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The effects of religious views and creationism on teleological reasoning, acceptance and understanding of natural selection: a preliminary mixed-methods study

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Abstract

Background Creationist religious views have a large influence on the public's views and learning related to evolution, especially human evolution. Creationism has been shown to reinforce students' design teleological stance, which creates a challenging conceptual obstacle for learning evolution. The purpose of the current study was to determine if students with creationist views responded differently to education intended to directly challenge design teleological reasoning in the context of a human evolution course, compared to students with naturalist views. In a convergent mixed methods design this study combined pre- and post-semester quantitative survey data (N = 48) on student endorsement of teleological reasoning, acceptance of evolution (Inventory of Student Evolution Acceptance), and understanding of natural selection (Conceptual Inventory of Natural Selection), with a thematic analysis of student reflective writing on their understanding and acceptance of natural selection and teleological reasoning.

Results This study found that students with creationist views had higher levels of design teleological reasoning and lower levels of acceptance of evolution at the beginning of the semester, compared to students with naturalist views ($p < 0.01$). Students with creationist views experienced significant ($p < 0.01$) improvements in teleological reasoning and acceptance of human evolution. While the changes in teleological reasoning, understanding and acceptance experienced by students with creationist views were similar in magnitude to changes in students with naturalist views, creationists never achieved levels of evolution understanding and acceptance seen in students with naturalist views. Multiple linear regression showed that student religiosity was a significant predictor of understanding of evolution, while having creationist views was a predictor of acceptance of evolution. Thematic analysis revealed that more students believed that religion and evolution are incompatible than compatible. However, more than one-third of students expressed openness to learning about evolution alongside their religious views.

Conclusions Students with creationist views made gains on nearly all measures, but significantly underperformed their counterparts with natural views. For many students, religiosity and creationism challenge their thinking about evolution. This paper describes pedagogical practices to help students understand their own teleological reasoning and support students with creationist views who are learning about evolution.

Keywords Design teleology, Teleological reasoning, Evolution acceptance, Evolution pedagogy, Creationism

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Background

Charles Darwin's theory of evolution by natural selection in his *On the Origin of Species* (Darwin 1859) was largely viewed as heretical in the Christian historical context in which it was published (Kampourakis 2020a). Prior to the publication of Darwin's theory, the Christian view of creationism was articulated by William Paley, who argued that organisms are so complex, that they could only be created by a designer. Paley further argued that since organisms are more complex and superior than anything created by humans, their designer must be God (Paley 1819). Even after more than 160 years of evidential support for Darwin's theories, Paley's Christian views of creationism continue to have an outsized influence on the public's views and learning related to evolution, particularly human evolution. A 2018 Pew Research Center survey found that 18% of adults in the United States believe that humans have always existed in their current form (and therefore, have not evolved); 48% believe that humans have evolved, but that God or a higher power played a role; and 33% believe that humans evolved by natural forces (Funk 2019). Other recent US public opinion surveys have shown that 38% of US adults have creationist views on human origins (Swift and In 2017) and 52% disagreed that humans have evolved from other animal species (National Science Board 2016). In contrast, an overwhelming majority of non-religiously affiliated US adults believe that humans have evolved over time (Funk 2019).

Although people with creationist views have a wide range of attitudes toward evolution (Barnes et al. 2020; Yasri and Mancy 2016), numerous studies have shown that one's level of religiosity is inversely related to their acceptance of evolution (Dunk et al. 2017; Glaze et al. 2015; Ha et al. 2012; Rissler et al. 2014; Mazur 2004; Baker 2013; Evans 2011). In a recent study of undergraduates in a human evolution course, we reported a significant positive correlation between level of religiosity and endorsement of teleological reasoning, as well as significant negative correlations between religiosity and acceptance and understanding of evolution (Wingert et al. 2022). One potential cognitive mechanism by which creationism may influence evolution acceptance and understanding is its reinforcement of design teleological reasoning because creationists believe, fundamentally, that God is the designer of living things (Scott 2001). Many previous studies have shown that people who believe in God have higher levels of unwarranted, design teleological reasoning (Banerjee and Bloom 2014; Diesendruck and Haber 2009; Kelemen 2004; Kelemen and DiYanni 2005) than non-believers. Design-based teleological reasoning forestalls understanding natural selection because it operates on the common misunderstanding of natural selection as a forward-looking, rather than a blind, process (Kelemen et al. 2013; Kampourakis 2020b). When the student uses design teleological reasoning, it often reflects reasoning about adaptation occurring according to the intentions of an external agent (external design teleology) or to fulfil the needs of the organism (internal design teleology) (Kampourakis 2020b). Reasoning in this way can lead students to argue that all traits are adaptations that evolved toward a prescribed functional endpoint due to a sense of goal-directed agency or conscious intention (Moore et al. 2002; Trommler and Hammann 2020), which is antithetical to veridical evolutionary mechanisms.

Efforts to attenuate student design teleological reasoning are relevant to science educators because numerous authors have suggested that design teleological reasoning disrupts student ability to learn about biology, especially evolution (Kampourakis 2020b; Trommler and Hammann 2020; Barnes et al. 2017b; Bishop and Anderson 1990; Demastes et al. 1996; Hammann and Nehm 2020; Kelemen 2012; Settlage 2007; Sinatra et al. 2008; Wingert and Hale 2021) and yet, science educators may underestimate the prevalence of the teleological bias and its cognitive impacts (Moore et al. 2002). Therefore, understanding the relationships between creationism, student endorsement of design teleological reasoning, and accepting and understanding natural selection is imperative to improving the public's knowledge of evolution. To replace the design teleological bias with veridical views on the natural world is cognitively challenging, but necessary to accurately understand biological sciences (Kampourakis 2020a; Gregory 2009; González Galli et al. 2020). Additionally, decreasing teleological thinking in an effort to facilitate greater understanding and acceptance of evolution has implications that reach beyond the classroom as application of evolution to societal issues such as climate change and health decisions can help students make more educated decisions grounded in science (Barnes and Brownell 2016).

Several authors (Kampourakis 2020a; Barnes et al. 2020; Wingert et al. 2022; Kampourakis 2020b; Trommler and Hammann 2020; Wingert and Hale 2021; González Galli et al. 2020; Galli and Meinardi 2011; Liquin and Lombrozo 2018; Ginnobili et al. 2022) have proposed that a goal of teaching evolution is to explicitly address the design teleology stance and provide opportunities for students to experience conceptual conflict from which they can learn to regulate their teleological reasoning as they realize that design-based explanations are insufficient. Addressing the design teleology stance in the classroom may include contrasting this way of thinking with veridical evolution mechanisms and examples of true teleology, which are true causal statements in the

artifact domain and, therefore, occur outside of evolution (Kelemen et al. 2013). Assigning active learning activities where students correct design teleology statements or contrast design teleology with veridical mechanisms are examples of misconception-focused instruction (MFI). Nehm et al. (2022) have recently shown that higher doses of MFI (up to 13% of class time) are associated with greater evolution learning gains and attenuated misconceptions in undergraduate students by adding opportunities for students to reason through problems that invoke cognitive dissonance or conceptual tension. However, the extent to which creationism affects students' responses to such pedagogies challenging design teleology has not been tested.

The purpose of the current study was to assess whether pedagogy directed at mitigating design teleological reasoning in the context of a human evolution course affected students' understanding and acceptance of natural selection differently between students with creationist views and students with naturalist views. We hypothesized that students with creationist views would enter a human evolution course with higher levels of design teleological reasoning, lower levels of evolution acceptance, especially related to macroevolution and human evolution, and lower levels of understanding of natural selection, compared to their counterparts with naturalist views. We additionally hypothesized that students with creationist views would have smaller changes in endorsement of teleological reasoning, understanding of natural selection, and acceptance of evolution in response to a course on human evolution and direct pedagogical challenges to design teleological reasoning.

In a mixed-methods design, we combined pre- and post-intervention quantitative assessments of teleological reasoning, evolution acceptance, and understanding of natural selection, with thematic analysis of student reflective writing on evolution acceptance and personal experience of design teleological reasoning. We sought to extend the existing literature by (1) quantifying changes in teleological reasoning over the course of the semester in response to evolution education with explicit instruction on teleological reasoning between two groups: students with and without creationist views, (2) quantifying changes in acceptance and understanding of natural selection between these two groups, and (3) gaining a deeper qualitative understanding of student perceptions of potential discordance or compatibility between religion, creationist views, and the study of evolution. This study presents data on the impact of religiosity and creationist views on student endorsement of design teleology and acceptance and understanding of natural selection in undergraduates at the beginning, during, and end of a human evolution course. Educational recommendations to support students encountering conceptual barriers associated with religiosity and creationism will be presented.

Methods

Participants

Forty-eight undergraduate students (N = 48, mean age (SD) = 23.5 (7.3) years, 64.5% female, 31.3% male, and 4.2% non-binary) in a course on the evolutionary principles of health volunteered for all aspects of this study, which occurred at a public liberal arts college in the Southeastern United States during three consecutive Fall semesters. This study was deemed exempt from further review by the Institutional Review Board at UNC Asheville and all participants provided signed informed consent prior to participating in the study.

Course description

The evolutionary principles of health course was a four-credit hour elective course taken primarily by students majoring in Health and Wellness Promotion, but also including non-majors. The course met two days per week for 100 min each class. The course was designed according to previously described evolutionary medicine courses (Wingert et al. 2022; Grunspan et al. 2018) and taught the fundamental concepts of evolution in a mostly human context, with a specific focus on adaptation and maladaptation related to human health and disease. This course was mostly introductory and assumed no prior exposure to evolutionary biology. The only pre-requisite was having taken Human Physiology.

By considering human health from an evolutionary perspective, students gained insights into how the human body has adapted to its various environments, and why particular diseases occur in the modern world. In addition to its focus on evolution of the human body over time, this course also explored pathophysiology attributable to evolution, including environmental and social evolutionary mismatches in the modern world contributing to disease. This course consisted of lectures, group discussions on readings, weekly quizzes, and a final research project exploring the evolutionary principles of a chosen disease.

In addition to evolutionary concepts, a major objective of this course was to discuss the challenges to learning evolution, including the potential obstacles of design teleological reasoning. The activities to address design teleological reasoning in the course included: (1) lectures related to core concepts in evolutionary biology, during which students were given a definition and several examples of design teleological reasoning compared with veridical evolutionary explanations. Design teleological and veridical evolutionary mechanisms were contrasted for the following examples: formation of limbs in early terrestrial

animals, evolution of the giraffe neck, evolution of human bipedalism, and expansion of the hominin brain. The class discussed how design teleology can disrupt learning of evolution, but that teleological reasoning is often used in biological explanations. (2) Students completed three consecutive weekly quizzes asking them to identify the design teleological statement(s) from a list of multiple statements on evolutionary mechanisms and to correct the teleological statements with veridical evolutionary mechanisms. The correct answers to these quiz questions were discussed with students after grading. (3) There were weekly class discussions on assigned readings, which included explicit discussions on the distinctions between design teleological reasoning and more veridical scientific explanations. Students were encouraged to identify teleological statements made by the author of the readings, professor, or other students during class discussions. Sometimes these statements were legitimate uses of teleology (i.e., selective teleology (Kampourakis 2020b; Lennox and Kampourakis 2013; Lombrozo and Carey 2006) and sometimes they were illegitimate (i.e., design teleology)). For example, *The Story of the Human Body* by Daniel Lieberman (Lieberman 2013) includes a sentence that some students initially thought was teleological: "Consequently, adaptations evolve to promote health, longevity, and happiness only insofar as these qualities benefit an individual's ability to have more surviving offspring." The semantic cue "evolve to" provided an opportunity to discuss that evolutionary biologists may appropriately use teleological statements as an organizing heuristic (i.e., selective teleology (Kampourakis 2020b) or epistemological teleology (Trommler and Hammann 2020)), and here Lieberman, in the context of the full paragraph, is indeed describing natural selection through veridical mechanisms. On another occasion, a student stated that bipedalism evolved so that early hominins could ambulate with greater energy efficiency, which prompted a discussion on whether this was a goal-directed, design teleological statement. (4) Finally, a short writing assignment in the tenth week of the semester asked students to respond to four open-ended questions (see assessment section below) on their level of teleological reasoning, how learning about teleology affected their learning of evolutionary concepts, and how awareness of teleology fits in the context of their understanding of the broader world. The class then discussed these reflections.

Assessment

Students completed three quantitative surveys during the first and last weeks of the semester, in the order presented below. The first survey measured students' understanding of natural selection with the Conceptual Inventory of Natural Selection (CINS), which consists of 20 multiple-choice questions each with one correct answer and has been shown to be valid and reliable (Anderson et al. 2002; Nehm and Schonfeld 2008). The number of correct answers out of 20 questions were recorded for each student and treated as a quantitative variable in the analysis.

The second survey was a subset of items from a larger measure of endorsement of teleological reasoning created by Kelemen et al. (2013). Their original measure included 100 one-sentence explanations for "why things happen," to which participants responded "true" or "false". Kelemen et al. (2013) presented the explanations as timed, two-alternative forced-choice statements. The Kelemen et al. (2013) measure had 30 test sentences and 70 control sentences (including 20 true causal explanations, 10 true teleological explanations, 30 false causal explanations, and 10 false teleological explanations). Test sentences proposed scientifically unwarranted design teleological explanations for natural phenomena, which were always inaccurate explanations of natural phenomena (Kelemen et al. 2013). An example of an unwarranted design teleological test sentence used was, "Bats hunt mosquitoes in order to control over-population." In contrast to test sentences, control sentences were included to prevent response strategies determined by simply skimming sentences for content words or cues, rather than considering the statement fully. All control sentences, like the test sentences, invoked closely associated concepts and used word cues such as "in order to" or "so that", requiring the content of each sentence to be fully considered for veracity by the student (Kelemen et al. 2013). True teleological control sentences invoked true purpose-driven relationships, but in the artifact domain, outside of evolutionary mechanistic relationships (e.g., "Children wear mittens in the winter in order to keep their hands warm."). Whereas false teleological control sentences invoked false purpose- or design-based reasoning in the social or artifact domain, again outside of evolutionary relationships (e.g., "Window blinds have slats so that they can capture dust.").

In the current study, a subset of items from the Kelemen et al. (2013) measure was chosen at random from each statement type in the original study to include 20 test sentences and 16 control sentences (4 true causal explanations, 5 true teleological explanations, 4 false causal explanations, and 3 false teleological explanations), without changing the sentences from the original version (see Additional file 1 for the full list of test sentences used). Therefore, the larger instrument was shortened here for time, but the subset used was intended to assess the construct of student endorsement of teleological reasoning, similar to the intent of the original version.

A second adaptation of the original measure was the use of a 5-point Likert scale in the current study to determine the student's level of agreement, rather than the previously used timed, two-alternative forced-choice test. Only student responses to the unwarranted teleological statements were included in the analysis because our focus in this paper was on student level of endorsement of teleological reasoning in the natural domain. The level of agreement on the 20 test questions were averaged to determine the level of student endorsement of teleological reasoning. Accordingly, the ordinal Likert variable was treated quantitatively in the analysis. The teleological reasoning survey scored student level of agreement with teleological, and thus inaccurate, explanations of natural phenomena. Therefore, a higher score on this measure indicated a higher endorsement of teleological reasoning and an underperformance in veridical evolution reasoning skills. Good-to-excellent reliability and criterion validity of this modified instrument has been presented (Wingert et al. 2022).

The third measure was the 24-item Inventory of Student Evolution Acceptance (I-SEA) which has been shown to be a reliable measure of evolution acceptance in college students (Nadelson and Southerland 2012; Nadelson and Hardy 2015; Sbeglia and Nehm 2018, 2019). The three subscales of the I-SEA (microevolution, macroevolution, and human evolution) were analyzed separately because evolution acceptance has been shown to be a multidimensional construct (Sbeglia and Nehm 2019). Each subscale consists of 8 questions each utilizing a 5-point Likert level-of-agreement scale. Therefore, the total score of out of a scale of 40 was recorded for each subscale.

This survey also included student demographic information, including gender (female, male, or non-binary), level of prior exposure to evolution, number of previous courses on evolution in high school and college, level of religiosity, and specific religious affiliation. Level of religiosity was assessed by asking students to self-report how important religion was in their life, using a 4-point Likert scale, ranging from *not important* to *very important*.

Students were classified as having either creationist or naturalist views on the origins of the world with a survey question on the pre-semester survey which asked: Which of the following views comes closest to your belief about the origins of the world? (a) God created the world or (b) The world is the product of purely natural forces like the Big Bang or evolution. This question was adapted from the National Survey of Youth and Religion (Youth and Religion//University of Notre Dame 2023). Students who selected the former option were categorized as having creationist views (CV) and students who selected the latter option were categorized as having naturalist views (NV).

Additionally, during the tenth week of the semester, students were asked to complete written responses to the following four open-ended questions: (1) Please describe your level of acceptance of evolution. (2) Have your views on evolution changed since an earlier point in your life? If so, what has caused this change? If not, please describe your reasons. (3) Have the readings and discussions in class been consistent with your views about life or has it been challenging? Please explain your answer. (4) Please describe your thinking about the causes of nature, evolution, and human life, rather than the purpose. Has your use of teleology changed?

Quantitative analysis

Mann–Whitney U (MWU) tests examined between-group (CV vs. NV) differences at both pre- and post-semester. Wilcoxon signed-rank (WSR) tests examined paired within-group differences between pre-and post-semester. Values are presented as mean (SD), effect sizes are presented as Hedges' g, and MWU and WSR test statistics are presented.

We also proposed five independent multiple linear regressions to determine the relative influence of each variable on the outcome variables. To assess the relative importance of the student variables in predicting post-semester teleological reasoning, we ran the following model: $Teleo_{post,i} = \beta_0 + \beta_1 \cdot CINS_{pre,i} + \beta_2 \cdot Teleo_{pre,i} + \beta_3 \cdot ISEA_{pre,i} + \beta_4 \cdot Creationism_i + \beta_5 \cdot Religiosity_i + \beta_6 \cdot PriorEdu_i + \varepsilon_i$; where $\varepsilon_i \overset{i.i.d}{\sim} N(0, \sigma^2)$. In this and the following models, the student's view of the world's origin was treated as a binary variable (i.e., creationist or naturalist views) and all other variables were linear variables. A second multiple linear regression assessed the relative importance of measured variables in predicting post-semester understanding of natural selection: $CINS_{post,i} = \beta_0 + \beta_1 \cdot CINS_{pre,i} + \beta_2 \cdot Teleo_{pre,i} + \beta_3 \cdot ISEA_{pre,i} + \beta_4 \cdot Creationism_i + \beta_5 \cdot Religiosity_i + \beta_6 \cdot PriorEdu_i + \varepsilon_i$; where $\varepsilon_i \overset{i.i.d}{\sim} N(0, \sigma^2)$. A third model assessed the relative importance of measured variables in predicting post-semester acceptance of macroevolution, a subset of the I-SEA: $ISEA_{Post-Macro,i} = \beta_0 + \beta_1 \cdot CINS_{pre,i} + \beta_2 \cdot Teleo_{pre,i} + \beta_3 \cdot ISEA_{pre-Macro,i} + \beta_4 \cdot Creationism_i + \beta_5 \cdot Religiosity_i + \beta_6 \cdot PriorEdu_i + \varepsilon_i$; where $\varepsilon_i \overset{i.i.d}{\sim} N(0, \sigma^2)$. A fourth model assessed the relative importance of measured variables in predicting post-semester acceptance of microevolution, a subset of the I-SEA: $ISEA_{Post-Micro,i} = \beta_0 + \beta_1 \cdot CINS_{pre,i} + \beta_2 \cdot Teleo_{pre,i} + \beta_3 \cdot ISEA_{pre-Micro,i} + \beta_4 \cdot Creationism_i + \beta_5 \cdot Religiosity_i + \beta_6 \cdot PriorEdu_i + \varepsilon_i$; where $\varepsilon_i \overset{i.i.d}{\sim} N(0, \sigma^2)$. Lastly, we assessed the relative importance of the

student variables in predicting post-semester acceptance of human evolution with the following model: $SEA_{Post-Human,i} = \beta_0 + \beta_1 \cdot CINS_{pre,i} + \beta_2 \cdot Teleo_{pre,i} + \beta_3 \cdot ISEA_{pre-Human,i} + \beta_4 \cdot Creationism_i + \beta_5 \cdot Religiosity_i + \beta_6 \cdot PriorEdu_i + \varepsilon_i$; where $\varepsilon_i \overset{i.i.d}{\sim} N(0, \sigma^2)$.

GraphPad Prism Version 9.3.1 (San Diego, CA) was used for all statistical analyses, except for the multiple regression analyses, which were calculated with R (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was set at $p < 0.05$.

Qualitative analysis

Two reviewers conducted a thematic analysis on the student responses to the open-ended questions. The first step of the thematic analysis was for both reviewers to independently read each student response and determine recurring themes (Additional file 2 for themes identified). The reviewers then independently re-read the student responses and identified when the themes were mentioned. If a student mentioned the theme at least once in their responses to any of the open-ended questions, a score of "1" was recorded for that theme in the student's response. Once interrater reliability of this method was established (Wingert et al. 2022), the total number of mentions from one reviewer (JW) was summed across students for each theme. Only the themes related to students' views on the impact of religion or creationism on learning and acceptance of evolution were included in this analysis.

Results

Of the 48 students who completed all surveys at both pre- and post-semester, 15 (31%) had creationist views and 31 (65%) had naturalist views. Two students (4%) selected both (a) God created the world and (b) The world is the product of purely natural forces like the Big Bang or evolution and their quantitative data were subsequently dropped from further analysis because the option to choose both answers was not offered as a choice. Therefore, the sample size for the statistical analysis was 46. Six percent (6%) of the students were sophomores, 35% juniors, 54% seniors, and 4% post-baccalaureate students. There were no between-group differences in gender, number of prior courses on evolution, or the students' self-reported level of prior exposure to evolution ($p > 0.05$). Self-reported religious affiliation included: 10% Catholic, 0% Eastern Religion, 15% Fundamental Christian, 2% Jewish, 0% Muslim, 17% Other Protestant, 19% Other, and 36% reported None. On the importance of religion in the students' lives at pre-semester, 35% listed "not important," 21% "slightly important," 17% "moderately important," and 25% listed "very important."

Endorsement of teleological reasoning

Students with creationist views (CV) entered the class with higher endorsement of teleological reasoning than students with naturalist views (NV) (Hedges' g = -0.73; MWU = 120.5; $p = 0.0077$) (Fig. 1A; Table 1). Over the semester, endorsement of teleological reasoning decreased for both CV (Hedges' g = −1.12; WSR = −120.0; $p = 0.0020$) and NV (Hedges' g = −1.24; WSR = −496.0; $p < 0.0001$), but the magnitude of teleology change was similar between groups ($p > 0.05$).

A multiple linear regression not only determined, but also quantified, the relative influence of each measured variable ($CINS_{pre}$, teleological $reasoning_{pre}$, $ISEA_{pre}$, and view on the world's origins (CV vs. NV), $religiosity_{pre}$, prior evolution education) on student post-semester endorsement of teleological reasoning. Although we include all pre-semester measurements in our model, our research focus was on the effects of creationist views. Our fitted model was:

$$\begin{aligned} Teleo_{post} = {} & 2.70 + 0.20 * Creationism - 0.04 * Religiosity_{pre} \\ & - 0.03 * CINSpre + 0.46 * Teleo_{pre} - 0.01 * ISEA_{pre} \\ & - 0.13 * PriorEdu \end{aligned}$$

To investigate the significance of the combination of all predictors, a F-test was conducted. The corresponding degrees of freedom of the underlying F-distribution are 6 and 39, since we have 6 predictors in the model, with a sample size of 46. (df1 = p-1, and df2 = n-p, where p is number of beta's in the regression model, and n is sample size). Together, an R^2 of 0.54 suggested that these variables accounted for 54% of the variance with significant unique variance contributed by only incoming level of endorsement of teleological reasoning (Additional File 3). Due to its small coefficient, having creationist views was not predictive or a determinant factor of endorsement of teleological reasoning.

Understanding of natural selection

Understanding of natural selection (CINS score) was significantly higher in the NV group compared to the CV group at both pre-semester (Hedges' g = 0.74; MWU = 143.5; $p = 0.036$) and post-semester (Hedges' g = 1.30; MWU = 84.0; $p = 0.0003$) (Fig. 1B; Table 1). Understanding of natural selection increased over the semester for both CV (Hedges' g = 0.70; WSR = 74.0; $p = 0.0078$) and NV (Hedges' g = 0.76; WSR = 377.0; $p < 0.0001$), but the magnitude of change did not differ between groups. At the end of the semester, understanding of natural selection in the CV group remained lower in magnitude than the NV group at pre-semester, indicating that the CV group never achieved the NV group level of understanding of natural selection entering the course.

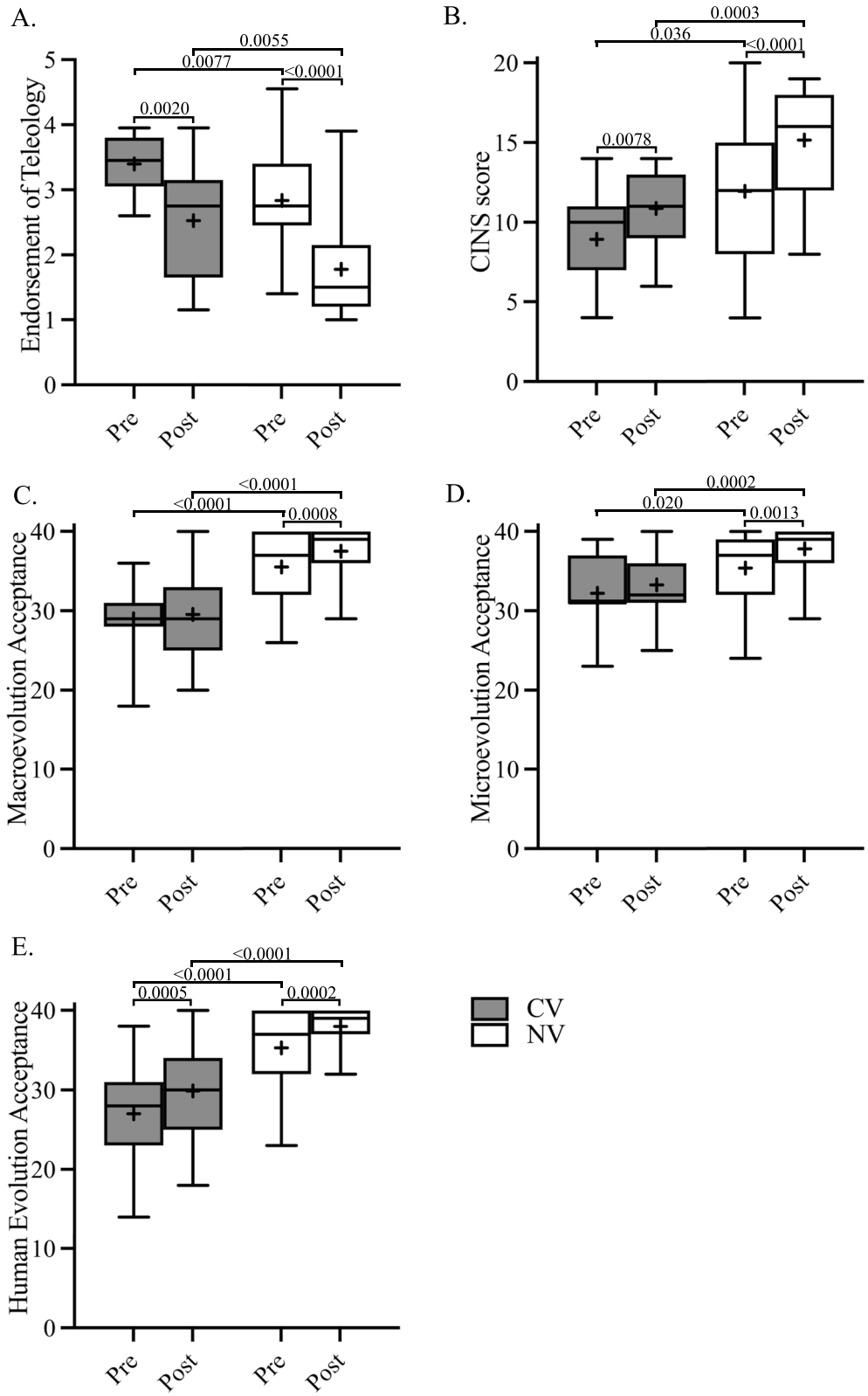

Fig. 1 Box and whisker plots of **A** endorsement of teleological reasoning, **B** understanding of natural selection (CINS), acceptance of **C** macroevolution, **D** microevolution, and **E** human evolution, at pre- and post-semester for the evolution course for students with creationist views (CV, gray) and naturalist views (NV, white). Mann–Whitney U test P-values and means (+) are shown

Table 1 Mann–Whitney U tests of the group differences between those with Creationist views and those with naturalist views are described below. Wilcoxon tests assessed within-group differences. Mean (SD) and effect size (Hedges' g) are reported.

	Creationist (CV) (n = 15)	Naturalist (NV) (n = 31)	Effect size (NV – CV)
Teleological reasoning			
Pre	3.40 (0.41)	2.84 (0.87)	− 0.73*
Post	2.53 (0.89)	1.78 (0.78)	− 0.90*
Effect size (Post–Pre)	− 1.12*	− 1.24***	
Natural selection understanding			
Pre	8.93 (2.74)	11.94 (4.49)	0.74*
Post	10.87 (2.42)	15.16 (3.56)	1.30**
Effect size (Post–Pre)	0.70*	0.76***	
Macroevolution			
Pre	29.00 (4.12)	35.52 (4.54)	1.48***
Post	29.53 (4.97)	37.48 (3.13)	2.09***
Effect size (Post–Pre)	0.12	0.51**	
Microevolution			
Pre	32.20 (4.77)	35.39 (4.71)	0.67*
Post	33.27 (3.92)	37.81 (3.12)	1.33**
Effect size (Post–Pre)	0.25	0.61*	
Human evolution			
Pre	27.00 (6.13)	35.29 (5.07)	1.53***
Post	29.87 (5.68)	37.97 (2.73)	2.07***
Effect size (Post–Pre)	0.49**	0.66**	

*p < 0.05; **p ≤ 0.001; ***p ≤ 0.0001

Table 2 Results from a multiple linear regression of post-semester student understanding of natural selection (CINS)

	β	SD(β)
Intercept	14.52	4.53
Creationist views	− 1.66	1.17
Religiosity_{pre}	− 1.15*	0.43
CINS_{pre}	0.43**	0.12
$\text{Teleological reasoning}_{pre}$	− 0.09	0.66
ISEA-total_{pre}	− 0.03	0.03
Prior evolution education	0.21	0.34
R^2	0.61	

*$p < 0.05$, **$p < 0.01$

The fitted multiple linear regression model was:

$$\begin{aligned}\text{CINS}_{post} = {} & 14.52 - 1.66 * \text{Creationism} - 1.15 * \text{Religiosity}_{pre} \\ & + 0.43 * \text{CINS}_{pre} + 0.09 * \text{Teleo}_{mathrmpre} \\ & - 0.03 * \text{ISEA}_{pre} + 0.21 * \text{PriorEdu}\end{aligned}$$

The model has a corresponding $R^2 = 0.61$; $F(6, 39) = 9.97$, $p < 0.0001$ (Table 2). Therefore, this model explains the majority of the variance of the post-semester CINS score. A closer look at creationism and pre-semester religiosity, shows that students' pre-semester religiosity has a strong influence on their post-semester CINS score, while being a creationist or naturalist does not impact post-semester CINS score. Recall that creationist vs naturalist views was a binary variable, while religiosity ranged from 1 to 4. Pre-semester religiosity score for the creationist group had a mean of 3.40 with a standard deviation of 0.63, while the naturalist group had a mean of 1.74 and a standard deviation of 1.03.

Acceptance of evolution

To analyze students' acceptance of evolution we analyzed the three I-SEA subscales (microevolution, macroevolution, and human evolution) individually. Pre- and post-semester between-group, as well as within-group, comparisons are conducted for each sub-scale study. Multiple linear regression models are considered for all three sub-scale I-SEA surveys.

Analysis of the I-SEA subscales showed differences in evolution acceptance between groups (Fig. 1C–E; Table 1). The NV group had higher acceptance of macroevolution compared to the CV at both pre- (Hedges' $g = 1.48$; $MWU = 68$; $p < 0.0001$) and post-semester (Hedges' $g = 2.09$; $MWU = 47$; $p < 0.0001$) (Fig. 1C; Table 1). The NV group's acceptance of macroevolution increased (Hedges' $g = 0.51$; $WSR = 193$; $p = 0.0008$)

during the semester, but there was no such change in the CV group ($p > 0.05$).

The corresponding fitted model was:

$$\begin{aligned}\text{ISEA\_Macro}_{post} = 19.30 - 4.21\text{*Creationism} - 0.01\text{*Religiosity}_{pre} \\ + 0.01\text{*CINS}_{pre} - 0.45\text{*Teleo}_{pre} \\ + 0.51\text{*ISEA\_Macro}_{pre} + 0.43\text{*PriorEdu}\end{aligned}$$

The model has a corresponding $R^2 = 0.73$; $F(6, 39) = 17.3$, $p < 0.0001$ (Table 3). Significant unique variance was contributed only by the student's creationism vs. naturalist views. Therefore, creationist reasoning did impact acceptance of macroevolution following the intervention. Having creationist views was associated with lower acceptance of macroevolution than having naturalist views (i.e., 4.21 points lower on the scale of 40).

Acceptance of microevolution was significantly higher in the NV group compared to CV at pre-semester (Hedges' $g = 0.67$; MWU = 134.5; $p = 0.020$). The NV group had increased acceptance of microevolution during the semester (Hedges' $g = 0.61$; MWU = 214.0; $p = 0.0013$), but the CV group did not change. At post-semester, the NV group had significantly higher acceptance of microevolution compared to the CV group (Hedges' $g = 1.33$; MWU = 85; $p = 0.0002$) (Fig. 1D; Table 1).

The fitted model was:

$$\begin{aligned}\text{ISEA\_Micro}_{post} = 29.36 - 1.85\text{*Creationism} - 0.86\text{*Religiosity}_{pre} \\ + 0.12\text{*CINS}_{pre} - 0.14\text{*Teleo}_{pre} \\ + 0.20\text{*ISEA\_Micro}_{pre} + 0.55\text{*PriorEdu}\end{aligned}$$

The model has a corresponding $R^2 = 0.49$; $F(6, 39) = 6.19$. None of the measured variables were predictive of post-semester acceptance of microevolution.

Acceptance of human evolution increased for both CV (Hedges' $g = 0.49$; WSR = 101.0; $p = 0.0005$) and NV (Hedges' $g = 0.66$; WSR = 182.0; $p = 0.0002$) during the semester and the changes for both groups were similar in magnitude (Fig. 1E, Table 1). But, the NV group had higher magnitude of human evolution acceptance compared with the CV group at both pre- (Hedges' $g = 1.53$; MWU = 66.50; $p < 0.0001$) and post-semester (Hedges' $g = 2.07$; MWU = 45.50; $p < 0.0001$). In fact, human evolution acceptance for the CV group remained lower at post-semester than the level of human evolution acceptance for the NV group at pre-semester (Hedges' $g = 1.01$; MWU = 108; $p = 0.0027$).

The fitted model was:

$$\begin{aligned}\text{ISEA\_Human}_{post} = 22.82 - 2.74\text{*Creationism} - 0.640\text{*Religiosity}_{pre} \\ - 0.10\text{*CINSpre} - 0.55\text{*Teleo}_{pre} \\ + 0.50\text{*ISEA\_Human}_{pre} + 0.39\text{*PriorEdu}\end{aligned}$$

This regression model has a corresponding $R^2 = 0.80$; $F(6, 39) = 26.28$; $p < 0.0001$ (Table 4). Significant unique variance was contributed only by the student's creationism vs. naturalist views. Therefore, creationist reasoning is relatively influential for post-semester acceptance of human evolution.

Qualitative analysis

All students also responded to four open-ended questions asking them to reflect on their experiences of learning about evolution and design teleology in this course. The thematic analysis in this paper focused on students who mentioned the relationship between religion or creationism and their learning or acceptance of evolution. (Additional file 2). A previously published paper described other aspects of the students' experiences with learning about evolution and design teleology (Wingert et al. 2022). Our thematic analysis determined that 66.7% (n = 32) of students mentioned religion or creationist views in their responses to four open-ended questions. For the students who mentioned religion or creationist views, we next analyzed themes related to religion or creationist views as being either *in conflict with* or *as compatible with* learning and/or accepting evolution.

Table 3 Results from a multiple linear regression of post-semester acceptance of macroevolution

	β	SD(β)
Intercept	19.30	5.22
Creationist views	−4.21**	1.42
Religiosity_{pre}	−0.01	0.50
CINS_{pre}	0.01	0.14
$\text{Teleological reasoning}_{pre}$	−0.45	0.76
$\text{Macroevolution}_{pre}$	0.51***	0.11
Prior evolution education	0.43	0.41
R^2	0.73	

$^{**}p < 0.01$, $^{***}p < 0.001$

Table 4 Results from a multiple linear regression of post-semester acceptance of human evolution

	β	SD(β)
Intercept	22.82	4.18
Creationist views	−2.74*	1.21
Religiosity_{pre}	−0.64	0.44
CINS_{pre}	−0.10	0.13
$\text{Teleological reasoning}_{pre}$	−0.55	0.66
$\text{Human evolution}_{pre}$	0.50***	0.08
Prior evolution education	0.39	0.35
R^2	0.80	

$^{*}p < 0.05$, $^{***}p < 0.001$

Perceived conflict between religion or creationist views and learning or accepting evolution

Half of our student sample (n = 24) mentioned their religious beliefs as being in perceived conflict with learning or accepting evolution, as if religion and evolution cannot be compatible with each other or are mutually exclusive. Below are example statements from students with this view.

> *"I'm a creationist. It is undeniable that microevolutionary occurrence has happened at a cellular level but I do not believe that we evolved over billions of years."*
> *"I struggle to say that I believe in evolution in its entirety, due to my being raised as a Christian."*
> *"I grew up in a household where religion was not present and so evolution has always been an easy concept for me to digest and to understand."*
> *"Evolution is a topic that I have not had much experience with growing up. I grew up in a Christian home with creationism as the main topic I was taught throughout my life. My Christian faith and beliefs are still extremely important to me, and are the way I see and view the world today. Coming into this class, I told myself to keep an open mind and strive to learn as much as I could about a topic I had not only hardly ever talked about in my childhood, but was also starkly different from my current beliefs. While I have appreciated the many different topics and discussions we have had in class, as well as the thought-provoking questions and readings, if I am to be fully honest I would have to say that up to this point there is still a lot about evolution that is hard for me to accept, […] a few months of this class has not been enough to change my thoughts about the world and my faith that have been characteristic of my life up to this point. Throughout this class there have been many points in time where I have struggled with questions and topics that have been hard to reconcile with my own beliefs. I think the one thing that has changed in my own head is just hearing and understanding that Evolution is simply change over time. I think this idea was largely absent in any mention of evolution throughout my life. Again, I believe that there is much I do not know on the arguments and research for evolution and that is something I hope to continue to educate myself on and learn. I have greatly appreciated hearing and learning so much about a topic that was not spoken of much in my upbringing, and it has been a very enlightening experience. However, even still evolution is difficult for me to accept in the present moment as I believe that God created the world, we are not here on accident, and there is intentional design in every human being. Along with this line of thinking, I also struggle with the concept of an extremely old earth and have always heard and believed that the earth was much younger than this."*
> *"This course has been challenging because it does contradict my faith and personal beliefs. My faith is something that is real. I choose to live my life trusting that God is my Creator and will continue to provide my basic needs and that I need Jesus Christ as my savior."*

Some students who accept evolution, stated that they are now able to do so only because they are no longer religious since they view religion and evolution as incompatible with each other. For example,

> *"I have believed in evolution for a long time. My belief really started when I moved away from religion in my personal life."*

Perceived compatibility between religion or creationist views and learning or accepting evolution

Nearly 40% of our student sample (n = 19) mentioned that they were able to view their religious views and their acceptance of evolution as compatible. For example,

> *"I am at a crossroads when it comes to evolution. Being raised in a Christian household, we never really talked about evolution, so it is interesting to learn about different ways the earth came about. I will say, this class has opened my eyes to many things, because the research is certainly there and is compelling. So, the crossroads I am at is balancing my beliefs in Christianity but also wanting to learn more about the earth and the human race as a whole. I would say my ideas of evolution have definitely developed from what they were before. As someone who didn't really understand or accept evolution (mostly because I wasn't introduced to it) I didn't really know much about its concepts. But this semester has been extremely fascinating in understanding viewpoints on how we've developed."*
> *"Growing up as a Christian at first it was hard to connect with the content of what we were reading and discussing in class. After learning about it, I can see and understand the ideas of evolution. I'm not 100% sure if I accept it, just from my religious background but I'm not opposed to learning more about evolution."*
> *"While I still believe that there may be higher powers at work in the universe, I do not believe that these higher powers had any say in evolution or that anything happens for a reason when it comes to*

mutations and adaptations."
"Evolution does not conflict with my spirituality because they can exist in tandem. We may all be expressions of God but that doesn't take away from the hard evidence that we evolved. Both can be true. If anything, the wondrous process of evolution validates and strengthens my faith in the divine mysteries of the universe."
"I am almost leading a double life with what I believe. I believe in evolution to an extent but I also have faith. This class has made this a struggle for me! Accepting both has been an interesting journey this semester."
"It is interesting to me as a Christian to believe in both evolution as well as god. There's a level to my acceptance as well as to my belief."

Religiosity

Students with creationist views (CV) had higher levels of religiosity than students with naturalist views (NV), at both pre- (CV mean (SD): 3.40 (0.63) vs. NV mean (SD): 1.74 (1.03); MWU = 55; $p < 0.0001$) and post-semester (CV mean (SD): 3.56 (0.63) vs. NV mean (SD): 1.48 (0.68); MWU = 15; $p < 0.0001$). However, there was no change in level of religiosity across the semester for either group ($p > 0.05$). On average, our students entered and completed this course with a moderate level of religiosity, suggesting that evolution instruction with specific efforts to regulate student endorsement of teleological reasoning did not affect the level of religiosity among students. Changing student level of religiosity was not an aim of this course. However, in response to the open-ended questions, many students mentioned that their perceptions of the relationship between religion or creationist views and evolution changed. Many students who mentioned that their religious views are compatible with evolution also wrote that this course was the first time that they had learned about evolution in an accurate and compelling way. Several students also wrote that evolution had not been a part of their family and peer discussions or previous education.

Discussion

The data presented in this study provide preliminary evidence describing the influence of student creationist views on levels of design teleological reasoning and acceptance and understanding of natural selection in undergraduate students in a semester-long course on human evolution. The purpose of this study was to evaluate quantitative data and open-ended responses describing students' experiences of learning about human evolution and increasing awareness of teleological reasoning. Taken together, these data reveal the real and perceived challenges that people with religious beliefs, especially those with creationist views, may face when learning evolution. Our primary findings were that students with creationist views had decreased teleological reasoning and increased learning and acceptance of evolution similar in magnitude to the gains observed in students with naturalist views. However, students with CV far underperformed their NV counterparts on all of these measures. We also found that religiosity negatively predicted student understanding of natural selection, whereas having creationist views negatively predicted acceptance of macro- and human evolution. The thematic analysis showed that more students viewed religion and evolution as incompatible than students who viewed them as compatible.

As hypothesized, students with creationist views entered the human evolution course with significantly higher endorsement of design teleological reasoning compared to students with naturalist views. This finding is consistent with those of Lawson and Weser (Lawson and Weser 1990) who found that undergraduates with less-skilled reasoning enter a Biology course more likely to believe in nonscientific concepts such as creationism and teleological reasoning. Several other previous studies have shown that people with religious, especially fundamentalist Christian, views are more likely to explain the existence of behaviors and origins of entities in the natural world with reference to design that serves a purpose, function, or goal (Banerjee and Bloom 2014). According to this view, Christians who take a literal view of the doctrine believe that God is the design agent for things in the natural world. The design-based teleological stance is reinforced by the creationism of fundamental Christianity (Diesendruck and Haber 2009). However, design teleological explanations of nature have also been shown in non-believers (Järnefelt et al. 2015). The level of student design teleological reasoning is important because this way of thinking impedes accurate learning of natural selection (Kampourakis 2020b; Barnes et al. 2017b; Hammann and Nehm 2020; Wingert and Hale 2021) and other biological sciences (Werth and Allchin 2020). Furthermore, level of endorsement of teleological reasoning was recently shown to be the strongest predictor of understanding of natural selection entering a course on evolution (Wingert et al. 2022).

The data presented here support the novel finding that student endorsement of teleological reasoning declines in magnitude similarly in both CV and NV groups in response to an evolution course which incorporates pedagogical activities intended to teach students to regulate their teleological reasoning. This finding is in

contrast with Lawson and Weser (1990) who found that students with less hypothetico-deductive reasoning skill were less likely than more skilled reasoners to change the degree to which they held non-scientific beliefs. In the current study, over the course of the semester, students with CV had decreased teleological reasoning, increased understanding of natural selection, and increased acceptance of macro- and human evolution. By the end of the semester, students with CV had lower levels of teleological reasoning than the NV group began the semester with. These findings suggests that religious faith does not restrict students to a design-based stance on nature, but that CV students can learn to regulate their teleological reasoning. Nonetheless, religious faith does appear to represent a sizeable emotional or conceptual obstacle for students with CV when learning about evolution (Kampourakis 2020b). Students with CV have been taught that God has a purposeful plan and being confronted with the reality that evolution is directionless and devoid of a greater meaning can cause these students to feel as though their belief system is incompatible with this new information (Yasri and Mancy 2016; Yasri et al. 2013). As a result, they may face an emotional, cognitive, and/or existential conflict (Long 2012; Thagard and Findlay 2010).

While the theory of evolution itself is not controversial, there is political controversy around the teaching of evolution among creationists, which may cause CV students to perceive evolution and religion as antithetical (Hildebrand et al. 2008). In their reflective writing, some students expressed a clear discordance between their belief in God and full acceptance of evolution or an inability to fully accept evolution as a result of their religious upbringing. Our data support efforts of science instructors to teach about the disruptive impact of design-based teleological explanations alongside the veridical evolutionary mechanisms. Encouragingly, our data also show that students with CV are responsive to these messages. It is possible that this latter finding may be specific to only students with creationist views who chose to take a human evolution course. Perhaps these students are more open to non-teleological thinking and human evolution instruction than people with creationist views in the general public who would be unwilling to take a course on human evolution. Barnes et al. suggested that teaching the application of evolution, in this case the application of evolution to understanding human health and disease, may enhance the ease of acceptance, especially acceptance of human evolution (Barnes et al. 2017b). Future research should look at the difference between applied and non-applied evolution courses and the level of acceptance in NV and CV students.

While magnitude of teleological reasoning of the CV group declined over the course of the semester to levels similar to the NV group at pre-semester, post-semester acceptance and understanding of natural selection in the CV group remained lower than NV levels, not only at post-semester, but also at pre-semester. Our data indicate that students with CV began the course on evolution with a significant knowledge gap on natural selection, despite similar levels of prior education on evolution. If the primary objective of a course on evolution is to improve understanding of natural selection, our data indicate that those with creationist views are capable of achieving learning gains similar to those with NV, but they are not able to catch up with those with NV by the end of the semester. Unfortunately, we were unable to directly associate student course grades with their quantitative data or reflective writing due to anonymous data collection to protect the privacy of our sample. However, we suspect that given the significantly lower CINS scores of the CV group at post-semester compared to the NV group, students with creationist views likely ended the semester with lower grades. Future research should investigate whether students with creationist views are at a grade-disadvantage in evolution courses, or science courses more generally, as a result of the presence of creationist views and/or a design-teleology stance.

The CINS does not include questions of understanding of human evolution, which was the focus of this course. Instead, it assesses general knowledge of evolutionary mechanisms using other animal examples (e.g., guppies, lizards, and finches), requiring a generalized understanding of natural selection. It is possible that students in the NV group were more capable than the CV group of applying the evolutionary concepts presented on humans to other species.

The CV group had lower acceptance of evolution than the NV group at both pre- and post-semester. The I-SEA allows a more granular look at component parts of evolution acceptance, namely macroevolution, microevolution, and human evolution (Nadelson and Southerland 2012). The three dimensions of evolutionary study carry different levels of acceptance for people with creationist views. Macroevolution is the study of speciation and the evolution of new taxonomic groups over long periods of time and tends to be challenging for those who believe that God created immutable organisms (Padian 2010; Mead et al. 2017). Accordingly, students in the CV group entered the course with significantly lower acceptance of macroevolution than those with naturalist views and acceptance of macroevolution remained lower over the semester for the CV group. Acceptance of macroevolution did not change in the CV group, but did increase for the NV group, over the semester.

In contrast, people with creationist views tend to be more accepting of microevolution because it describes small, less conspicuous changes within a species (Scott 2001). However, only the NV group made significant gains in microevolution acceptance over the course of the semester, which did not occur for the CV group. These data suggest that students in the NV group were more receptive to learning about microevolution than the CV group, which was not predicted.

Perhaps most relevant in a course on human evolution is level of student acceptance of human evolution. Students in the NV group had higher acceptance of human evolution compared to the CV group at both pre- and post-semester. This is consistent with public opinion surveys showing that people with fundamental religious, especially creationist, views believe that God created humans and tend to reject human evolution (Funk 2019; Swift and In 2017). Surprisingly, students in the CV group did demonstrate significant gains in their acceptance of human evolution over the semester, suggesting that students with creationist views were similarly receptive to learning about human evolution. However, the CV group's human evolution acceptance at post-semester remained lower than the NV group's human evolution acceptance prior to instruction. Therefore, similar to evolution understanding, acceptance of human evolution in the CV group never caught up with the levels of the NV group. In fact, multiple regression analyses showed that having creationist views was a significant predictor of both lower macroevolution and lower human evolution acceptance at the end of the semester. These findings are consistent with those of Jensen et al. (2019), who proposed the model that religiosity directly influences the acceptance of creationist views and that creationist views, in turn, directly influence evolution acceptance.

Our thematic analysis showed that the majority of students who mentioned religion in their reflective writing on acceptance of evolution described a potentially insurmountable conflict between religion and accepting evolution. The majority of students who mentioned religion in their reflective writing described believing that religion and evolution are discordant. Even several students with naturalist or atheistic views wrote that they believe in evolution *because* they did not grow up in a religious family, describing a perceived conflict between the two. Consistent with this finding, a Pew Center Research survey found that people who are not affiliated with a religious tradition are more likely to think that science and religion conflict (76%), while about half of surveyed evangelical Protestants and Catholics believe science and religion are mostly compatible (Pew Research Center 2015). Over one-third of students in our study viewed religion and evolution to be compatible. Several students mentioned an interest in or willingness to learn more about evolution alongside their religious views, an openness that is sometimes referred to as theistic evolution (Scott 2001) or accommodation (Pennock 2000). Below, we discuss ways to support these students' learning of evolution.

Limitations

Although there is value to the findings presented here on the effects of creationist views on student teleological reasoning and learning and acceptance of evolution, this study has several limitations that should be considered. The primary limitation of this study is its small sample size, which compromises generalizability to the wider population. Further affecting generalizability is the fact that students who strictly oppose human evolution are doubtful to enroll in a course on human evolution, which may cause selection bias and skew data toward acceptance and decreased teleological thinking compared with a representative sample. Unknown is the extent to which the wider population of people with creationist views could alter their endorsement of design teleology and acceptance and understanding of evolution. However, this study does provide evidence to support pedagogies directed at decreasing design teleology.

A second important limitation is the unknown validity and reliability of the measure of teleological reasoning, modified here from Kelemen et al. (2013). Although preliminary support for criterion reliability and validity has been presented (Wingert et al. 2022), work to further validate this measure is needed.

Another important limitation is our use of a single dichotomous question to determine whether students have creationist or naturalist views on the origins of the world. This method is potentially oversimplified and may not have captured students' true or nuanced views on the origins of the world. For example, two students in our sample selected both options, suggesting that the options, presented as such, did not match their views (quantitative data from these students were not included in the analysis). Perhaps a third option allowing the choice of "Other" or that a higher power created life and that natural forces had an influence, should have been included as an option (Hill 2014). Also, a fourth choice of "None" could have been used. Or, follow-up questions exploring additional nuanced views on the origin question could have revealed more accurate information on students' views on the world's origins (Jensen et al. 2019; Hill 2014). A related limitation is our use of a single question to determine student level of religiosity. Perhaps a better method for determining religiosity is the scale developed by Cohen et al. (2008), which has

been validated in and widely used to assess religiosity of college students (Barnes et al. 2017a).

Another limitation is that all data were collected anonymously to protect the privacy of students, which prevented the direct linking of quantitative data with qualitative responses or final course grades. Therefore, we were unable to determine if certain themes in student writing were related to the quantitative measures of design teleological reasoning, understanding natural selection, or acceptance of evolution. Another limitation may be the result of students trying to meet their perceived expectations of the professor (Long 2012). This could lead to students not sharing their true beliefs about evolution in their open responses or selecting a choice on the survey because they know that is the correct answer in terms of the course, but not because they actually believe it is correct. However, the anonymity of the responses and surveys hopefully attenuated the extent to which this occurred. A further potential limitation identified by Gouvea and Simon is that the wording of questions in the surveys may cause students to acknowledge a teleological statement as correct because they identify a true relationship between two variables, however the use of a Likert scale, rather than a two-alternative forced-choice, in this study sought to address this by not requiring students to fully accept or reject each statement (Gouvea and Simon 2018).

Implications for Teaching

The data presented adds support to the findings of others that students with creationist views have higher endorsement of design-based teleological reasoning and lower acceptance and understanding of natural selection. Importantly, this study adds to previous work with the novel finding that similar levels of improvement on all of these measures were evident in both groups following a semester-long course on human evolution. Taken together, our quantitative and qualitative data support the idea that religion, even creationism, and evolution do not have to be strictly in conflict within students' thinking. Some instructors may not address this perceived conflict, but this study supports the stance of Barnes and Brownell that allowing room for open discussion may help CV students accept evolution to a greater extent than if their views on life's origins are rejected outright (Barnes and Brownell 2016). Barnes et al. suggest including a short (e.g., two-week) module describing the potential compatibility between religion and evolution, which may include a presentation from a religious evolutionary scientist (Barnes et al. 2017a) or, if applicable, the instructor's description of their own experiences with religion and evolution (Barnes and Brownell 2016). Winslow et al. (2011) detail the potential role of a religious science professor in helping their Christian science students seek reconciliation between evolutionary theory and their personal religious beliefs, including, and perhaps most consequentially, discussions with their parents about understanding evolution.

Evolution instructors should assess their students' views on the origins of life and their openness to evolution to find ways of supporting student learning for students with diverse backgrounds. The framework synthesized by Yasri et al. (2016) on the relationship between religion and science might be a helpful starting point for these classroom discussions. This framework describes different stances a student might take in determining whether science and religion are compatible or incompatible (Yasri and Mancy 2016; Yasri et al. 2013). Barnes et al. have shown that a majority of students appreciate learning that religion and evolution do not have to be in conflict, and that they do not need to pick a side in order to be a successful student in an evolution course (Barnes et al. 2017a). Several pedagogical tools are available for use in an evolution course to help students, especially religious students, to reconcile perceived differences between evolution theory and religion. For example, science educators have suggested that nature of science (NOS) instruction, especially prior to instruction on evolution, increases evolution acceptance and understanding in undergraduates (Scharmann 2018; Nelson et al. 2019), as well as facilitation of reconciliation of evolution with religious values (Winslow et al. 2011). NOS familiarizes students with the limits of evolutionary theory and helps them recognize that evolutionary theory does not preclude other explanations. NOS also teaches students to determine which explanations about life, (e.g., evolution and/or religion) are more scientific (Scharmann 2018). As a result, NOS teaches a useful set of principles by which students can determine whether commonly held beliefs such as intelligent design stand up to scientific analysis and can produce valid scientific research programs (Peterson 2002; Scharmann et al. 2005). Similarly, Gould's essay "Nonoverlapping Magesteria" describes religion and science as two distinct domains of inquiry, which need not be in conflict (Gould 1997). Gould's essay might teach students with religious values that not only can religion and science be compatible, but in Gould's view, attention to both are necessary to attain wisdom. Therefore, if no longer perceiving a conflict, religious students may be better positioned to understand, and even accept, evolution.

Our data indicate that students with creationist views who choose to take a course on human evolution are more likely to begin the course with higher levels of teleological endorsement, likely resulting from their greater exposure to design-based theology (Banerjee and Bloom 2014;

Diesendruck and Haber 2009). We agree with Barnes et al. (2020) that evolution should be taught in agnostic, rather than atheistic, terms in order to facilitate learning in students with creationist views, especially those who are open to learning about evolution. In teaching this course, we utilized advocacy and procedural neutrality, two approaches described by Hermann as being effective in the teaching of evolution (Hermann 2008). Advocacy specifically targets increasing student understanding which can lead to improved acceptance, and neutrality is aimed at promoting acceptance. Both approaches allow opportunities for students to investigate their own views on evolution (Hermann 2008).

Our data also provided further evidence that ingrained teleological reasoning is a mechanism for decreased understanding of evolution. We encourage evolution instructors to discuss the ubiquity, universality, and potential pitfalls of design-based teleological reasoning and the potential reinforcing influence of fundamental religious views, particularly creationism, on teleological reasoning as part of a course on evolution. The purpose of this discussion with students is not to be critical of their creationist views, but to describe the documented challenges in an evolution classroom associated with those views. Awareness of the understanding and acceptance deficits associated with creationist views may motivate some students to think deeper about the evolution evidence and their own beliefs and design-based teleological reasoning. While some authors have suggested that students with creationist views be examined separately in evolution courses from students with naturalist views (Barnes et al. 2020), we believe the instructor should provide support to students with religious views in this important critical thinking process by providing opportunities for students to self-assess and receive feedback on their teleological tendencies. Such support is intended to acknowledge, not ignore, that there can be tension between the concepts of evolution and one's religious views (Hildebrand et al. 2008). This approach does not disregard the value of one's religious beliefs, but, consistent with NOS principles, emphasizes that science is uniquely able to explain the natural world (Hildebrand et al. 2008; Scharmann 2018; Gould 1997). The evolution teacher will be better positioned to achieve greater learning gains across students with diverse backgrounds when they acknowledge the tension between religious and scientific thinking, the differences between the two ways of understanding life, and the effects of teleology on learning.

Despite being commonly used in scientific explanations, design teleological reasoning is learned behavior and can be modified with additional causal evolution evidence and opportunities for reflection on one's cognitive biases. We presented evidence to show that directly addressing the tendency to rely on design teleological reasoning and to challenge this way of thinking supports students' conceptual change (Kampourakis 2020a). To decrease design teleological reasoning and increase evolution learning, we suggest the pedagogical methods presented here: a series of quizzes which ask the student to identify and then re-write the teleological statement, class discussion on design teleology with numerous examples, and reflective writing on one's experiences with teleological thinking. These activities will give the student opportunities to think critically about design teleology versus veridical evolutionary mechanisms. Such activities can be effectively incorporated into misconception-focused instruction, which has been shown to increase understanding of evolution (Nehm et al. 2022). A course on human evolution provides opportunities for the instructor to exhibit a strong scientific foundation with appropriate uses of teleological thinking patterns, which has the potential to modify students' cognitive processes (Kampourakis 2020b; González Galli et al. 2020; Liquin and Lombrozo 2018.

Conclusion

Students with creationist views demonstrated decreases in teleological reasoning and improvements in understanding and acceptance of natural selection. In fact, the magnitudes of these changes were similar to students with naturalist views. This suggests that having religious views does not restrict students' abilities to learn about natural selection and to think less teleologically. However, students with CV did not catch up with NV students on these measures by post-semester. Half of the students in this sample believed that religious views and evolution were not compatible, and a smaller percentage believed that the two views could accommodate each other. It is important to identify strategies to help students with a variety of religious perspectives to better learn science.

Abbreviations

ISEA	Inventory of Student Evolution Acceptance
CINS	Conceptual Inventory of Natural Selection
CV	Creationist views
NV	Naturalist views
MWU	Mann Whitney U test statistic
WSR	Wilcoxon Signed Rank test statistic

Supplementary Information

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Additional file 1. The following survey items were selected from a larger sample developed by Kelemen et al. (2013). Participants were asked to select how they would respond to each of the following statements using a 5-point Likert scale, where 1=Strongly Disagree, 2=Disagree, 3=Neither

Agree or Disagree, 4=Agree, 5=Strongly Agree. Following each item is its designation as unwarranted teleological (UT), true teleological (TT), false teleological (FT), true causal (TC), and false causal (FC), from Kelemen et al. (2013). Only student responses to the UT statements were used in the analysis. Likert-score responses were averaged across the 20 UT statements.

Additional file 2. The themes identified from the student responses to four open-ended questions and coding strategy for thematic analysis. Only themes related to students' views on religion and learning/acceptance of evolution were included in this analysis. The included themes are indicated(*).

Additional file 3. Results from a multiple linear regression of post-semester student teleological reasoning (Teleo).

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Author contributions
JRW: Conception and design of study, statistical analysis, data interpretation, prepared figures and tables, manuscript authorship. GB: Manuscript authorship. CT: Data analysis and interpretation, manuscript authorship. KC: Statistical analysis, data interpretation, manuscript authorship. JL: Statistical analysis, data interpretation, manuscript authorship. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets supporting the conclusions of this article are available in the Open Science Framework repository, https://osf.io/4cq3e/?view_only=252d3ee79e944ad48797f00a3a48131b.

Declarations

Ethics approval and consent to participate
This research has been determined to be exempt from further review by the IRB at the University of North Carolina Asheville. Research participant consent forms have been obtained according to the policies of the Human Studies Committee at the University of North Carolina Asheville.

Consent for publication
Not applicable.

Competing interests
The authors have no conflicts of interest.

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