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Predicting evolution acceptance among religious students using the predictive factors of evolution acceptance and reconciliation (*p*FEAR) instrument

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Abstract

Evolution is one of the controversial topics in biology primarily because of the perceived conflict between religion and evolution. Religiosity is one of the biggest predictors of evolution acceptance, i.e., the more religious an individual, the less accepting they are of evolution. Most students in the United States are religious, so how evolution is taught in the classroom is essential for a more inclusive experience. However, educators do not have a way to measure what factors influence students' evolution acceptance. We developed a survey instrument with validity evidence called the "predictive Factors of Evolution Acceptance and Reconciliation" (*p*FEAR). Using this measure, with data from eight religiously affiliated institutions in the United States, educators can understand how their religious and scientific worldview factors influence their students' views on evolution acceptance. Our study showed that religious influence was the most statistically significant predictor of evolution acceptance among religious students by a factor of 2, when compared to students scientific worldviews and the perceived conflict between science and religion. It also showed that perceived conflict between science and religion and being influenced by science were significant positive predictors of evolution acceptance. Further, this study identifies ways educators can use the *p*FEAR in the classroom to better understand their student's views and better modify how they approach teaching evolution in their classroom.

Introduction

A 2019 national survey of over 2,700 adults in United States were asked if they agreed with the phrase "Human beings, as we know them, developed from earlier species of animals"; 54% agreed, 37% disagreed, and 12% were unsure (Miller et al. 2022). This shows an increase in evolution acceptance from 15 years earlier, when 40% agreed, 40% disagreed, and 20% were unsure. Even with the increase of evolution acceptance in the United States, they still have one of the lowest acceptance rates of evolution in the world (J. D. Miller 2006). Some studies have even shown that when the word "human" is removed from the question, evolution acceptance changes. For example, a Gallup (2009) survey asked participants whether they accepted the evolution of organisms without a specific reference to humans. The results showed that rejection dropped to 25%. This difference between the acceptance of human evolution versus other organisms illustrates the complex, multifaceted

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nature of evolution acceptance (Barnes et al. 2017a, b; Dunk 2019; Rutledge and Warden 2000; Wiles and Alters 2011; Winslow et al. 2011). And this complexity further complicates how educators approach the topic in their classrooms. Our research aims to inform instructional practices by offering insight into the factors influencing the acceptance of human evolution.

Predictors of evolution acceptance

Understanding what factors influence evolution acceptance is complicated because there are many variables that influence evolution acceptance. For example, some studies have found that evolution knowledge, cognitive dispositions, epistemological beliefs, and open-mindedness have been shown to predict evolution acceptance in some studies (Dunk et al. 2017; Ingram and Nelson 2006; Nadelson and Sinatra 2009; Sinatra et al. 2003), but lacked statistical significant in other studies (Bishop and Anderson 1990; Dunk et al. 2017). In this study, we focus on three evolution acceptance predictors that when compared to other factors, explain more variance in evolution acceptance models: religiosity, nature of science, and perceived conflict between religion and evolution (Barnes et al. 2021a, b; Dunk et al. 2017; Manwaring et al. 2015). We believe continuing to understand the influence that religiosity, nature of science, and perceived conflict has among our students is still a worthy cause and has a large impact on how evolution is taught.

With many of the students in our classrooms being religious (Barnes et al. 2017a, b; Pew 2015), understanding the role religion plays in their life, is important. In our study, we define the role that religion in an individual's life as ones level of commitment to their religious practices and beliefs, or religiosity (Cornwall et al. 1986). One study found that religiosity was negatively correlated with pre-course and post-course evolution acceptance scores (Carter and Wiles 2014). Other studies found similar patterns—as religiosity increased evolution acceptance decreased (Barnes et al. 2019; Dunk et al. 2017; Glaze et al. 2015; Rissler et al. 2014). Because of this strong correlation, some scientists have argued that religion is the biggest barrier to accepting evolution and religion being the main problem should be removed (Coyne 2012). However, some studies have shown that removing an individual's beliefs, may not be necessary given that an individual can be religious and still accept evolution (Barnes et al. 2021a, b; Ferguson and Jensen 2021; Ferguson et al. 2022; Winslow et al. 2011). There are even studies that show specific religious denomination having different levels of evolution acceptance and even different races with different religious beliefs have different level of acceptance (Ferguson and Jensen 2021; Lindsay et al. 2019; Pew 2015). It seems that it is not some much as strictly removing religious beliefs from our students, but how we approach teaching evolution to religious students that may be more helpful. Since religion is still a big part of many students' identity, understanding how religious beliefs influence someone's evolution acceptance is important and is not yet fully understood.

Perceived conflict between someone's religious beliefs and the theory of evolution is another factor that may influence whether someone accepts evolution or not. A recent study by Barnes et al. (2021a, b), found that a students perceived conflict between evolution and belief in God was a stronger predictor of evolution acceptance than religiosity alone. Other studies have also documented from interviews that many students held a perceived conflict between evolution and their belief in god (Barnes et al. 2017a, b; Winslow et al. 2011), although some students reported a decrease in their perceived conflict over a semester, while increasing their evolution acceptance. Evidence also suggests that students who claimed that evolution conflicted with their personal cultures, values, and beliefs, were less accepting of evolution compared to students with low personal conflict with evolution (Sbeglia and Nehm 2020). Understanding how conflict with evolution connects to students' worldviews is something that is lacking and more research will beneficial.

The other strong predictor that influences evolution acceptance is the Nature of Science (NOS) as students better understand how science is done—how scientists make observations, create hypotheses, obtain knowledge, and interpret data—they become more accepting of evolution. One study by Dunk et al. (2017) showed that the when compared to cognitive factors such as thinking dispositions and openness to experience, students' understanding of the Nature of Science (NOS) and a student's religiosity where the most significant predictors of evolution acceptance. A different study found similar results as they found that students' changes in evolution acceptance were positively correlated with changes in their understanding of the NOS (Carter and Wiles 2014). How understanding students' are by the processes of science or how influenced they are by science may have an impact on how they view and accept controversial like evolution.

Bridging science and religious worldviews

A worldview is defined as someone's views or conceptions of the world. Cobern (1996) defined a student's worldview as a "student's fundamental understanding of what the world is like" (Cobern 1996, p. 584) and claimed that all epistemologies are worldview presuppositions (Cobern 2000). In these definitions, science and religion influence

students' worldviews when entering a classroom, which may influence their learning about topics like evolution. One study found that students with differing worldviews will have differing views on science (Liu and Lederman 2007), which may be especially true with evolution. With a majority of students in the United States being religious (Barnes et al. 2017a, b; Pew 2015), a majority of students in science classrooms may feel differently than their instructors or scientists (Pew 2019) about evolution and may feel that evolution conflicts with their religious beliefs or worldviews (Cobern 1994; Coyne 2012; Dagher and BouJaoude 1997; Schilders et al. 2009). This may be especially troublesome for religious students who may have difficulty accepting speciation events or human evolution as it contradicts a literal interpretation of the bible. When students have conflicts with their religious worldview, it has been shown to affect their learning and evolution acceptance (Dagher and BouJaoude 1997; Downie and Barron 2000; Stanger-Hall and Wenner 2014). How instructors approach students' religious worldviews when teaching evolution is essential and can impact student learning and evolution acceptance.

Understanding the impacts of religious worldviews on evolution acceptance

One way to approach teaching evolution to students with differing worldviews is to use Religious Cultural Competence in Evolution Education (ReCCEE) practices. In their 2017 article, Barnes et al. (2017a, b) highlighted six ReCCEE practices to be used by instructors and scientists to better educate religious students about evolution that may help them maintain their religious views and accept evolution. The six culturally competent ways to teach evolution are (a) to teach the NOS, explicitly helping students understand what questions science can answer and what questions science cannot answer (Carter and Wiles 2014; Dunk et al. 2017; Rutledge and Warden 2000); (b) having a role model present in class (even if for a single class period) [this should be someone who is religious and accepts evolution (Holt et al. 2018)]; (c) acknowledging a potential conflict (Brickhouse et al. 2000; Dagher and BouJaoude 1997);(d) highlighting potential compatibility between religious worldviews and evolution (Scharmann and Butler 2015; Wiles and Alters 2011); (e) having students explore their worldviews between religion and evolution (Ferguson and Jensen 2021; Lindsay et al. 2019; Manwaring et al. 2015; Tolman et al. 2020); and (f) outlining the spectrum of viewpoints (Barnes, Elser, et al. 2017a, b; Wiles and Alters 2011). These methods have been shown to help religious students increase their evolution acceptance while decreasing the perceived conflict between science and religion.

Nevertheless, what is unknown is how influential students' religious worldviews are and how that might influence their decision-making regarding controversial topics like evolution. What is needed is a tool that teachers can use to understand how influential a student's worldview is on evolution acceptance, so teachers can modify their teaching to reflect the views of their students better. Most survey tools can tell us how accepting students are of evolution, but none can show how a religious or scientific worldview might influence a student's evolution acceptance.

Theoretical rationale

Many surveys measure evolution acceptance, although some have not considered the large religious population in the United States when validating their instruments. Instruments such as The Measure of Acceptance of the Theory of Evolution (MATE) (Rutledge and Warden 1999), The Inventory of Student Evolution Acceptance (I-SEA) (Nadelson and Southerland 2012), and Generalized Acceptance of EvolutioN Evaluation (GAENE) (Smith et al. 2016) have shown to be strong measures of evolution acceptance. Still, they have also received criticism because some measure more than evolution acceptance, such as evolution knowledge or evolution advocacy (Barnes et al. 2019). These measures can tell us if a teaching strategy led to an increase in evolution acceptance or how accepting students are of evolution at a given time in the semester. But they cannot tell us what part of a student's worldview might be preventing them from accepting evolution in the first place. Thus, we aimed to create an instrument that focused on aspects of students' religious and scientific worldviews that may influence decision-making on controversial issues that would predict student acceptance of evolution.

Our three variables that we highlighted earlier strongly correlate with evolution acceptance: religiosity, understanding the nature of science, and perceived conflict between evolution and religion. Highly religious students are typically less accepting of evolution, and less religious students are more accepting of evolution (Barnes et al. 2019; Dunk et al. 2017; Glaze et al. 2015; Rissler et al. 2014). In comparison, students who have a better understanding of the process of science are more accepting of evolution (Dunk et al. 2017). Students who perceive a conflict between evolution and religion were less accepting of evolution, and perceived conflict was a stronger predictor of evolution acceptance than religiosity. Our research aimed to create a survey that highlighted these three variables as predictors of evolution acceptance. We wanted to focus our research on how influenced a student is by their religious and

scientific worldviews and how that might predict evolution acceptance.

Our survey is different in that we wanted to measure how influenced a student is by religious beliefs, not how religious they are. Or how influenced a student is by science, not by how much they understand the nature of science. We created two variables within each of these categories *Religious Influence on Evolution* and *General Religious Influence* which measures a student's religious influence and *Scientific Influence on Evolution* and *General Scientific Influence* which measures a students' scientific influence. We also had a specific variable that looked at students perceived conflict between science and religion. Specifically for this measure, we wanted to look at how someone is religious might be influenced by their religious beliefs in general but also by stances or statements that their religion has taken on evolution. We did the same thing with a science influence. We looked at how influenced a student was about science in general, and at how influence a teacher, textbook, or peer-reviewed science articles are on their views about evolution. For example, we defined *General Religious Influence* as "Students who rely on religious beliefs for navigating controversial topics." Which used items such as *How much does religion influence your opinions on controversial issues, in general?* Or *how much do you agree with this statement: Religion influences my opinion about whether scientists should be allowed to alter human embryonic DNA.* For more details about our defined variables see Table 1; for more information on the items within each variable, see Table 2.

For our research questions, we wanted to know how a student's perceived conflict between science and religion might influence students' views on evolution acceptance. Thus, when creating our survey, we specifically asked questions about science and religion, rather than focusing specifically on the relationship between evolution and religion (Barnes et al. 2021a, b). We also wanted to know what how a scientific worldview or a religious worldview might influence a student's acceptance of evolution. Through this approach, it is thought that instructors might better know what variables act as barriers to students' evolution acceptance and can tailor their instruction accordingly. Through our survey formation:

1. We hypothesized that these variables—*Religious Influence on Evolution, General Religious Influence, Science/Religion Conflict, Scientific Influence on Evolution, and General Scientific Influence*—influence students' evolution acceptance. Specifically, we sought to examine the relationships between our latent variables (see Table 1 for definitions) and the I-SEA measured latent variables (i.e., *Macroevolution acceptance* and *Human evolution acceptance*) See Fig. 1 for the hypothesized model.
2. We hypothesized that each factor we measured (latent and manifest) would predict evolution acceptance in a biology class. We predict that these latent variables measuring religious and science influences, will follow a similar pattern as found in the literature (i.e., religiosity, nature of science, perceived conflict between evolution and religion) and give us a better understanding of influential tendencies of worldviews on evolution acceptance.

This report details the development and refinement of our measure: the predictive Factors of Evolution Acceptance and Reconciliation (*p*FEAR) [pronounced "fear," with a silent "*p*"], which measures religious worldview influences that predict evolution acceptance. By understanding the religious worldview factors influencing students' evolution acceptance, educators can better modify how they approach evolution instruction in their classrooms and include additional topics that might benefit their student's ability to overcome barriers to acceptance (e.g., a focus on the NOS).

Table 1 Definitions of our created latent variables

Latent variables	Definitions
Science/religion conflict	Students perceive a conflict between being a religious individual and being a scientist. They think some cannot be religious and a scientist
General religious influence	Students who rely on religious beliefs for navigating controversial topics
Religious influence on evolution	Students who rely on religious authority for navigating thoughts on evolution
General scientific influence	Students who rely on scientific authority for navigating controversial topics
Scientific influence on evolution	Students who rely on scientific authority for navigating thoughts on evolution

Table 2 The questions and factors loadings for the *p*FEAR instrument. All factor loadings are standardized

Questions from the inventory on student evolution acceptance—ISEA	Question included in pFEAR	Reverse coded item
Human evolution		
There is reliable evidence to support the theory that describes how humans were derived from ancestral primates	Yes	No
Although humans may adapt, humans have not/ do not evolve	No	Yes
I think that the physical structures of humans are too complex to have evolved	No	Yes
I think that humans and apes share an ancient ancestor	Yes	No
I think that humans evolve	Yes	No
Humans do not evolve; they can only change their behavior	No	Yes
The many characteristics that human share with other primates (i.e., chimpanzees, gorillas) can best be explain by our sharing a common ancestor	Yes	No
Physical variations in humans (i.e., eye color, skin color) were derived from the same processes that produce variation in other groups of organisms	No	No
Macroevolution		
I think that new species arise from ancestral species	No	No
I think that the fossil evidence that scientists use to support evolutionary theory is weak and inconclusive	No	Yes
There are a large number of fossils found all around the world that support the idea that organisms change over time	No	No
I think all complex organisms evolved from single celled organisms	Yes	No
I think that new species evolve from a lot of small changes occurring over relatively long periods of time	Yes	No
There is little or no observable evidence to support the theory that describes how one species of organism evolves from another ancestral form	No	Yes
The forms and diversity of organisms have changed dramatically over time	Yes	No
I think that all organisms are related (or share a common ancestor)	Yes	No

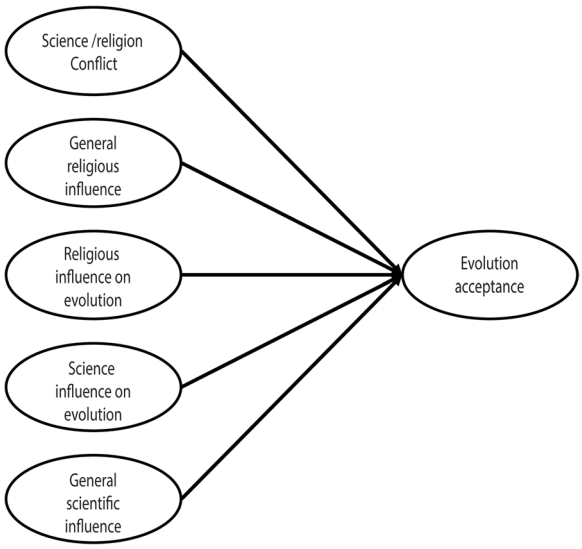

Fig. 1 The hypothesized structural equation model

Methods

Ethics statement

We acquired permission to research human subjects from the Institutional Review Board at the primary author's institution.

Survey design

The *p*FEAR was constructed and developed as a single instrument to assess religious and scientific worldview influences on evolution acceptance, as available inventories addressing religious and scientific worldviews on evolution acceptance are lacking. The main goal of the *p*FEAR is to help educators understand how students' worldviews influence their evolution acceptance. We based the *p*FEAR on prior literature from religiosity, the nature of science, and perceived conflict as a source of content validity, which helped guide the formation of items for this measure (AERA 2018).

Creation of the predictive factors of evolution acceptance and reconciliation (pFEAR)

The survey aimed to understand the perceived conflict between students' science and religious culture and how much they relied on their understanding and influences of science and religion when dealing with controversial issues. To establish content validity, we used professors (experts) in the field of biology and theology and local religious leaders from four religiously-affiliated institutions who attended a pilot workshop to reconcile religious faith with the science of evolution (see (Lindsay et al. 2019) for more details) to create this

survey. The biology and theology professors had over ten years of teaching experience helping students reconcile evolutionary thought with religious beliefs. These experts and the local religious leaders were familiar with religious barriers preventing students from accepting evolution. They collaboratively designed the survey to assess potential influences on student views about evolution (the original survey can be found in the supplementary materials). Additionally, the survey was reviewed by two external assessment experts who offered their expertise on survey design, wording, and structure. The assessment experts offered suggestions of wording and guidance on best practices to analysis our datasets and helped in analyzing the data. After the educators, religious leaders, and assessment experts were satisfied with the questions, the instrument was distributed to students.

Initial distribution and focus groups

In the fall of 2017 and spring of 2018, we distributed the first iteration of the survey to 359 students at four private religious institutions that consisted of religious students from The Church of Jesus Christ of Latter-day Saints, Non-denominational Christians, Assemblies of God, and the Church of the Nazarene. To better establish content and response processing validity, we conducted focus groups with 15 respondents at each of the four institutions. As a group we went over each question from the survey and asked respondents to explain what they thought the questions was asking, if they had any points of confusion, and how they responded. The focus groups lasted about 60 min and notes were taken live during the discussions. If the respondents had difficulty with a question, we asked them for ideas on different words or phrases that could be used.

After the focus groups, the two-researchers conducting them met and discussed the recommended wording changes from the group and decided on the clearer and concise wording based on feedback. This helped us confirm that students were answering the questions as we expected. Any ambiguous or confusing questions based on student feedback were modified to make them more straightforward and concise. Our goal through these focus groups was to understand ambiguous words, phrases, and questions and adjust them as needed to make the survey more appropriate for multi-denominational audiences.

pFEAR modification and second distribution

In the fall of 2018, after modifying the questions based on feedback, we distributed the surveys for a second iteration to 797 students at the same four private religious institutions. Additionally, we measured the evolution acceptance and religiosity of the students. Data were collected using Qualtrics, LLC (2016) in the fall of 2018.

The measure of evolution acceptance. In the first and second iterations, we used the Generalized Acceptance of EvolutioN Evaluation, or GAENE (Smith et al. 2016), as a quantitative measure of evolution acceptance. The GAENE measures evolution acceptance using 13 items on a five-point Likert scale for a total sum score of 65 points. The GAENE is valid and reliable in specific populations, with a Lawshe content validity score of 0.72 and Cronbach's alpha of 0.94 (Smith et al. 2016).

The measure of Religiosity. In this second iteration, we used a published religiosity measure (Manwaring et al. 2015), previously validated for a similar population (Manwaring et al. 2018). The original instrument consists of 15 questions on a six-point Likert scale that measures self-reported religious practice (e.g., frequency of prayer), religious influence (e.g., religion's influence on the food you eat), and religious hope (e.g., belief in miracles). Total religiosity was calculated by summing the responses to the 15 questions for a total score of 90.

Refinement and distribution of the final pFEAR

For further validation, we distributed our survey instrument in a third iteration to 546 students at an additional eight religiously affiliated institutions with five different religious denominations: The Church of Jesus Christ of Latter-day Saints, Evangelical Presbyterian Church, Presbyterian Church, United Methodist Church, Christian non-denominational, and the Reformed Church in America. Data were collected using Qualtrics, LLC (2016) in the fall 2019 and spring 2020 semesters.

Statistical analysis

To measure how well our hypothesized model fit the data we used Confirmatory Factor Analysis and Structural Equation Modeling. For more clarity on how we did this and how we determined whether it was worked we will briefly describe it below.

Confirmatory factor analysis

We used confirmatory factor analysis (CFA) on the second and third iteration data (N = 797, N = 546) (Bollen 1989; Brown 2015) to evaluate whether the model fits the data. CFAs are generally used to test whether hypothesized factorial structures or latent variables of the items in an instrument are valid (Wang And Wang 2019). We hypothesized five latent variables within the *p*FEAR and used CFA to measure each of those latent variables (see Table 2 and Fig. 1). To show the reliability of the variables within the *p*FEAR, we calculated the omega coefficient of each latent variable. Items in the measurement model were removed until fit indices were

acceptable. We also used CFA on the I-SEA to measure evolution acceptance and the construct reliability of our population's two latent variables (*Macroevolution acceptance* and *Human evolution acceptance*). Again, items in the measurement model were removed until fit indices were acceptable. Each construct was run independently and then run together. We also used CFA on the religiosity measure. CFA is the first step in a Structural Equation Model (SEM) to determine the fit of our latent variables (Wang and Wang 2019).

Structural equation model

After we evaluated the latent variables, we moved forward with the Structural Equation Model (SEM) on the third iteration of the data. SEM integrates factor analysis and path analysis (Jöreskog 1967). In CFA, unobservable latent variables are estimated indirectly from observable items, and SEM takes it a step further by comparing relationships among latent and observed variables. In research, SEM examines a hypothesized model based on potential theoretical relationships between variables. SEM also provides a means to consider measurement errors in a model (Bollen 1989; Wang and Wang 2019), whereas traditional statistical methods (e.g., multiple regressions and ANOVA) ignore potential measurement errors. Ignoring measurement errors can lead to biased estimates. A benefit of using SEM is that it can assess the quality of the measurements and examine the relationships among constructs simultaneously.

Specifically, we sought to examine the relationships between our *p*FEAR latent variables (i.e., *Religious Influence on Evolution, General Religious Influence, Science/Religion Conflict, Scientific Influence on Evolution, and General Scientific Influence*) and the I-SEA latent variables (i.e., *Microevolution*, *Macroevolution*, and *Human evolution*). Full Information Maximum likelihood (FIML) was used to deal with the missing data, as it is better than listwise deletions (Enders and Bandalos 2001). All other assumptions were met before the CFA and SEM analysis.

To assess whether our model was good and fit the data, we used a model fit evaluation which consists of the root mean square error of approximation (RMSEA), comparative fit index (CFI) cutoff is greater than 0.90, Tucker-Lewis index (TLI) cutoff is greater than 0.90, and standardized root mean square residual (SRMR) cutoff is less than 0.08. The RMSEA is a parsimonious measure that measures a standardized error of approximation, which can tell us the lack of fit of the specified model for the population. For the RMSEA a cutoff of less than 0.08 shows good model fit. The SRMR shows the difference between the observed correlation matrix and the model estimated matrix. For the SRMR a cutoff of less than 0.08 shows good model fit. The CFI compares the hypothesized model to the null model and assumes zero covariances among the observed variables. The TLI is a way to compare the lack of fit of a specified model to the lack of fit to null model. For the TLI and CFI a cutoff of greater than 0.90 is usually acceptable (Wang and Wang 2019), but a fit of above 0.95 is considered good (Mueller and Hancock 2018). These are the measures that we used to measure whether our hypothesized model was good.

The measure of evolution acceptance. In this third iteration, we used the Inventory on Student Evolution Acceptance (I-SEA) because, in our previous sample, the GAENE did not fit well with our religious sample (CFI = 0.784, TLI = 0.740, RMSEA = 0.131). We chose to use the I-SEA instead, as it has shown to be a good way to look at different levels of evolution acceptance, especially in religious populations (Barnes et al. 2019). The I-SEA consists of eight items in each of the three constructs (microevolution, macroevolution, and human evolution) and has shown to be reliable with Cronbach's alphas for micro, macro, and human subscales were 0.96, 0.92, and 0.93, respectively (Nadelson and Southerland 2012). In our population of religious students, the I-SEA did not fit the data well, so we used a modified version based on the four items that measured the construct defined by Nadelson and Southerland (2012), which consisted of four items from each construct. Even with four items in each construct, there were still issues with the model fit. After reviewing a manuscript by Barnes et al. (2022), which showed issues with questions about microevolution, we removed the microevolution and found good fit statistics (See Table 3 for details).

The measure of Religiosity. We used a modified version of our religiosity measure in this third iteration. Based on CFA analysis, we only used questions from religious practice to measure religiosity (i.e., How often do you read holy scriptures, How often do you attend Sunday School, religious classes, or seminars, How often do you attend organized worship services, and How often do you attend other activities sponsored by a religious group) and found these questions to be a good fit for our population (TLI = 0.995; CFI = 0.998; RMSEA = 0.03; SRMR = 0.010).

Analyses

We used Mplus software ver. 8 (Muthén and Muthén 1998-2017) to analyze our model's measurement and structural portions. We used the statistical package for the social sciences (SPSS, Version 26.0) to adjust and prepare data for statistical analyses and checked each survey question for full coverage of each response. There were no ceiling or floor effects in the data. We also reviewed the data for other assumptions, such as

Table 3 Indicates which I-SEA questions were included in the *p*FEAR and which ones were removed

Science/religion conflict
How much do you agree with this statement: "When someone is trained in science, they can no longer be religious." (.893)
How much do you agree with this statement: "The concepts of science are frequently in conflict with religion." (.582)
How much do you agree with this statement: "If someone is deeply religious, they cannot be a scientist." (.863)
General Religious Influence
How much do you agree with this statement: "Religion influences my opinion about whether scientists should be allowed to alter human embryonic DNA." (.584)
To what degree is your opinion about same-sex marriage influenced by your religious community's perspective on the topic? (.809)
How much does religion influence your opinions on controversial issues, in general? (.887)
Religious Influence on Evolution
How often do you hear or read a statement from your current religious community that expresses negative sentiments about evolution? (.426)
How influential was each of the following sources in forming your opinion regarding evolutionary theory?—Local clergy, local pastor, or youth leader (.821)
How influential was each of the following sources in forming your opinion regarding evolutionary theory?—Official Church authorities and publications(.797)
General Scientific Influence
Science has shown vaccines to be highly effective. Putting aside the issue of a parent's right to choose, do you agree that children should be vaccinated? (.323)
How much do you agree with this statement: "My opinion about climate change is influenced by scientific data."? (.621)
How much do you agree with this statement: "When forming an opinion about Genetically Modified Organisms (GMOs), I would rely on scientific data."?(.612)
How much does scientific data influence your opinions on controversial issues, in general? (.714)
Scientific Influence on Evolution
How influential was each of the following sources in forming your opinion regarding evolutionary theory?—Professors/Teachers (.597)
How influential was each of the following sources in forming your opinion regarding evolutionary theory?—Scientists and published, peer-reviewed scientific articles(.800)
How influential was each of the following sources in forming your opinion regarding evolutionary theory?—Scientific textbooks(.858)
How influential was each of the following sources in forming your opinion regarding evolutionary theory?—Popular scientific literature(.654)

collinearity and linearity. We concluded that our data met the specified assumptions.

Results

*p*FEAR: the first and second iterations

The first iteration consisted of the creation of the *p*FEAR. Experts who have taught evolution to religious students for many years and understood the barriers to teaching evolution to religious students created this survey. To better validate our survey, we wanted to ensure that language was understandable to students from various religious beliefs. Most survey creators came from a single religious denomination, and the first iteration had words that may have confused students from other religious denominations. We changed wording such as "Pastor" to "Religious leader" and removed any questions participants found redundant. Our think-aloud interviews were helpful as we found words and questions that did not make sense to students of different religions. After modifying and adjusting the questions, we validated our survey through CFA.

Confirmatory factor analysis: second iteration

For the second iteration, we used a CFA to confirm our hypothesized latent variables (N = 797). The CFA suggested five latent variables but did not have fit statistics for our model because of conflicting questions about demographics (e.g., whether they were STEM majors, political ideology, and parents' education level). After we removed the conflicting questions, the CFA confirmed five latent variables, which we named: *Religious Influence on Evolution* (three items), *General Religious Influence* (three items), *Science/Religious Conflict* (three items), *Scientific Influence on Evolution* (four items), and *General Scientific Influence* (four items). The factor loadings for each item were high (above 0.5) and significant ($p < 0.05$). When all five latent variables were placed in a model, it demonstrated robust fit statistics and probability scores (TLI = 0.942; CFI = 0.965; RMSEA = 0.053; SRMR = 0.042).

pFEAR: the third iteration

The biggest issue we discovered in the second iteration was that our evolution acceptance survey

(GAENE) did not fit the data (TLI = 0.740; CFI = 0.784; RMSEA = 0.131; SRMR = 0.076). Moving forward with the third iteration, we decided to use the I-SEA to measure evolution acceptance as it has been shown to work better in religious populations (Barnes et al. 2019). These were the only questions that differed between the second and third iterations.

Confirmatory factor analysis

CFA was used to confirm the hypothesized model from the previous iteration for each construct (See Fig. 2). The CFA again confirmed five latent variables: *Religious Influence on Evolution*, *General Religious Influence*, *Science/Religious Conflict*, *Scientific Influence on Evolution*, and *General Scientific Influence* (see Tables 2 and 4). Factor loadings for each item were high (above 0.5) except two: *How often do you hear or read a statement by a religious authority, clergy, or leader*

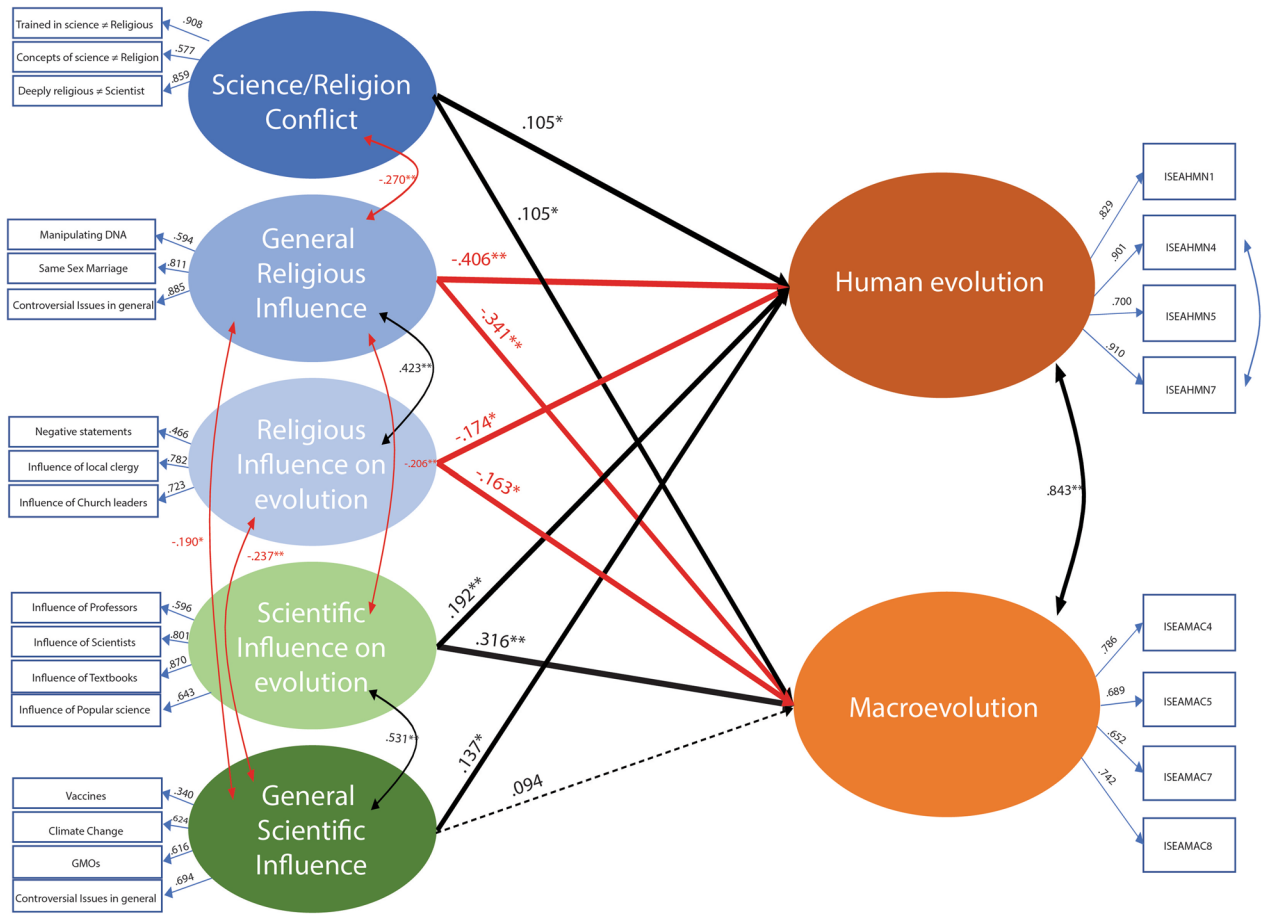

Fig. 2 Design and results of the structural equation model. Solid lines indicate a significant relationship between latent variables, dashed lines indicate non-significant. Black line indicant positive relationships and the red line indicates negative relationships. *p < 0.05, **p < 0.001

Table 4 Final Fit statistics for each construct and full measurement model

Statistics of the final pFEAR							
Construct	**TLI**	**CFI**	**RMSEA**	**SRMR**	**Chi-squared test**		
					X^2	**DF**	**p-value**
I-SEA (CFA)	0.953	0.97	0.074	0.034	74.02	18	< 0.0001
pFEAR (CFA)	0.962	0.969	0.034	0.047	180.52	109	< 0.0001
Complete SEM model	0.939	0.948	0.043	0.048	518.08	254	< 0.0001

from your current religious community that expresses negative sentiments about evolution? (0.426), and *Science has shown vaccines to be highly effective. Putting aside the issue of a parent's right to choose, do you agree that children should be vaccinated? (0.323).* These questions were kept in the model as we were interested in students' responses and because removing these items did not improve or diminish the fit statistics significantly. All factor loadings were significant ($p < 0.05$). When all five latent variables were placed in a model, it demonstrated robust fit statistics and probability scores (TLI = 0.962; CFI = 0.969; RMSEA = 0.034; SRMR = 0.047), which suggest construct validity. We also assessed the construct reliability of the *p*FEAR based on the calculated omega coefficients for each construct. For *Religious Influence on Evolution* OMEGA = 0.680 [95% CI 0.568, 0.749], *General Religious Influence* OMEGA = 0.797 [95% CI 0.751, 0.832]. *Science/Religious Conflict* OMEGA = 0.779 [95% CI 0.727, 0.819]., *Scientific Influence on Evolution* OMEGA = 0.817 [95% CI 0.775, 0.849]., and *General Scientific Influence* OMEGA = 0.673 [95% CI 0.593, 0.736]. Showing that the *p*FEAR, based on the data, is considered a functional survey that may give educational insight to religious populations.

Using our data, we also ran a CFA on the I-SEA and the religiosity measure. The following items were excluded from this analysis due to lack of fit: all eight items from microevolution, four from macroevolution, and four from human evolution (see Table 4 for details). All factor loadings for the I-SEA were high (above 0.5) and significant ($p < 0.05$). The I-SEA demonstrated robust fit statistics (TLI = 0.953; CFI = 0.970; RMSEA = 0.074; SRMR = 0.034) and showed congruent validity with significant R_2 values for *Human evolution acceptance* ($R_2 = 0.479$, $p < 0.001$) and *Macroevolution acceptance* ($R_2 = 0.485$, $p < 0.001$). The I-SEA also showed construct reliability based on the calculated omega coefficients for *Human evolution acceptance* OMEGA = 0.902 [95% CI 0.877, 0.921] and *Macroevolution acceptance* OMEGA = 0.806 [95% CI 0.760, 0.842].

Structural equation model

Our structural model of the *p*FEAR (see Fig. 2) demonstrated a robust fit for the data as indicated by fit statistics (TLI = 0.939; CFI = 0.948; RMSEA = 0.043; SRMR = 0.048, see Table 4 for more details).

Science/ Religion Conflict on evolution acceptance. In our model, *Science/Religion Conflict* significantly positively predicted *Human evolution* and *Macroevolution* ($p < 0.05$) acceptance with standardized betas of 0.105 and 0.105. Standardized beta tells us that for every one standard deviation unit increase in *Science/ Religion Conflict*, we would predict a 0.105 standard deviation unit increase in *Human evolution.* This shows that students with a higher conflict between science and religion were more accepting of *human* and *macroevolution.*

General Religious Influence. In our model, *General Religious Influence* significantly predicts a negative relationship with *Human evolution* ($p < 0.001$) and *Macroevolution* ($p < 0.001$) acceptance, with a standardized beta of − 0.406 and − 0.341, respectively. The more influenced a student is by their religion's general views, the less accepting they are of evolution.

Religious Influence on evolution acceptance. Religious Influence on Evolution also negatively predicts *Human evolution* and *Macroevolution* ($p < 0.05$) acceptance with a standardized beta of -0.174 and − 0.163. The more influenced students are by their religion's views on evolution, the less likely they are to accept human evolution and macroevolution.

Scientific influence on evolution acceptance. In our model, *Scientific Influence on Evolution* positively predicts *Human evolution* and *Macroevolution* ($p < 0.001$), with a standardized beta of 0.192 and 0.316. The more influenced a student is by the scientific view on evolution, the more accepting they are of evolution.

General scientific influence. In terms of *General Scientific Influence*, it positively predicts *Human evolution* ($p < 0.05$) acceptance with a standardized beta of 0.137. It shows no significant relationship with *Macroevolution* acceptance. The more influenced a student is by general scientific views on controversial topics, the more accepting they are of human evolution.

Post hoc analysis 1: general religious influence on evolution acceptance through science/religion conflict

In our SEM model, *Science/ Religion Conflict* significantly positively predicted *Human evolution* and *Macroevolution* acceptance but was significantly negatively correlated with *General Religious Influence.* Due to the unique relationship between these variables—the higher a student's conflict between science and religion, the less influenced students are by their religious beliefs, and the more accepting they are of evolution—we wanted to test them further. Specifically, we wanted to know the effect of *General Religious Influence* on *Human evolution* and *Macroevolution* acceptance in the presence of *Science/Religion Conflict.* We analyzed another SEM that measured the indirect effect of *General Religious Influence* on *Human evolution* and *Macroevolution* acceptance via *Science/ Religion Conflict* (see Fig. 3). Our results showed a small significant indirect effect of *General Religious Influence* on *Human evolution* and *Macroevolution* acceptance through *Science/ Religion Conflict* ($p < 0.05$) with a standardized

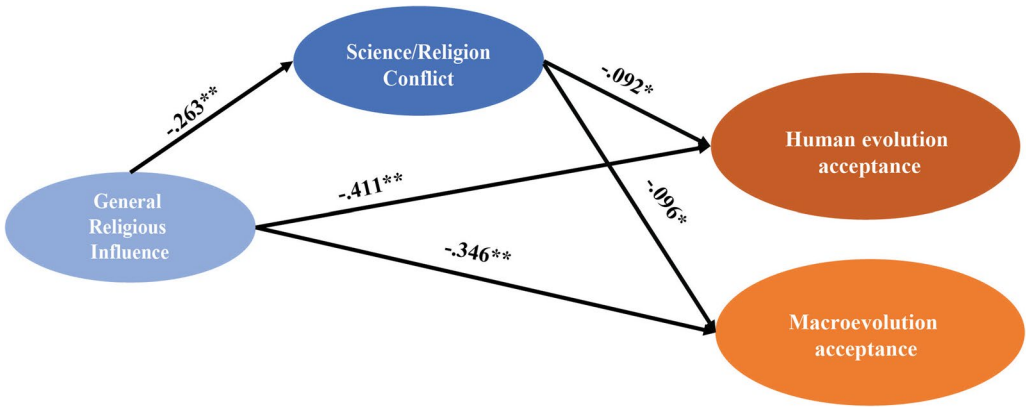

Fig. 3 Design of the indirect effect of the structural equation model. This model measures the effect of *General Religious Influence* on *Human evolution acceptance* and *Macroevolution acceptance* through *Science/Religion Conflict*. *p < 0.05, **p < 0.001

beta of − 0.024 for *Human evolution* and − 0.025 for *Macroevolution* acceptance. In contrast, the direct effect of *General Religious Influence* on *Human evolution* and *Macroevolution* acceptance was large and statistically significant ($p < 0.001$) with a standardized beta of − 0.411. The indirect effect of *Science/ Religion Conflict* only accounts for 5.5% of the total effect on *Human evolution* and 6.7% on *Macroevolution*.

Post hoc analysis 2: religiosity on evolution acceptance through science/religion conflict

We wanted to test further the effect of *Religiosity* on *Human evolution* and *Macroevolution* acceptance through *Science/Religion Conflict* (See Fig. 4). To do this, we also wanted to measure their religiosity, which is data we previously collected but chose not to use for this study initially. Our results showed no significant indirect effect of *Religiosity* on *Human evolution* and *Macroevolution* through *Science/ Religion Conflict* with a standardized beta of − 0.019 for *Human evolution* and − 0.019 for *Macroevolution* acceptance (p = NS). In contrast, the direct effect of *Religiosity* on *Human evolution* and *Macroevolution* acceptance was statistically significant ($p < 0.001$) with a standardized beta of − 0.404. The indirect effect of *Science/ Religion Conflict* only accounts for 4.5% of the total effect on *Human evolution* and *Macroevolution* acceptance.

Post hoc analysis 3: interaction between religiosity and conflict on human evolution acceptance

After we viewed our results, we decided to test whether there was an interaction between *Religiosity* and *Science/Religion Conflict* on *Human evolution acceptance.* We used SPSS to run multiple regression analysis to analyze the interaction effect between *Religiosity* and *Science/Religion Conflict* on *Human evolution acceptance*. The multiple regression analysis showed a potential interaction between *Religiosity*

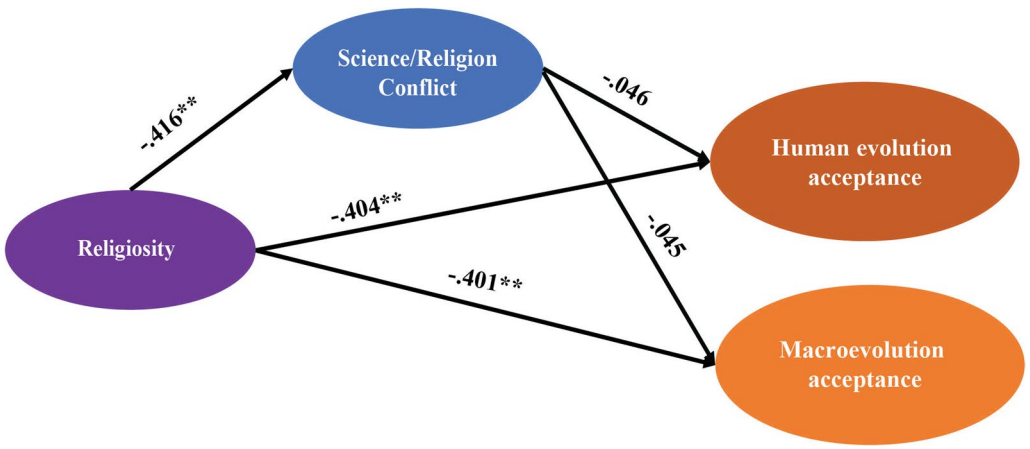

Fig. 4 Design of the indirect effect of the structural equation model. This model measures the effect of *Religiosity* on *Human evolution acceptance* and *Macroevolution acceptance* through *Science/Religion Conflict*. *p < 0.05, **p < 0.001

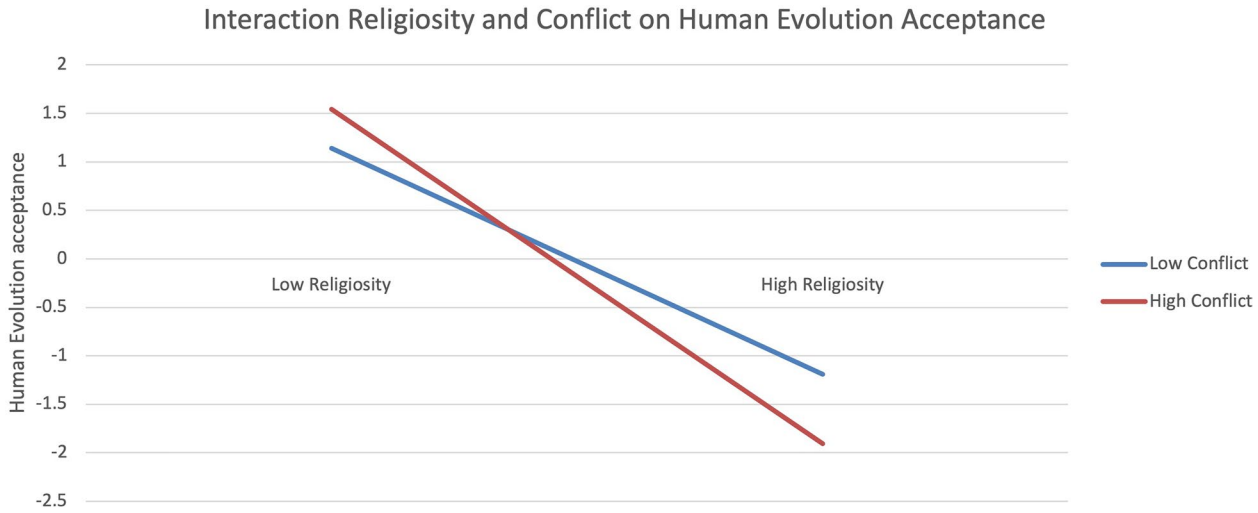

Fig. 5 Multiple regression analysis measure the interaction between *Science/Religion Conflict* and *Religiosity* on *Human evolution acceptance*. $p = 0.076$. N = 534

and *Science/Religion Conflict*, with conflict increasing acceptance for non-religious students but decreasing acceptance for religious students. However, the interaction did not reach significance ($p = 0.076$, see Fig. 5 for details).

Discussion

In this paper, we developed the *p*FEAR, which predicts evolution acceptance by measuring students' religious and scientific worldviews. This instrument includes *general religious influence* and *religious influence on evolution*, *general scientific influence* and *scientific influence on evolution*, and a *perceived conflict between science and religion*. We used CFA to assess defined latent variables and SEM to test and measure the relationships between latent variables. We created this survey with input from external religious leaders and biology instructors to establish expert and content validity. We gathered response processing validity through think-aloud interviews with students (García 2011; Willis 2004). Further, we used CFA to evaluate the construct validity of the *p*FEAR. Correlations with prior measures and research show that the *p*FEAR provides concurrent validity evidence with similar relationships identified in the literature.

The *p*FEAR is a survey tool educators can use to quickly assess whether their students are influenced by their religious beliefs and their perceived conflict between science and religion regarding how they might view evolutionary science. Educators could then modify or adjust their pedagogical approach to better meet the needs of their students.

The conflict between science and religious worldviews predicts evolution acceptance

The *p*FEAR uses questions about the perceived conflict between scientific and religious worldviews. The SEM shows that *Science/ Religion Conflict* significantly positively predicts *Human evolution* acceptance and *Macroevolution* acceptance. In other words, students with a higher perceived conflict between religion and science are *more* accepting of human evolution and macroevolution, than students with a lower perceived conflict between religion and science. This did not align with our second research question and hypothesis. Interestingly, the construct, *Science/ Religion Conflict,* is negatively correlated with *General Religious Influence*. Due to the negative correlation, we further analyzed the relationship between *General Religious Influence* and *Science/Religion Conflict*. Our results showed that *General Religious Influence* significantly negatively predicts *Science/ Religion Conflict*, meaning that the more influenced a student was by their religion, the lower their perceived conflict between science and religion. We saw a similar trend with religiosity—the higher a student's religiosity score, the lower their perceived conflict between religion and science—but when religiosity was in the indirect model, *Science/ Religion Conflict* was no longer a significant predictor of *Human evolution acceptance* and *Macroevolution acceptance*. Thus, unexpectedly, our data shows that this "conflict model" is being driven by the less religious respondents in our survey rather than the more religious individuals. So, even though religious influence is a strong negative predictor of evolution acceptance, it does not appear to be driven by perceived conflict.

Our results showed *General Religious Influence* and *Religiosity* were our model's strongest predictors of evolution acceptance. This aligns with what others have found about the relationship between religion and evolution acceptance (Dunk 2019; Dunk et al. 2017). However, a recent study created a survey, the Perceived Conflict between Evolution and Religion (PCoRE), that measured perceived conflict between religion and evolution and found that a student's perceived conflict between evolution and religion was a stronger predictor of evolution acceptance than religiosity (Barnes et al. 2021a, b). Our data from the *p*FEAR seems to contradict Barnes et al. (2021a, b) and the PCoRE, as our data shows that religious influence and religiosity were the strongest predictors of evolution acceptance, while conflict, at least among highly religious individuals, is not influential. However, this is most likely due to the nuances of the latent variable "conflict" we measured.

The PCoRE asks students about the perceived conflict between religious beliefs and evolutionary theory. In contrast, the *p*FEAR asks questions about science and the ability to be a scientist while maintaining religious beliefs. Thus, while students in our response pool may (and likely did) find conflict between evolutionary theory and their religious beliefs, they do not find conflict between being a scientist and being religious. Those with the lowest religious belief were likelier to perceive this conflict as a reality. Further studies looking at the relationship between being a scientist and being religious and looking at the relationship between evolutionary thought and religious beliefs may yield interesting insights on students' perceptions of the world.

Religious influence and scientific influence predict evolution acceptance

Not unexpectedly, the *p*FEAR reveals that students highly influenced by their religion's views on evolution and those who rely on religious authority for navigating controversial topics in general (*Religious Influence on Evolution and* General Religious Influence) are less likely to accept macroevolution and human evolution. Many religions support organisms adapting to their environment (i.e., microevolution); however, many religious people struggle with the idea of speciation (a population of organisms changing enough to be considered new species, usually over many generations) and the evolution of humans (Lindsay et al. 2019). Interestingly, the *p*FEAR also shows expected relationships between religious influence and scientific influence among our student population. Students who relied on their religions' influence on evolution were less influenced by science on evolution and vice-versa. Students more influenced by science were more accepting of evolution, and students more influenced by their religious beliefs were less accepting of evolution.

These findings indicate strong congruent validity of the *p*FEAR as it aligns with previous research. The literature shows that religiosity negatively predicts evolution acceptance (Barnes et al. 2021b; Dunk et al. 2017; Glaze et al. 2015; Rissler et al. 2014) and that an understanding of the NOS is a positive predictor of evolution acceptance (Dunk et al. 2017). The *p*FEAR shows both relationships, as explained in the literature, and is a simple combined tool that educators can use to understand their students' worldviews in both areas.

The *p*FEAR is a tool for teachers: how it can be used in the classroom

Although the *p*FEAR has yet to be tested in populations with differing worldviews (e.g., non-religious), it can be a support tool for educators nervous about teaching evolution to their students, especially those in religious areas who might avoid teaching evolution altogether (Berkman and Plutzer 2011; Rutledge and Mitchell 2002). The *p*FEAR can help teachers know what best practices might be necessary for their students, such as helping students manage conflict (Meadows et al. 2000), teaching the NOS, or using culturally competent methods (Barnes et al. 2017a, b) that help students to bring both scientific and religious views into harmony (e.g., Ferguson and Jensen 2021). Our goal with this survey was to make a quick, easy-to-use tool to help teachers better understand their students' worldviews and how to approach teaching evolution in the classroom. The *p*FEAR is freely available to all on the pfear.byu.edu website (Reconciling Evolution, 2022) and is easy to implement in any class with simple instructions on how to use the survey and interpret the data. The *p*FEAR on the website is anonymous; teachers cannot see individual students' results. The results will be shown to the teacher as a conglomerate score of the whole class.

The *p*FEAR is a tool for researchers: how it can be used in discipline-based education research studies

This instrument can also serve as a validated inventory in discipline-based education research (DBER) studies. It measures several latent factors that encompass students' religious and scientific worldviews. As such, for example, researchers can use it in both a pretest–posttest design or in a comparison study testing the effectiveness of curricular materials in improving student impressions of the utility of science in helping us make informed decisions about controversial topics (*general scientific influence*) and evolution, specifically (*scientific influence on evolution*). Additionally, researchers can use it to measure changes in the perceived conflict

between science and religion (*science/religion conflict*). While we do not encourage active attempts to change religious worldviews through educational interventions, the religious variables (*general religious influence* and *religious influence on evolution*) can be used in survey studies to compare populations across different cultural, ethnic, or national samples, and to track religious trends over time (e.g., are the number of negative statements about evolution changing in any given religious population over time).

Future directions for the *p*FEAR

Further our understanding of the influence of conflict between science and religion

The *p*FEAR showed a unique relationship between *General Religious Influence* and *Science/ Religion Conflict* constructs. Our data show that the more religious students are, the less conflict they perceive between being a scientist and being religious. Further, our multiple regression analysis showed an almost significant interaction between conflict and religiosity when regressed on human evolution acceptance ($p < 0.076$; see Fig. 4)—suggesting that secular individuals who do not hold religious beliefs might have a higher conflict between science and religion than religious students. We think the lack of significant interaction is from our sample of religiously affiliated institutions (i.e., we had very few students with low religiosity); using the *p*FEAR in more heterogeneous populations will help us understand this interaction further.

The future of the pFEAR

Educators can start using the *p*FEAR now to understand better what worldviews influence their students when learning about evolution. However, we also believe the *p*FEAR can be improved as we learn more about students' worldviews and influences on evolution acceptance. We hope to add additional questions assessing the perceived conflict between evolution and religion (rather than the more general science and religion in the current survey) and the effects on evolution acceptance. We predict we will see similar results as Barnes et al. (2021a, b) did with the PCoRE. Using the PCoRE might show interesting relationships between our latent and evolution acceptance variables. We also hope to continue adding more questions to the *p*FEAR to help us better understand other aspects of a student's religious and scientific worldviews. The questions we currently have in the *p*FEAR work well for our defined latent variables, but more questions may further strengthen and solidify our latent variables.

Future considerations

The *p*FEAR is not perfect and has limitations. We hope that as this survey is used in classrooms and as we receive feedback, it can be revised to be better and more accurate over time. We used experts to create this survey, along with think aloud group interviews to clear up some of our wording, but it is possible that outside sources or more individualized interviews with students might give more informative data for future iterations. One potential limitation is that this survey has only been used in religious populations, so we cannot yet infer the results in a heterogeneous non-religious population. Along that line, the measure lacks control variables, such as demographics, religiosity, and evolution knowledge, that may give better insight into students' views. As we try to better understand our defined variable in this instrument with more trials, we plan to add these latent variables in the future. Another limitation is that our defined latent variable may not encompass all questions that genuinely define our latent variables. As we progress with this survey, we plan to continue to ask and find questions that might better help us understand our latent variables. The evolution acceptance survey we used (I-SEA) is also a potential limitation in this research. Moving to a different evolution acceptance survey will be looked at as we proceed with the *p*FEAR.

We should note that the *p*FEAR does not measure how religious a student is, but measures how influenced they are by religious beliefs. It also does not measure how well they understand the nature of science, but measures how influenced they are by science. Regardless of limitations, we think this survey can be used as a tool for teachers and, with time, will be modified and improved.

Conclusion

We created the *p*FEAR as both a readily accessible survey tool for teachers and a worldview inventory for researchers. Teachers can use it to help them understand how much religious worldviews influence their students' evolution acceptance so that they can better focus instruction on the needs of their students. Researchers can use it to assess scientific influences across educational interventions and to track religious trends between populations over time. The *p*FEAR shows how the perceived conflict between science and religion and a scientific worldview positively predicts evolution acceptance and how religious worldviews negatively predict evolution acceptance. We have gathered evidence to suggest the validity and reliability of the *p*FEAR as an instrument measuring these defined latent variables among religious populations. This manuscript explains how we created, tested, and modified the *p*FEAR. This

manuscript also serves as a guide to educators looking to use the *p*FEAR in the classroom and researchers hoping to measure worldviews. We hope that this instrument can serve as a helpful step in improving evolution education.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Author contributions
JLJ and DGF conceptualized and designed the study. JLM, DGF, and AL curated the data. JLM, DGF, AL, and EGB analyzed and interpreted the data. JLM, DGF, AL, and EGB drafted and revised the manuscript. DGF revised the manuscript. All authors have approved the version to be published and have participated sufficiently to take public responsibility for appropriate portions of the content. The authors agree to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part are appropriately investigated and resolved.

Availability of data and materials
Requests for access to the data used to establish validity and reliability may be directed to author DGF who will provide de-identified data as allowed under the IRB protocol. The pFEAR survey can be found https://pfear.byu.edu/ and is freely assessable to all.

Declarations

Competing interests
The authors claim no competing interests.

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