre-service coursework on evolution is associated with classroom endorsement of evolution.[1] Aguillard (1999) reported a significant association between coursework in biology and evolution and emphasis placed on evolution among Louisiana public high school biology teachers. Berkman and Plutzer (2011), reporting on a 2007 survey of which the 2019 survey underlying the present study is a partial replication, found in a national sample of public high school biology teachers that evolution instruction that closely followed the recommendations of the National Academy of Sciences was more likely among teachers who completed a class on evolution. Benson reported that among Connecticut in-service public high school biology teachers, “Respondents who were not required to take evolutionary biology for their teacher preparation program but took the course to fulfill an elective requirement demonstrated a 26% increased probability of adhering to all three [National Academy of Sciences] goals when compared to those who were not required to take evolutionary biology and did not take it as an elective” (2021, p. 78).

Emphasis on specific topics in teaching evolution

The choice of what topics to include and exclude in teaching evolution can be important. Teachers who are willing to teach evolution in general may nevertheless skimp on teaching about particular areas they perceive as controversial, such as the origin of life, macroevolution, and human evolution (Berkman and Plutzer 2011; for discussion of the importance of these areas to high school biology evolution, see respectively Lazcano and Peretó 2010, Padian 2010, and Pobiner 2012). Surprisingly, there is apparently no previous work investigating association between pre-service coursework and choice of topics to emphasize in teaching evolution.

The present study

In the present study, we examined seven types of pre-service coursework. Four are classes typically offered by faculty in the sciences: classes in the earth and space sciences, classes in the biological and life sciences, classes entirely focused on evolution, and classes that devoted one or more sessions to evolution. In addition, we asked about three classes typically provided in colleges of education: classes about methods of science teaching, classes about methods of science teaching that devoted one or more sessions to problem-based learning,[2] and classes about methods of science teaching that devoted one or more sessions to the challenges of teaching controversial topics. For brevity, we will refer to these as ESS (earth and space sciences), biology, evolution-focused, evolution-containing, methods, PBL (problem-based learning) methods, and TCT (teaching controversial topics) methods classes, respectively.

Based on a review of the literature and other considerations, we expected to find significant associations between evolution-focused coursework on the one hand and acceptance of evolution, accurate perception of scientific consensus on evolution, greater instructional time devoted to evolution, classroom endorsement of evolution as a matter of scientific consensus, and emphasis on topics related to evolution on the other hand. Similarly,

[1] Although Nehm et al. (2009) found among precertified in-service public school science teachers in New York City that completion of a class focused primarily on evolution was not associated with any significant differences in preference for students to learn and to accept evolution and not creationism, their study did not investigate the teachers’ actual classroom practice.

[2] Problem-based learning involves students learning through solving problems with the guidance of the instructor (Hmelo-Silver 2004). Aspects of problem-based learning (and the similar approach of inquiry-based learning) are incorporated in the Next Generation Science Standards (NGSS Lead States 2013).

we expected to find significant, but less substantial, associations for evolution-containing coursework. We also expected to find significant, but less substantial, associations for methods classes, especially TCT methods classes, on the grounds that evolution is notoriously a socially controversial topic which such classes should prepare teachers to teach effectively in the face of potential conflict.

Methods

The survey in general

Fielded between February and May of 2019, the 2019 Survey of American Science Teachers included both a high school and a middle school sample. The former is the focus of this paper and is based on a probability sample of public high school biology (and life science) teachers. Further results from the high school responses can be found in Plutzer et al. (2020), and the methods for the present study are described in detail in that report. We repeat the description of the methods here for the convenience of readers. The sample was drawn, based on investigator specifications, from a national teacher file maintained by MDR (Market Data Retrieval), a Dunn and Bradstreet direct mail firm that maintains the largest mailing list of educators in the U.S. To ensure national coverage, the national list of 30,847 high school biology teachers was first stratified by state and urban/suburban/other location. With the District of Columbia serving as a single stratum, this produced 151 segments. Within each segment, we selected a random sample with a sampling probability of roughly 0.08, yielding an initial set of 2503 high school biology teacher names and addresses.

Following the 2007 protocol exactly, and consistent with best practices for mail surveys (Dillman et al. 2014), we then sent each teacher an advance prenotification letter explaining the survey and telling them that a large survey packet would arrive in a few days. The packet included a cover letter, a token pre-incentive (a $2 bill), a 12-page survey booklet, and a postage-paid return envelope. One week later a reminder postcard was sent, and a complete replacement packet (though without an incentive) two weeks after that. In the week after the replacement packet was mailed, we emailed reminders to the roughly 85% of non-responding teachers for whom we had valid emails. Two email reminders and one final postcard—saying that the study was about to close—followed.

In all, 1434 teachers completed the questionnaire. The overall response rate was 37% (using American Association for Public Opinion Research response rate formula #4: AAPOR 2016) and 40% for the high school teacher sample used in this paper (N = 762). To place this in context, sample surveys of teachers vary considerably in their overall response rate, ranging from the low single digits (Puhl et al. 2016; Troia and Graham 2016; Davis et al. 2017; Dragowski et al. 2016) and the mid-teens (Dragowski et al. 2016; Hart et al. 2017) to Department of Education survey programs that approach 70% (National Center for Education Statistics n.d., 2018; Centers for Disease Control and Prevention 2015). In that light, our response rate is at the high end of results achieved outside of government-sponsored studies. However, survey scientists have sought to discourage a heavy reliance on response rates as indicators or data quality. Indeed, scores of studies show that there is no simple relationship between response rates and Total Survey Error or response bias (e.g., Keeter et al. 2000; Groves and Peytcheva 2008; Keeter 2018), leading to a greater focus on direct measures of a sample's representativeness. To this end, we conducted a detailed non-response audit, and found that the responding teachers were broadly representative of the target population. Details are provided in Plutzer et al. (2020, Tables 12–16). The high school sample was 62% female (weighted percentage = 63%); 21% (weighted 21%) with less than ten years of seniority, and 39% (38% weighted) with 20 or more years of seniority.

We augmented the design weights with a non-response adjustment, and we report weighted estimates throughout this report, although the unweighted results are almost always similar. Full details on the methods of contact, the non-response audit, and methods of weight calculation are provided in Plutzer et al. (2020).

The full pencil-and-paper questionnaire was a twelve-page booklet. In addition to the items discussed in this report, the questionnaire also included sections on the teaching of climate change, textbook selection, and additional questions about how teachers manage controversy in their classrooms—topics that are beyond the scope of this paper.

Measuring pre-service coursework

The survey questionnaire used a battery of questions to ask respondents to indicate how many semester- or quarter-length college classes they had completed as pre-service teachers in various areas, from zero to four or more.

Four of the questions asked about *content classes*: ESS (earth and space sciences), biology, evolution-focused, and evolution-containing. For these last two options, respondents were instructed that they could double-count, so an evolution-focused class could count as a biology class as well as an evolution-focused class. When these variables are all used in a multivariate model, the measures of the number of biology and earth science classes essentially become measures of the number of those courses which *did not* include evolution, as the more specific measures account for (and statistically partial out) this portion of the variance.

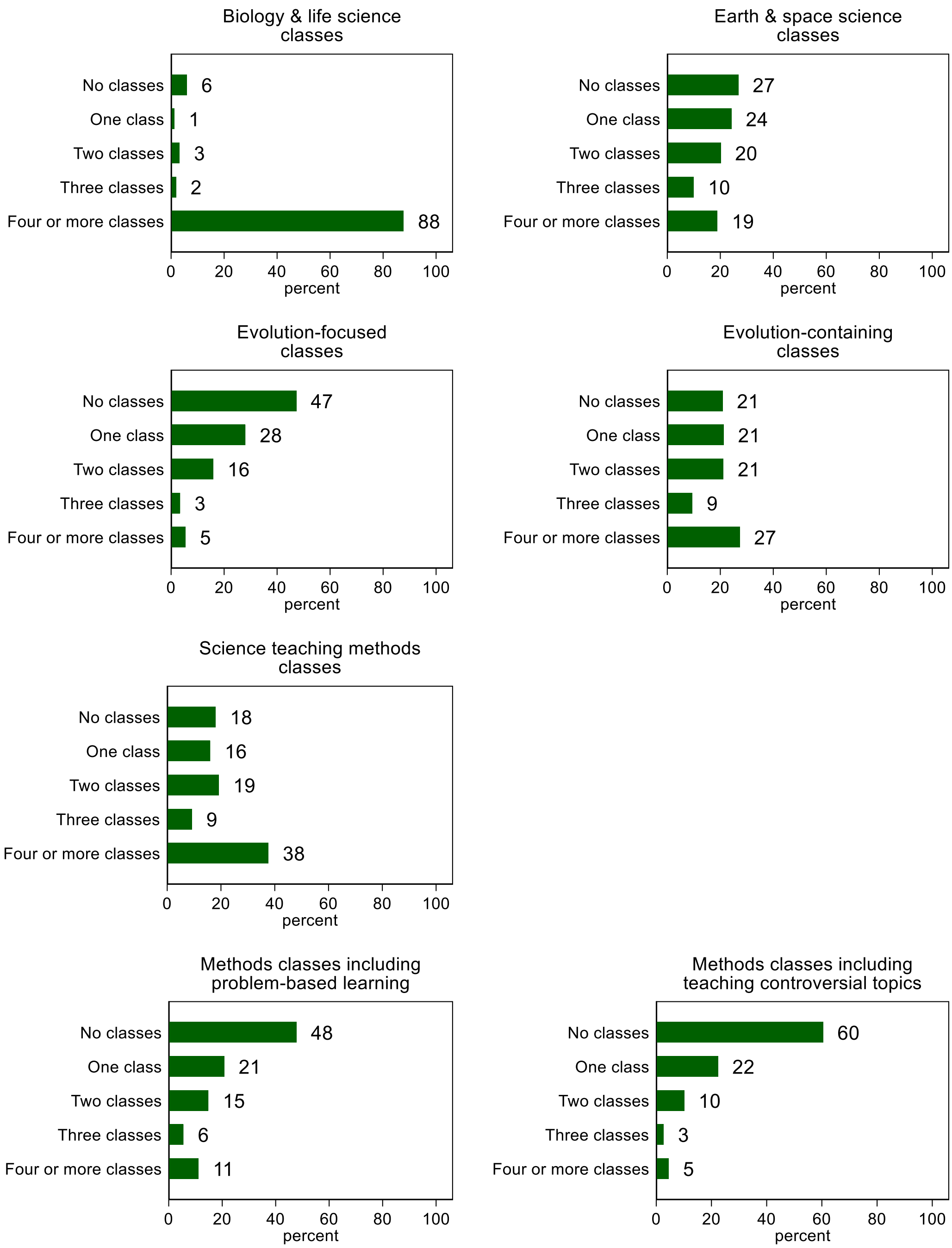

Fig. 1 Coursework in biology, earth science, evolution, and teaching methods

Three of the questions asked about *methods instruction*: methods classes, classes covering PBL (problem-based learning) methods, and those addressing TCT (teaching controversial topics). For these last two options, respondents were instructed that they could double-count, so a single methods class could be counted as many as three times if it devoted one or more sessions to both problem-based learning and the challenges of teaching controversial topics. As with the content classes, when these variables are all used in a multivariate model, the measure of the number of methods classes in general essentially becomes a measure of the number of those classes which do not include sessions on PBL and TCT.

The distributions of these variables are described in Fig. 1, which shows extensive coursework in biology for nearly all teachers in the sample. However, only 53% report taking at least one evolution-focused class.

Measuring the key outcomes

The survey questionnaire used a variety of instruments to investigate the dependent variables relating to personal acceptance of evolution, perception of scientific consensus on evolution, instructional time devoted to evolution, classroom characterization of evolution and creationism, and emphasis on specific topics in teaching evolution. We think that it aids comprehension to describe each instrument immediately before reporting the relevant results, rather than describing the instruments altogether and then reporting the results altogether, and we do so in the following Results section.

Results

Throughout the following, we report two-tailed tests at the 95% significance level unless otherwise noted. Due to missing values, descriptive statistics represented in bar graphs are based on samples ranging from N = 712 to N = 753. All regressions have additional control variables that are reported in the full tables presented in the appendix, but are omitted for clarity in the graphical reports of model estimates: teacher seniority, teacher gender, and nature of the state science standards in the teacher's state.[3] Each of these have been previously shown to predict one or more of our dependent variables. We first present analyses that show the association of pre-service coursework on two important personal beliefs relevant to science teaching: acceptance of evolution and perception of the scientific consensus on evolution.

Personal acceptance of evolution

In the present study, personal acceptance of evolution was assessed using the Gallup instrument, which asks, "Which of the following statements comes closest to your views on the origin and development of human beings?" and offers the options "Human beings have developed over millions of years from less advanced forms of life, but God guided this process" (guided evolution), "Human beings have developed over millions of years from less advanced forms of life, but God had no part in this process" (unguided evolution), and "God created human beings pretty much in their present form at one time within the last 10,000 years or so" (creationism). We acknowledge that the Gallup instrument is crude, failing both to reflect the complexity of the conceptual geography and to accommodate ambivalence and uncertainty (see Branch 2017 for discussion). But the fact that it is frequently used makes it helpful for purposes of comparison.

As the left-hand panel of Fig. 2 shows, creationism is rare among the responding teachers (N = 661), with just 10.5% reporting acceptance of creationism. In comparison, about 40% of the general U.S. public reports acceptance of creationism (Brenan 2019).

As the right-hand panel of Fig. 2 shows, however, for none of the seven types of classes considered is increased coursework significantly associated with any answer to the Gallup question. (The first set of estimates shows the relative risk ratios for unguided evolution as compared to guided evolution; the last set shows the relative risk ratios for creationism as compared to guided evolution).

Perception of scientific consensus on evolution

In the present study, to assess perception of scientific consensus on evolution, respondents were asked "To the best of your knowledge, what proportion of scientists think that humans and other living things have evolved over time?" and invited to select a quintile (81–100%, 61–80%, 41–60%, 21–40%, or 0–20%.) The Pew Research Center's (2015) survey of members of the American Association for the Advancement of Science estimates the actual proportion as 98%, so 81–100% is the correct answer.

As the left-hand panel of Fig. 3 shows, only 71% of the responding teachers (N = 694) selected the correct quintile. This is surprising, since even those who do not accept evolution should be able to acknowledge that nearly all scientists do (Tourangeau et al. 2016). However, it appears that personal views about evolution are associated with perception of scientific consensus: only 36% of those who opted for the creationist option when describing their own beliefs estimated that more than 80% of scientists accept evolution.

The right-hand panel of Fig. 3 shows that increased coursework of evolution-containing classes and of methods classes in general are significantly associated with a greater chance of being aware of the scientific consensus on evolution. Specifically, the odds of being aware that between 81 and 100% of scientists accept evolution increased by 21% for each additional evolution-containing class and by 17% for each additional methods class.[4] While just shy of conventional levels of statistical significance, increased coursework of PBL methods classes and

[3] There are three possibilities for the latter: the Next Generation Science Standards, non-NGSS standards based on the same Framework on which the NGSS is based, and non-Framework standards.

[4] It might appear surprising that increased coursework of evolution-focused classes is not significantly associated with a greater chance of being aware of the scientific consensus on evolution. But because double-counting was allowed, any class counted as evolution-focused would also be counted as evolution-containing. So, the actual relevant result is that increased evolution-focused coursework *insofar as it goes beyond evolution-containing coursework* is not significantly associated with a greater chance of being aware of the scientific consensus on evolution, suggesting that a relatively brief exposure to evolution is helpful in conveying awareness of the scientific consensus but further exposure is not. We are grateful to a reviewer for asking a question that prompted this clarification.

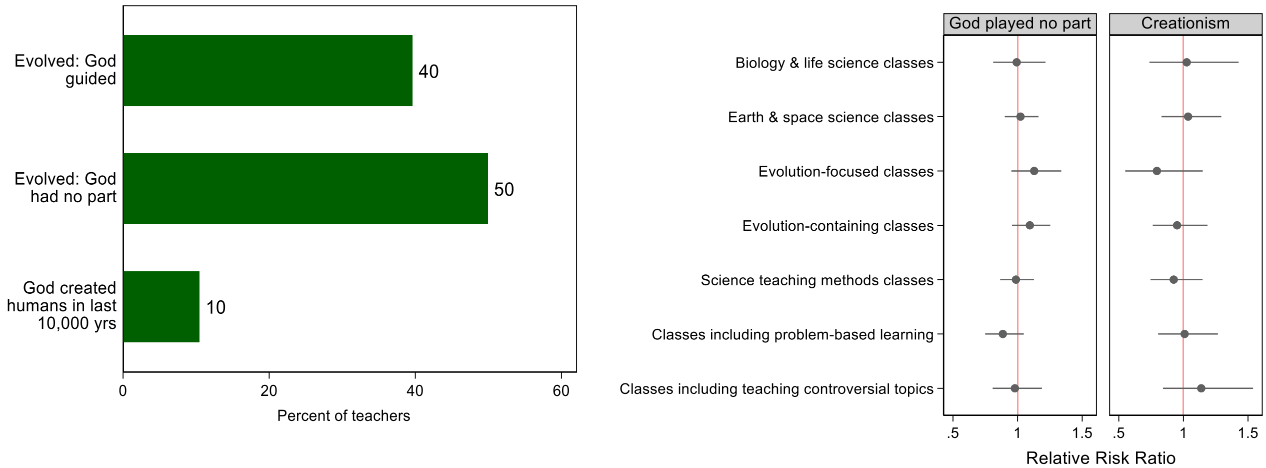

Fig. 2 Effect of coursework on personal acceptance of evolution. The left panel shows the distribution of the dependent variable. The right panel shows the estimates from a multinomial logit model. The filled circles represent the estimated effect of each independent variable, and the horizontal lines show the 95% confidence interval. The vertical reference line represents the null hypothesis of no effect (a relative risk ratio of 1.0). An effect is significant at the 0.05 level whenever the confidence interval does not intersect the reference line. Full results are reported in Appendix Table 1

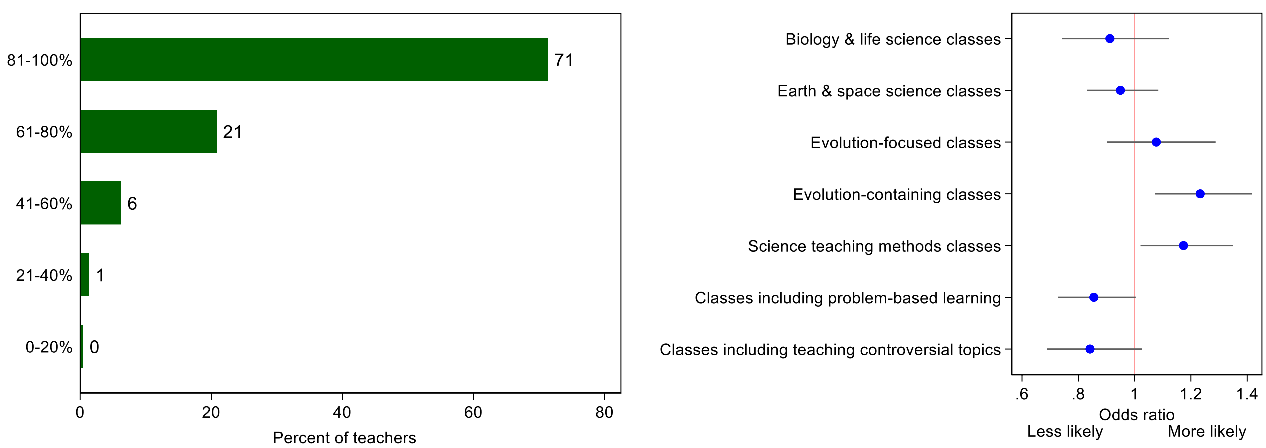

Fig. 3 Effect of coursework on perceived scientific consensus on evolution. The left panel shows the distribution of the dependent variable. The right panel shows the estimates from a binary logit model predicting selection of the "81–100%" answer. The filled circles represent the estimated effect of each independent variable, and the horizontal lines show the 95% confidence interval. The vertical reference line represents the null hypothesis of no effect (an odds ratio of 1.0). An effect is significant at the 0.05 level whenever the confidence interval does not intersect the reference line. Full results are reported in Appendix Table 2

TCT methods classes are associated with a lesser chance of being aware of the scientific consensus on evolution. Specifically, the odds of being aware that between 81 and 100% of scientists accept evolution decreased by 16% for each additional PBL methods class (with $p = 0.056$) and by 14% for each additional TCT methods class (with $p = 0.09$).

Instructional time devoted to evolution

In the present study, respondents were asked how many class hours (i.e., 40–50-min periods) they devoted to human evolution and to evolution in general in their primary class (defined in the questionnaire as their class with the highest number of students). The left-hand panel in Fig. 4 summarizes the answers of the responding teachers (N = 688) to both questions taken together. A mean of 17.9 class hours was devoted to discussing evolution. (By way of comparison, cell biology, ecology, biodiversity, human health, and global warming received a mean of 14.9, 14.1, 9.8, 8.7, and 5.8 class hours, respectively.)

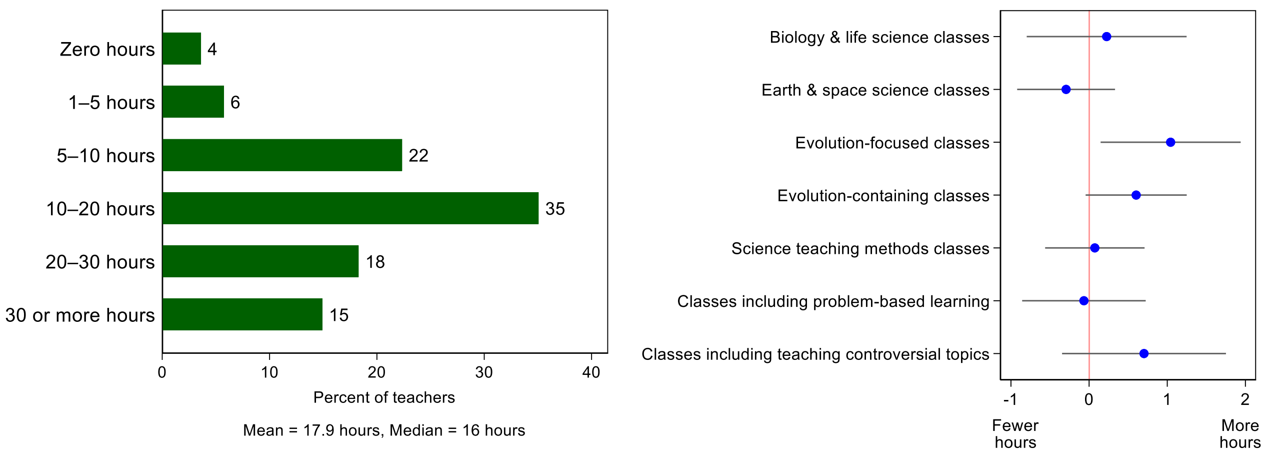

Fig. 4 Effect of coursework on the number of classroom hours devoted to evolution. The left panel shows the distribution of the dependent variable. The right panel shows the estimates from an ordinary least squares regression model. The filled circles represent the estimated effect of each independent variable, and the horizontal lines show the 95% confidence interval. The vertical reference line represents the null hypothesis of no effect (a regression slope of 0.0). An effect is significant at the 0.05 level whenever the confidence interval does not intersect the reference line. Full results are reported in Appendix Table 3

As the right-hand panel in Fig. 4 shows, every additional evolution-focused class is significantly associated with about a further class hour devoted to evolution (ß = 1.04, $p = 0.02$), but there was no significant association for evolution-containing classes.

Classroom characterization of evolution and creationism

In the present study, we assess how evolution and creationism are characterized in the classroom using the typology developed in Plutzer et al. (2020). In this typology, there are four groups of teachers, classified in terms of their response to the following statements:

When I teach evolution (including answering student questions)…

- I emphasize the broad consensus that evolution is a fact, even as scientists disagree about the specific mechanisms through which evolution occurred.
- I emphasize that intelligent design is a valid, scientific alternative to Darwinian explanations for the origin of species.
- I emphasize that many reputable scientists view creationism or intelligent design as valid alternatives to Darwinian theory.

A teacher may be classified as friendly to evolution (by agreeing only to the first prompt), sending mixed messages (by agreeing to the first but also to either or both of the other prompts), avoiding the issue (by disagreeing with all of the prompts), or friendly to creationism (by disagreeing with the first but agreeing to either or both of the other prompts).

As Fig. 5 shows, among the responding teachers (N = 708), those who are friendly to evolution are in the clear majority (67%), a substantial gain since 2007 when such teachers were in the bare majority (51%): see Plutzer et al. (2020) for a detailed comparison and discussion.

The plots in Fig. 6 show how coursework is associated with the odds of being in each category.

They show that increased coursework of evolution-containing classes significantly increases the probability of friendliness to evolution and significantly decreases the probability of two of the three alternatives. Specifically, for each additional evolution-containing class, the odds of friendliness to evolution increased by 23%, while the odds of sending mixed messages decreased by 20%, the odds of avoiding the issue decreased by 16%, and the odds of friendliness to creationism decreased by 21% (though not significantly, with $p = 0.08$). They also show that increased coursework of evolution-focused classes significantly and substantially decreases the probability of friendliness to creationism. Specifically, for each additional evolution-focused class, the odds of friendliness to creationism decreased by 40%.

The plots in Fig. 6 present two surprising results, however. The first is that increased coursework of PBL methods classes was significantly associated with sending mixed messages. Specifically, for each additional PBL methods class, the odds of sending mixed messages increased by 27%. The second is that increased coursework of TCT methods class was significantly associated with friendliness to creationism. Specifically, for each additional TCT methods class, the odds of friendliness to creationism increased by 46%.

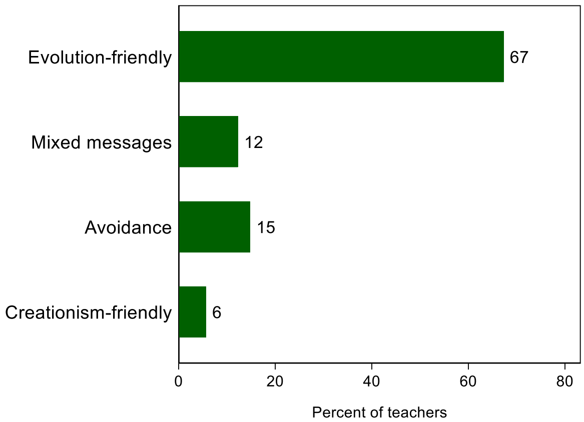

Fig. 5 Summary of classroom characterization of evolution and creationism

Emphasis on specific topics related to evolution

In the present study, respondents were prompted with "Imagine that you were asked to teach a 2-week unit on evolution. What priority would you give to including each of the following possible topics?" and asked to answer with "A high priority," "A medium priority," "Not necessary," or "Should not be covered." (A similar question was used in a similar survey of climate change educators in 2014–2015, although different topics relevant to climate science were used: see Plutzer et al. 2016 for details.) We report the answers for five topics.

First, the common ancestry of all life. (Since universal common ancestry is the maximal case of macroevolution, common ancestry can be regarded as a rough proxy for macroevolution.) As Fig. 7 shows, the responding teachers (N = 684) generally put a high or medium priority on teaching common ancestry: 97% of them do so. As the left-hand panel of Fig. 8 shows, increased evolution coursework significantly increases the odds a teacher will rank teaching common ancestry as a high priority. Specifically, the odds of ranking teaching the common ancestry of all life as a high priority increased by 20% for each additional evolution-focused class and by 16% for each additional evolution-containing class.

Second, the shared ancestry of humans with the rest of life. (Since shared ancestry of humans with the rest of life is a presupposition of human evolution, shared ancestry can be regarded as a rough proxy for human evolution.) As Fig. 7 shows, the responding teachers (N = 678) generally put a high or medium priority on teaching the shared ancestry of humans with the rest of life: 89%, about split between high and medium priority. As the right-hand panel of Fig. 8 shows, increased coursework of evolution-focused classes and PBL methods classes significantly increases the probability of putting a high priority on teaching shared ancestry. Specifically, the odds of ranking the shared ancestry of humans with the rest of life as a high priority increased by 23% for each additional evolution-focused class and by 20% for each additional PBL methods class. (Recall, however, that increased coursework on PBL methods classes was significantly associated with increased probability of sending mixed messages about evolution.) Increased coursework on methods classes in general and increased coursework on TCT methods classes, however, are associated, although not quite

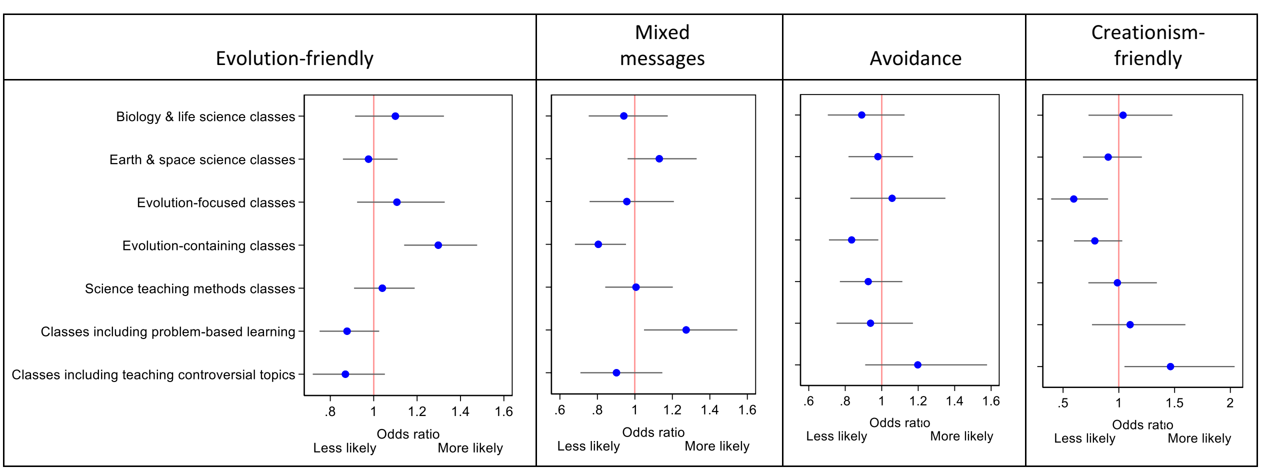

Fig. 6 Effect of coursework on the odds of teaching typology placement. The left panel shows the distribution of the dependent variable. The right panel shows the estimates from four independently estimated binary logit models. The filled circles represent the estimated effect of each independent variable, and the horizontal lines show the 95% confidence interval. The vertical reference line represents the null hypothesis of no effect (an odds ratio of 1.0). An effect is significant at the 0.05 level whenever the confidence interval does not intersect the reference line. Full results are reported in Appendix Table 4

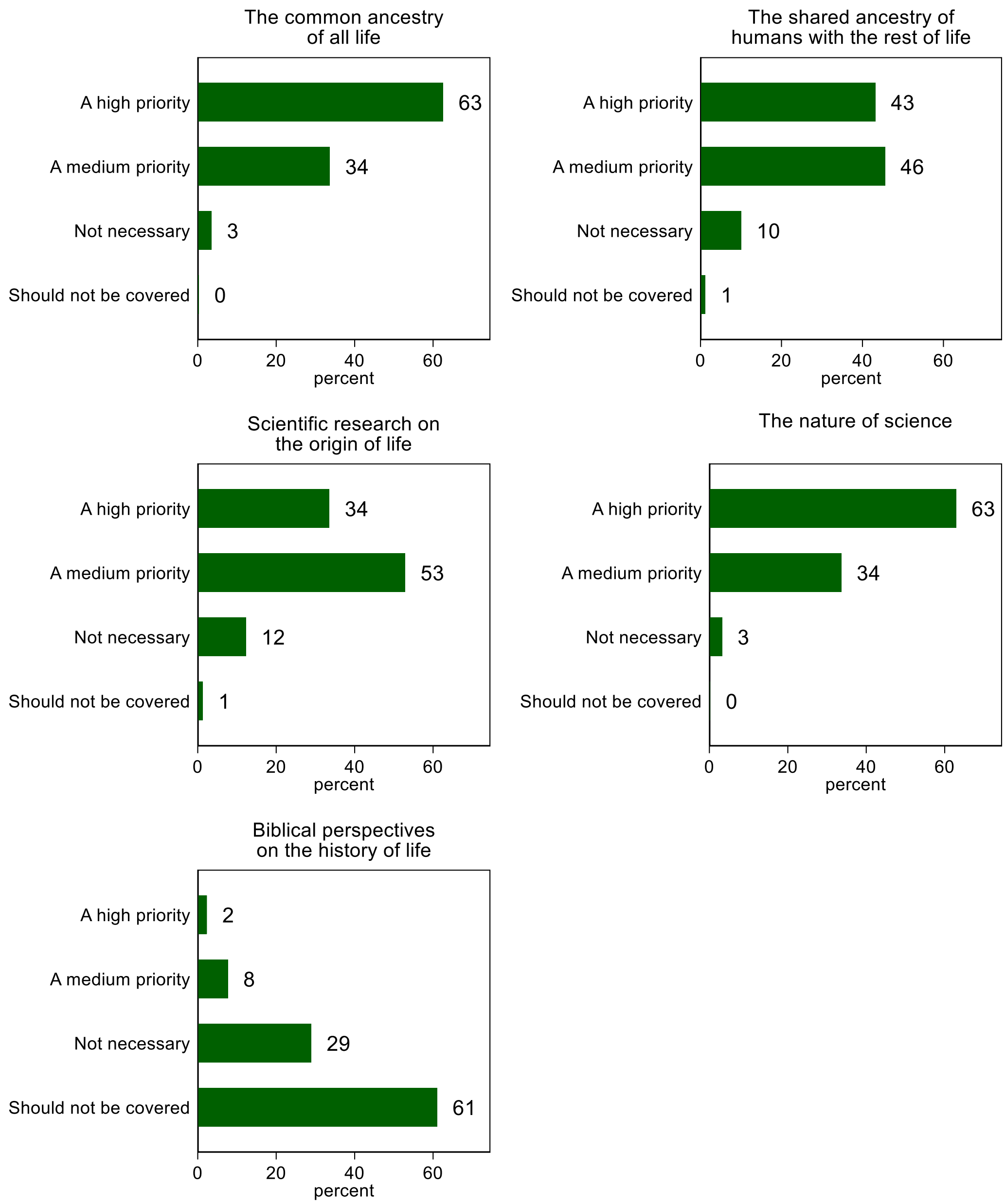

Fig. 7 Priorities of teachers for a two-week unit on evolution

significantly, with a lower probability of ranking teaching shared ancestry as a high priority. Specifically, the odds of ranking the shared ancestry of humans with the rest of life as a high priority decreased by 10% for each additional methods class (with $p=0.09$) and by 15% for each additional TCT methods classes (with $p=0.06$).

Third, scientific research on the origin of life. As Fig. 7 shows, the responding teachers (N=662) generally put a high or medium priority on teaching the origin of life, but the medium priority predominates. As the left-hand panel of Fig. 9 shows, increased coursework of evolution-focused classes (but not evolution-containing classes) and ESS classes significantly increases the probability of putting a high priority on teaching the origin of life. Specifically, the odds of ranking teaching the origins of life as a high priority increased by 20% for each additional evolution-focused class and by 16% for each additional ESS class. (The latter result is not surprising in light of the

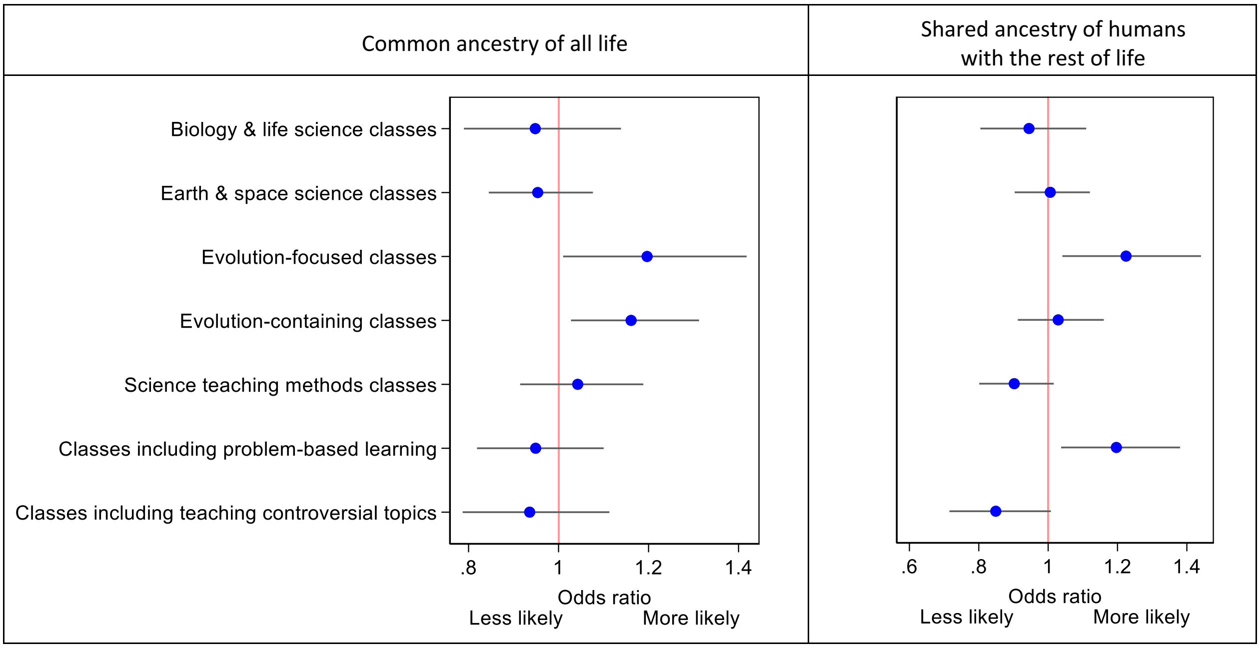

Fig. 8 Effect of coursework on the odds of prioritizing the concepts of common ancestry and shared ancestry of humans. The figure shows the estimates from two independently estimated binary logit models. The filled circles represent the estimated effect of each independent variable on the odds of designating a topic a "high priority," and the horizontal lines show the 95% confidence interval. The vertical reference line represents the null hypothesis of no effect (an odds ratio of 1.0). An effect is significant at the 0.05 level whenever the confidence interval does not intersect the reference line. Full results are reported in Appendix Table 5

close association between origin-of-life research and ESS topics such as deep time, the early history of the earth, and geochemistry.)

Fourth, the nature of science, which in U.S. science education means basically a targeted selection of topics in the history and philosophy of science (see, e.g., Appendix H of the Next Generation Science Standards: NGSS Lead States 2013). As Fig. 7 shows, the responding teachers (N = 675) generally put a high or medium priority on teaching the nature of science: 97%, of which the majority is a high priority. As the middle panel of Fig. 9 shows, there is minimal variation here and no strong effect visible, with none of the effects reaching significance at the 0.05 level.

Fifth, we asked whether "Biblical perspectives on the history of life" merited inclusion. No definition of "Biblical perspectives" or indication of whether they should be presented positively, neutrally, or negatively was presented on the questionnaire. As Fig. 7 shows, most of the responding teachers (N = 639) regarded it as unnecessary or unwelcome to include such perspectives—90% in all—which suggests that they understand the inclusion of such perspectives as more likely to be motivated by a desire to proselytize than by the intention to present historical or cultural context. It is unclear, however, how the remaining 10% of the responding teachers construe the purpose of including such perspectives. (It is suggestive that among those who prioritize Biblical perspectives, nearly half, 49%, reported emphasizing the scientific credibility of creationism.) As the right-hand panel of Fig. 9 shows, increased coursework of evolution-focused and evolution-containing classes significantly decreased the probability of putting a high priority on Biblical perspectives, while increased coursework of PBL methods classes significantly increased it. Specifically, the odds of ranking teaching Biblical perspectives on the history of life as a high priority decreased by 23% for each additional evolution-focused class and by 17% for each additional evolution-containing class but increased by 30% for each additional PBL methods class.

To summarize the important results with regard to emphasis on specific topics related to evolution: coursework of evolution-focused and evolution-containing classes is often significantly associated with putting high priority on topics that deserve high priority and not on items that do not deserve it. Methods coursework, whether methods classes in general, PBL methods

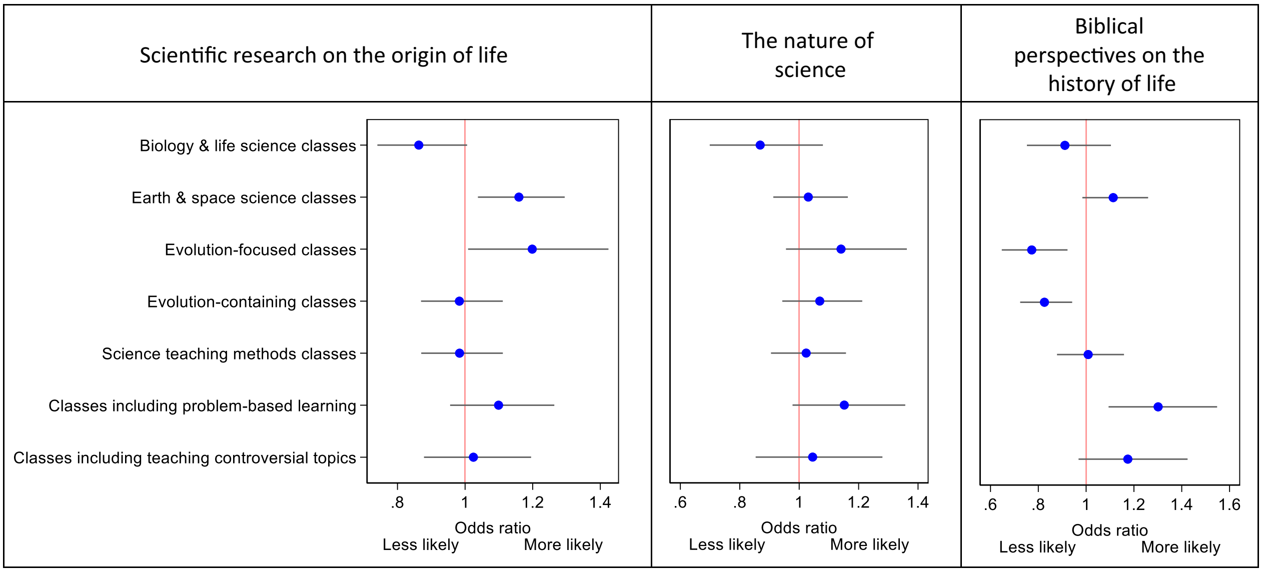

Fig. 9 Effect of coursework on the odds of prioritizing the concepts of the origin of life, the nature of science, and Biblical perspectives. The figure shows the estimates from two independently estimated binary logit models. The filled circles represent the estimated effect of each independent variable on the odds of designating a topic a "high priority," and the horizontal lines show the 95% confidence interval. The vertical reference line represents the null hypothesis of no effect (an odds ratio of 1.0). An effect is significant at the 0.05 level whenever the confidence interval does not intersect the reference line. Full results are reported in Appendix Table 5

classes, and TCT methods classes, is generally not significantly associated with putting high priority on any of these topics, except that coursework on PBL methods classes was significantly associated with putting high priority on the shared ancestry of humans with the rest of life and on Biblical perspectives on the history of life. These heterogeneous and seemingly contradictory effects may reflect a lack of standardization in how PBL is introduced and explained to pre-service teachers, or it could be due to introductions so superficial that future educators interpret the goals of PBL in ways that reinforce their prior values.

Discussion

Coursework promoting deeper content knowledge with regard to evolution

Coursework focused on evolution was significantly associated with positive outcomes: more class hours devoted to evolution, lack of friendliness to creationism, and prioritizing common ancestry, human evolution, and the origin of life as topics of instruction, while shunning Biblical perspectives on the history of life. Similarly, coursework with some evolution content was significantly associated with positive outcomes: awareness of the scientific consensus, friendliness to evolution, and prioritizing common ancestry as a topic of instruction. These results were broadly in accord with our expectations.[5]

Coursework expected to promote pedagogical effectiveness with regard to evolution

Surprisingly, methods coursework on problem-based learning was significantly associated with negative outcomes: presenting mixed messages and prioritizing Biblical perspectives on the history of life as a topic of instruction. (It was significantly associated also with a positive outcome: prioritizing human evolution as a topic of instruction). Similarly, and likewise surprisingly, methods coursework on teaching controversial topics was associated with a negative outcome: friendliness to creationism. Both are thus associated with the negative outcome of presenting creationism as scientifically credible.

[5] It might appear surprising that there is so little overlap between the two sets of positive outcomes. But again, because double-counting was allowed, any class counted as evolution-focused would also be counted as evolution-containing. So, the actual relevant result is that increased evolution-focused coursework *insofar as it goes beyond evolution-containing coursework* is not significantly associated with a greater chance of being aware of the scientific consensus on evolution or with friendliness to evolution, suggesting that a relatively brief exposure to evolution is helpful in producing these positive outcomes but further exposure is not. We are grateful to a reviewer for asking a question that prompted this clarification.

It is useful to note that teachers appear to receive instruction on effective implementation of problem-based learning and guidance on how to teach controversial topics in the same classes. Among our sample, 60% of those reporting PBL methods coursework also reported TCT methods coursework; and nearly four in five (79%) of those reporting TCT methods coursework also reported PBL methods coursework. For this reason, we believe the surprising findings are connected and require a single explanation.

One potential explanation is self-selection: perhaps religiously conservative or politically conservative students deliberately seek TCT methods classes out in order to prepare themselves to navigate science education as teachers with a minority view as regards controversial topics. But when we explored this, we found the data are inconsistent with this idea: teachers reporting that they were biblical literalists or Republicans were no more likely to have taken TCT methods classes.

We then speculated that perhaps religiously affiliated institutions might offer TCT methods classes for similar reasons, to help equip their students navigate science education as teachers with a minority view. We had asked each teacher to provide the name of the institution where they received their BA or BS degree, and we used these answers to identify 98 teachers who received their degree from religiously affiliated colleges or universities. But these teachers were no more likely to take TCT methods classes than others. Moreover, when we excluded these teachers from the analysis, the negative effect of TCT coursework became slightly more negative.

Finally, we speculated that teachers who studied PBL and TCT in their pre-service methods classes could be more likely to come away committed to introducing inquiry-based methods without having a sufficient appreciation of the role in guidance in using such methods effectively. The emphasis in problem-based and inquiry-based learning on the role of students in actively constructing their own scientific knowledge may discourage teachers from acting as "the main repository of knowledge" (Hmelo-Silver 2004, p. 239) by offering any, or more than minimal, guidance: in the present case, by authoritatively dismissing creationism as not scientifically credible and Biblical perspectives on the history of life as irrelevant to teaching evolution. But in fact, guidance remains important in these pedagogical approaches for a variety of reasons and in different ways (see Vorholzer and von Aufschnaiter 2019 for a discussion). And given the importance of students coming to understand the status of evolution as a central, unifying, and unrivaled principle of science, it is appropriate for educators using these approaches while teaching evolution to guide their students to conclusions consistent with the foundational principles.

To explore the possibility that a misunderstanding of PCP and TCT methods coursework leads to the negative outcomes, we draw on a different portion of the survey that asks specifically how teachers navigate controversy. We prompted teachers by first noting, "Some teachers tell us that they acknowledge that evolution is controversial and adopt particular strategies in teaching it." We than asked them to "Tell us about your approach to each of the following: … Give equal time to perspectives that raise doubt about evolution." Giving equal time to creationism is the epitome of ceding authority to advocates of non-scientific alternatives to evolutionary biology. Here we focus on teachers who reported "I have done this." Fig. 10 reports the percentage who report giving "equal time" to both sides, broken down by the number of classes with PBL (in the left-hand panel) and TCT (in the right-hand panel) methods classes. The results are quite clear: teachers reporting a high number of classes covering these topics are more than twice as likely to give "equal time" to non-scientific alternatives.

The implication is that some pre-service teachers, especially those with multiple exposures to problem-based learning in the context of teaching controversial topics, are drawing lessons that lead them as in-service teachers to miseducate their students about evolution on the basis of their understanding of these pedagogical approaches. To be clear, such pedagogical approaches, properly understood, are fully compatible with presenting evolution as a central, unifying, and unrivaled principle of science; the question is whether they are properly understood. Future research would usefully probe in-service science teachers to learn how they understand the advantages and disadvantages of problem-based learning and whether and if so, how they structure inquiry by providing students with facts and skills before inquiry exercises.

Relation to prior research

With three exceptions, the results of the present study confirm the results of the prior work discussed above (viz., Aguillard 1999; Benson 2021; Berkman et al. 2008; Berkman and Plutzer 2011; Rutledge and Mitchell 2002; Toro 2018), in the sense that for every significant result found in the prior research and addressed in the present study, a corresponding significant result was found.

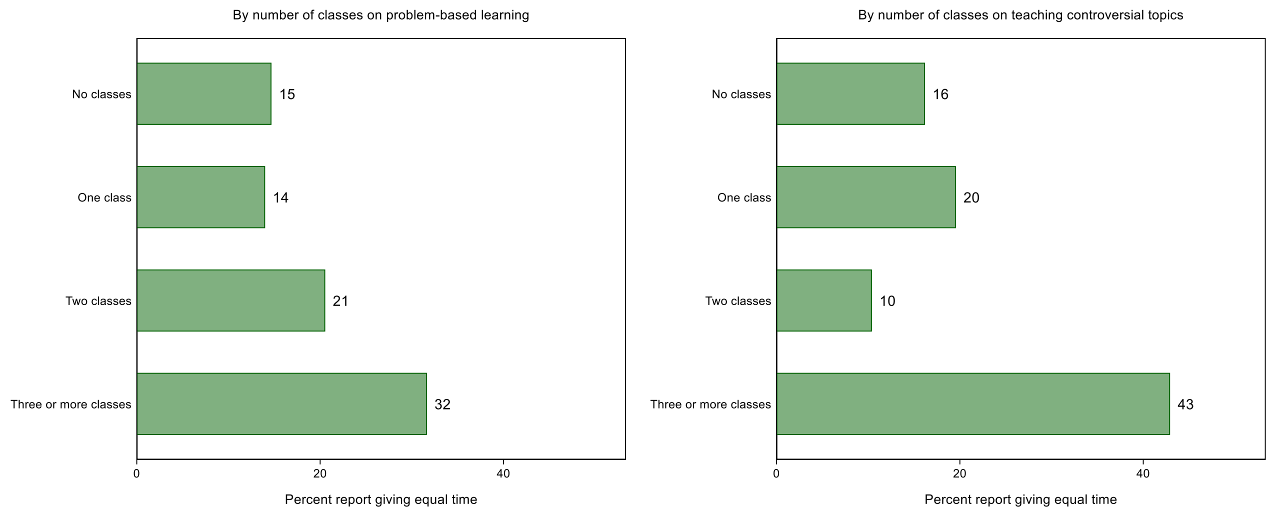

Fig. 10 Proportion of teachers reporting they have given "equal time to perspectives that raise doubt about evolution," by number of methods classes including problem-based learning (left) and teaching controversial topics (right)

The first exception is that we did not find any significant association between increased coursework in biology and any of the dependent variables, contrary to Aguillard (1999) and Rutledge and Mitchell (2002). We suspect that this is due to our asking more specific questions about classes with evolution content: once we account for the effects of these, additional classes in biology in general seem not to affect evolution instruction.

The second exception is that we did not find any significant association between personal acceptance of evolution and any aspect of pre-service coursework, contrary to Rutledge and Mitchell (2002) and Toro (2018). The discrepancy between the present study and the previous studies may be owing in part to the paucity of creationists (10.5%) in our sample as compared to Rutledge and Mitchell's[6] and in part to the different instruments used. The Gallup instrument specifically asks about "your views," while the instruments used by Rutledge and Mitchell and by Toro may have been interpreted by respondents as asking not about their personal views but about whether evolution is regarded by the scientific community as credible. As Sickel and Friedrichsen (2013) note, "Studies reporting findings that differentiate between acceptance items reveal… [that] teachers tend to accept the notion that evolution is valid within the scientific community more than other items." For example, Moore and Kraemer (2005) found that among a sample of Minnesota high school biology teachers none disagreed with "Most scientists believe that the modern theory of evolution is scientifically valid" while 16% answered no to "Do you think that the modern theory of evolution has a valid scientific foundation?".

The third exception is that we did not find any significant association between increased coursework in evolution-containing classes and increased instructional time devoted to evolution, contrary to Aguillard (1999), which found that 56% of Louisiana teachers who reported having taking three or more evolution-containing classes also reported devoting more than five class hours to evolution, as opposed to only 43% of teachers who reported having taken fewer than three evolution-containing class. We suspect that the increasing presence of evolution in state science standards since 1999 is largely responsible for decreasing variance in instructional time devoted to evolution.[7]

Limitations of the present study and suggested directions for future research

The results of the present study rely on the respondents' answers to the questions on the survey, which introduces various possible sources of uncertainty and bias. First, as with any survey questionnaire, different respondents

[6] Although Rutledge and Mitchell didn't include the Gallup instrument in their questionnaire, the fact that preference for the creationist option significantly declined in the U.S. population between 2001 and 2019 (Brenan 2019) and among public high school teachers between 2007 and 2019 (Plutzer et al. 2020) suggests that their sample would have included a higher percentage of teachers preferring the creationist option than ours did. But the same is not true of Toro's (2018) sample.

[7] In the case of Louisiana in particular, the 1997 high school state science standards for biological evolution in place when Aguillard conducted his survey consisted, in their entirety, of only 25 words (quoted in Lerner 2000, p. 21), while just the performance expectations of the 2017 high school state science standards for biological evolution in place now occupy 170 words (Louisiana Department of Education 2017, pp. 16–20).

might have interpreted the questions differently.[8] Second, there may have been a social desirability bias, with teachers tending to overreport the extent and the rigor of their coursework in an attempt (conscious or more likely unconscious) to impress the researchers. Third, there may have been a response bias, with more dedicated and diligent teachers being more likely to complete the survey and teachers with ideological objections to evolution (or climate change) less likely to do so. Fourth, there may have been, especially with the more senior teachers, a failure to remember the details of pre-service coursework accurately.

But the most important limitation of the present study is its inability to ascertain the causes underlying the results. Although it is clear that PBL and TCT methods coursework was significantly associated with negative outcomes, particularly presenting creationism as scientifically credible, it is not clear to what extent taking these types of methods classes disposes teachers to be more likely to be ineffective evolution educators and to what extent teachers who are disposed to be ineffective evolution educators are more likely to take these types of methods classes. By the same token, although it is clear that evolution coursework is significantly associated with positive outcomes, it is not clear to what extent studying evolution disposes teachers to be more likely to be effective evolution educators and to what extent teachers who are disposed to be effective evolution educators are more likely to study evolution.

In order to surmount these limitations, it would be useful to secure further details about the pre-service coursework of the respondents to the survey. It would be difficult to do so by examining the syllabi or interviewing the instructors of their classes, especially in the case of the more senior teachers, but it would be feasible to conduct structured interviews with a sample of the respondents (or perhaps of the younger respondents only) in order to attain a better understanding of their pre-service coursework.

Also worthy of future research would be investigating where and how PBL and TCT methods coursework is provided. In general, methods coursework seems to be more often provided by instructors with primary expertise in education rather than science and in colleges of education rather than in colleges of science. We speculate that these differences may play a role in explaining the surprising results with regard to such coursework. Instructors with a background in science addressing classes that include aspiring scientists may tend to emphasize the scientific consensus on evolution and minimize the social controversy over evolution more than instructors without a background in science addressing classes that include aspiring educators. But we were unable to identify any definitive research about this issue.

In any case, it appears that in their pre-service PBL and TCT methods coursework, pre-service teachers are either not learning what they're being taught or not being taught what they should about how to teach evolution effectively: either way, the consequence is that they are not teaching evolution as effectively as they should—especially by presenting creationism as scientifically credible—when they're in service. Hence it would be particularly valuable for instructors of methods classes to investigate, using pre-testing and post-testing, ideally both immediately after the class and then later when their students are in-service teachers, to ascertain what content and instructional techniques in their own classes result in their students teaching evolution effectively in their own classrooms.

Conclusion

The results of the present study confirm that pre-service coursework in evolution is important in preparing educators to teach evolution effectively. Requiring pre-service teachers to take even a single more evolution-containing class more than they are presently required to take would make a measurable difference for the better, although only evolution-focused coursework was associated with increased instructional time devoted to evolution. But the present study also suggests, surprisingly, that pre-service methods coursework aimed at preparing educators to teach evolution effectively tends, at present, to be counterproductive, especially insofar as it results in educators presenting creationism as scientifically credible. Systematic investigation of how methods classes present problem-based learning and ways of teaching controversial topics, followed by appropriate reforms, is clearly in order.

Appendix

See Tables 1, 2, 3, 4, 5.

Tables reporting full results that underlay coefficient plots.

[8] It is entirely conceivable that two respondents who took the very same content class in oceanography, for example, might differ in their views of whether it ought to be counted as an ESS class or not, or that two respondents who took the very same methods class that discussed inquiry-based learning might differ in their views of whether it ought to be counted as a methods class that discussed problem-based learning or not. Similarly, when asked about what topics they would prioritize if asked to teach a two-week unit on evolution, some respondents may have been imagining an ideal situation, in which none of the constraints of time, expense, resources, or community pressure might apply, while others may have been imagining a more realistic situation: their prioritization of topics may have varied as a consequence.

Table 1 Multinomial logistic regression estimates predicting evolution beliefs (results used to generate Fig. 2)

	Humans evolved. God had no part in the process			God created humans in the last 2000 years		
	ß	Std Err	p	ß	Std Err	p
College courses in biology	− 0.007	(0.103)	0.947	0.025	(0.168)	0.880
College courses in earth sciences	0.022	(0.065)	0.730	0.036	(0.113)	0.751
College courses in science teaching methods	− 0.013	(0.067)	0.850	− 0.078	(0.110)	0.480
College courses focused on evolution	0.121	(0.087)	0.163	− 0.229	(0.188)	0.222
College courses with some evolution	0.091	(0.069)	0.189	− 0.050	(0.113)	0.657
Methods courses covering PBL	− 0.121	(0.086)	0.158	0.009	(0.116)	0.935
Methods courses covering controversial topics	− 0.021	(0.099)	0.831	0.129	(0.154)	0.400
Under 10 years seniority						
10–19 years seniority	0.046	(0.239)	0.848	1.537	(0.523)	0.003*
20+ years seniority	− 0.292	(0.246)	0.236	1.382	(0.524)	0.009*
Female	− 0.209	(0.186)	0.262	− 0.198	(0.295)	0.502
Not based upon NGSS						
Based upon NGSS	0.267	(0.236)	0.257	0.198	(0.358)	0.581
Adopted NGSS	0.421	(0.230)	0.067	− 0.099	(0.393)	0.802
Constant	0.006	(0.494)	0.991	− 2.203	(0.931)	0.018*
N	661					

*$p < 0.05$

Table 2 Binary logistic regression estimates predicting knowledge that more than 80% of scientists accept evolution (results used to generate Fig. 3)

	ß	Std Err	p
College courses in biology	− 0.092	(0.105)	0.383
College courses in earth sciences	− 0.052	(0.068)	0.445
College courses in science teaching methods	0.160	(0.071)	0.024*
College courses focused on evolution	0.074	(0.091)	0.413
College courses with some evolution	0.210	(0.071)	0.003*
Methods courses covering PBL	− 0.156	(0.082)	0.056
Methods courses covering controversial topics	− 0.173	(0.102)	0.090
Under 10 years seniority (omitted)			
10–19 years seniority	0.287	(0.235)	0.223
20+ years seniority	0.328	(0.246)	0.183
Female	− 0.135	(0.191)	0.480
Not based upon NGSS (omitted)			
Based upon NGSS	0.420	(0.227)	0.065
Adopted NGSS	0.434	(0.230)	0.059
Constant	0.394	(0.509)	0.439
N	694		

*$p < 0.05$

Table 3 Ordinary least squares regression estimates predicting number of hours devoted to human evolution and general evolution (results used to generate Fig. 4)

	Hours		
	ß	**Std Err**	***p***
College courses in biology	0.225	(0.521)	0.666
College courses in earth sciences	− 0.294	(0.319)	0.357
College courses in science teaching methods	0.073	(0.324)	0.821
College courses focused on evolution	1.043	(0.456)	0.023*
College courses with some evolution	0.602	(0.329)	0.068
Methods courses covering PBL	− 0.066	(0.403)	0.869
Methods courses covering controversial topics	0.703	(0.534)	0.189
Under 10 years seniority (omitted)			
10–19 years seniority	− 0.771	(1.191)	0.518
20+ years seniority	− 0.398	(1.124)	0.723
Female	0.458	(0.934)	0.624
Not based upon NGSS (omitted)			
Based upon NGSS	0.942	(1.092)	0.389
Adopted NGSS	3.582	(1.096)	0.001*
Constant	11.231	(2.379)	0.000*
R^2	0.057		
N	688		

*$p < 0.05$

Table 4 Binary logistic regression estimates predicting typology classification (each model estimated independently; results used to generate Fig. 6)

	Evo-friendly ß/se/p	Mixed ß/se/p	Avoidance ß/se/p	Creationism ß/se/p
College courses in biology	0.095	− 0.061	− 0.116	0.037
	(0.094)	(0.113)	(0.119)	(0.181)
	0.312	0.592	0.331	0.836
College courses in earth sciences	− 0.024	0.123	− 0.021	− 0.100
	(0.066)	(0.083)	(0.092)	(0.147)
	0.713	0.139	0.817	0.495
College courses in science teaching methods	0.039	0.006	− 0.077	− 0.013
	(0.068)	(0.091)	(0.094)	(0.156)
	0.567	0.947	0.413	0.935
College courses focused on evolution	0.102	− 0.044	0.055	− 0.518
	(0.092)	(0.119)	(0.124)	(0.212)
	0.271	0.712	0.656	0.015*
College courses with some evolution	0.261	− 0.217	− 0.18	− 0.242
	(0.066)	(0.086)	(0.082)	(0.139)
	0.000*	0.012*	0.029*	0.082
Methods courses covering PBL	− 0.131	0.242	− 0.063	0.096
	(0.079)	(0.099)	(0.113)	(0.189)
	0.100	0.015*	0.575	0.611
Methods courses covering controversial topics	− 0.14	− 0.103	0.18	0.381
	(0.097)	(0.122)	(0.140)	(0.169)
	0.150	0.398	0.199	0.024*
Under 10 years seniority (omitted)				
10–19 years seniority	− 0.693	0.271	1.01	0.288
	(0.252)	(0.319)	(0.385)	(0.574)
	0.006*	0.396	0.009*	0.616
20+ years seniority	− 0.482	− 0.118	0.965	0.297
	(0.259)	(0.342)	(0.379)	(0.543)
	0.063	0.73	0.011*	0.585
Female	0.038	− 0.046	0.125	− 0.346
	(0.185)	(0.246)	(0.260)	(0.374)
	0.837	0.853	0.631	0.355
Not based upon NGSS (omitted)				
Based upon NGSS	− 0.069	− 0.009	0.004	0.366
	(0.223)	(0.295)	(0.305)	(0.416)
	0.756	0.976	0.990	0.379
Adopted NGSS	0.107	0.013	− 0.251	0.109
	(0.228)	(0.299)	(0.304)	(0.541)
	0.638	0.965	0.410	0.841
Constant	0.287	− 1.743	− 1.643	− 2.223
	(0.470)	(0.602)	(0.572)	(0.914)
	0.542	0.004*	0.004*	0.015*
N	708	708	708	708

*$p < 0.05$

Table 5 Ordinal logistic regression estimates predicting prioritization of topics in a hypothetical two-week unit on evolution (each model estimated independently; results used to generate Figs. 8 and 9)

	Common ß/se/p	**Shared ß/se/p**	**Origins ß/se/p**	**Nature ß/se/p**	**Biblical ß/se/p**
College courses in biology	− 0.053	− 0.057	− 0.147	− 0.141	− 0.093
	(0.093)	(0.082)	(0.078)	(0.111)	(0.098)
	0.569	0.489	0.06	0.204	0.341
College courses in earth sciences	− 0.047	0.006	0.148	0.03	0.107
	(0.062)	(0.055)	(0.056)	(0.062)	(0.063)
	0.442	0.911	0.009*	0.625	0.088
College courses in science teaching methods	0.042	− 0.103	− 0.017	0.023	0.009
	(0.067)	(0.061)	(0.062)	(0.063)	(0.071)
	0.532	0.09	0.791	0.711	0.904
College courses focused on evolution	0.18	0.203	0.181	0.132	− 0.258
	(0.086)	(0.083)	(0.088)	(0.090)	(0.090)
	0.038*	0.015*	0.039*	0.145	0.004*
College courses with some evolution	0.149	0.029	− 0.017	0.067	− 0.192
	(0.062)	(0.061)	(0.063)	(0.064)	(0.067)
	0.017*	0.64	0.785	0.295	0.004*
Methods courses covering PBL	− 0.052	0.18	0.094	0.141	0.263
	(0.075)	(0.073)	(0.071)	(0.084)	(0.088)
	0.488	0.014*	0.185	0.091	0.003*
Methods courses covering controversial topics	− 0.066	− 0.164	0.024	0.044	0.161
	(0.088)	(0.087)	(0.078)	(0.103)	(0.098)
	0.453	0.061	0.757	0.668	0.102
Under 10 years seniority (omitted)					
10–19 years seniority	0.256	− 0.149	− 0.402	0.353	0.344
	(0.222)	(0.208)	(0.221)	(0.227)	(0.252)
	0.249	0.474	0.069	0.121	0.173
20+ years seniority	0.066	− 0.256	− 0.305	0.441	0.425
	(0.218)	(0.198)	(0.215)	(0.223)	(0.252)
	0.761	0.196	0.156	0.049*	0.092
Female	0.06	0.317	0.254	0.068	0.042
	(0.177)	(0.165)	(0.168)	(0.178)	(0.185)
	0.734	0.056	0.132	0.704	0.821
Not based upon NGSS					
Based upon NGSS	− 0.274	− 0.146	− 0.14	− 0.04	− 0.113
	(0.213)	(0.204)	(0.212)	(0.214)	(0.217)
	0.198	0.474	0.51	0.852	0.604
Adopted NGSS	− 0.077	0.248	− 0.046	0.124	− 0.344
	(0.216)	(0.208)	(0.202)	(0.217)	(0.235)
	0.72	0.233	0.821	0.569	0.143
Cut1	− 5.46	− 4.383	− 4.483	− 5.435	0.247
	(0.721)	(0.519)	(0.551)	(0.855)	(0.456)
	0.000*	0.000*	0.000*	0.000*	0.588
Cut2	− 3.016	− 2.049	− 1.917	− 2.635	2.157
	(0.484)	(0.422)	(0.399)	(0.512)	(0.476)
	0.000*	0.000*	0.000*	0.000*	0.000*
Cut3	− 0.169	0.329	0.709	0.165	3.709
	(0.446)	(0.425)	(0.408)	(0.488)	(0.626)
	0.704	0.438	0.082	0.735	0.000*
N	684	678	662	675	639

*$p < 0.05$

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Author contributions
EP was responsible for all fieldwork, data collection and data analysis, contributed to questionnaire content, and collaborated in the writing of the manuscript. GB and AR contributed to questionnaire content and collaborated in the writing of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The questionnaire, replication data set, codebook, and code to replicate all tables and figures will be made available at https://dataverse.harvard.edu/dataverse/2019_Science_Teachers/ no later than 12 months after publication. Investigators may request access to these materials sooner.

Declarations

Ethics approval and consent to participate
This project involved voluntary participation in a survey. The procedures and recruitment materials were reviewed by the IRB at Penn State University (study #00011249) and declared exempt.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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