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An exploratory study on students' denominations, personal religious faith, knowledge about, and acceptance of evolution

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Abstract

Background The theory of evolution serves as an overarching scientific principle for all areas of biology. Hence, knowledge about and acceptance of evolution are indispensable for holistic education. However, the levels of knowledge about and acceptance of evolution vary greatly. It is supposed that insufficient knowledge and lack of acceptance are associated with high personal religious faith and affiliated denominations. Therefore, it is fundamental to examine knowledge about and acceptance of evolution, personal religious faith, and denomination.

Results We conducted an exploratory study with German upper secondary school students ($N = 172$). Firstly, the results showed a weak to moderate correlation between knowledge about and acceptance of evolution. Secondly, students of different denominations differed in their knowledge about evolution, use of key concepts, acceptance of evolution, and personal religious faith but not in their use of misconceptions. Thirdly, the findings revealed that a student's denomination predicts knowledge level, whereas personal religious faith predicts acceptance.

Conclusions Our exploratory study indicates that, in addition to the strength of personal religious faith, the denomination may be critical to knowledge about and acceptance of evolution.

Keywords Acceptance, Concept, Contextual reasoning, Denomination, Education, Evolution, Evolutionary knowledge, Faith, Religiosity, Secondary school students

Introduction

Biological evolution (in the following referred to as evolution) is the explanatory theory for the development of living nature, with natural selection as the key mechanism for the development of species (German National Academy of Sciences Leopoldina 2017). An understanding of evolutionary processes is an essential requirement for students' active and educated participation in social discourse on topics such as species extinction due to climate change or the adaptation of vaccines due to the mutation of viruses (Council of Europe 2007; Dunk et al. 2019; Smith 2010). Therefore, understanding of evolution has societal value (e.g., Brasseur 2007; German National Academy of Sciences Leopoldina 2017) and is elementary to educational curricula (e.g., Department for Education [England] 2014; Ministry for School and Education of North Rhine-Westphalia 2013). Evolution and the underlying process of natural selection are important learning contents, but they are difficult for students to understand and reason about it (Beniermann 2019; Fenner 2013; Kuschmierz et al. 2020b; Lammert 2012). Further difficulties arise from students' conceptions about evolution, which often consist of a mixture of scientific facts or key concepts and naïve ideas or misconceptions (Opfer

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et al. 2012). To address misconceptions and strengthen scientific understanding of evolution and the use of key concepts, it is necessary to examine factors related to or predictive of students' knowledge about evolution. Studies suggest that knowledge is positively associated with a high level of acceptance (e.g., Großschedl et al. 2018; Kuschmierz et al. 2020b). Furthermore, knowledge acquisition could be inhibited by alternative explanations or beliefs, such as religious views (Dunk et al. 2019).

However, it is not fully understood how the interplay between these alternative explanations or beliefs, the knowledge about and acceptance of evolution is constituted. Moreover, it is unknown, to what extent these variables are predictive of knowledge about and acceptance of evolution (Dunk et al. 2019; Smith & Siegel 2016). Previous studies of individuals' religious characteristics commonly only collected data on the construct of personal religious faith and disregarded denominations. Consequently, this study investigates whether and to what extent personal religious faith and denominations predict knowledge about and acceptance of evolution. Additionally, this study assesses whether and to what extent the two variables lead to differences in reasoning about evolutionary processes of natural selection. Our findings support previous results on personal religious faith and the relation between knowledge about and acceptance of evolution of different denominations of German secondary school students. The findings can be used to inform educators about potential barriers of students learning evolution. Our recommendations focus on the importance of educators' awareness of religious groups and the position of their views in evolution lessons. Based on our findings, educators can derive teaching approaches that create a learning environment in which students can bring their religious views in accordance with knowledge about evolution in a scientifically compliant manner. Such approaches could focus on a more agnostic than an atheistic view of evolution to help students with the often-suggested reconciliation of religious and scientific views (e.g., Barnes 2020b, 2021b; Truong 2018).

Background

Knowledge about evolution, key concepts, and misconceptions

Knowledge about evolution is the basis for understanding evolution (Anderson et al. 2001; Bloom et al. 1956; Kuschmierz et al. 2020b; Smith & Siegel 2016). In particular, knowledge about the evolutionary process of natural selection is widely studied for students' use of key concepts and misconceptions. Key concepts constitute scientific ideas (Opfer et al. 2012). They are divided into three core concepts (variation, heritability, and individual fitness; Nehm & Ha 2011), which are essential for a scientifically correct explanation of evolutionary change and can be complemented by additional concepts (e.g., resource limitation) that allow for a more in-depth explanation (Bishop & Anderson 1990; Nehm & Reilly 2007).

The counterparts of key concepts are misconceptions, which are defined as inaccurate (Nehm et al. 2010), non-normative (Opfer et al. 2012), or naïve ideas (Federer et al. 2015; Nehm & Ha 2011) and may result from cognitive biases (Heddy & Sinatra 2013; Kelemen 2011). Previous research has shown that misconceptions are already developed in childhood. Subsequent attempts to clarify these misconceptions through scientific explanations encounter great resistance (Bloom & Weisberg 2007; Kuschmierz et al. 2020b). Moreover, key concepts and misconceptions can co-exist (Opfer et al. 2012). Students' most common misconceptions are based on teleological ideas (or finalism; the assumption that evolution is purposeful), intentionality (the assumption of the intentional, active adaptation of individuals to new situations), and essentialism (the assumption of fixed categories based on an immutable essence, which creates the illusion that the evolutionary emergence of new species from different ancestors is impossible; e.g., Beniermann 2019; Kelemen 2011; Opfer et al. 2012; Sinatra et al. 2008; Smith 2010).

Studies investigating the knowledge about evolution of German secondary school students are still rare (Kuschmierz et al. 2020b). There are indications that students possess very low to moderate knowledge about evolutionary processes and concepts (Beniermann 2019; Fenner 2013; Kuschmierz 2020a, 2020b; Lammert 2012) and continue to use misconceptions after learning about evolution (Lammert 2012).

Conceptual ecology

The conceptual ecology model offers an explanation for understanding how people interpret information through individual frames. A person's conceptual ecology may contribute to the person's difficulties to develop or transform a preliminary understanding of a particular topic (Park 2007; Posner & Strike 1992; Strike & Posner 1982). Thus, acquiring knowledge or accepting scientific facts can be the result of several considerations which differ based on the individual prerequisites (e.g., knowledge, attitudes, and epistemological beliefs; Deniz et al. 2008). The conceptual ecology model explains interactions between personal prerequisites and their impact on knowledge development (e.g., learning about evolution and the acceptance of it; Deniz et al. 2008; Park 2007). Therefore, it can be assumed that a person's religious characteristics, consisting of the personal religious faith and the denomination, are relevant to knowledge

about and acceptance of evolution (Deniz et al. 2008; Großschedl et al. 2014; Kuschmierz et al. 2021).

Acceptance of evolution

In a cross-country public opinion survey of the Eurobarometer, participants were asked whether they agree with the statement "[h]uman beings, as we know them today, developed from earlier species of animals" (European Commission 2021). Similar surveys, using the same item, were conducted with participants in the United States (Miller et al. 2006, 2022). The international comparison of acceptance scores shows that the acceptance of human evolution in Germany is rather high. For example, 66% of the participants in Germany and 53% in the United States accept human evolution as true (European Commission 2021; Miller et al. 2022). The results on German participants reflect the average European acceptance (67%; European Commission 2021). Compared to an earlier Eurobarometer survey of Germany's public acceptance of human evolution in 2005, the acceptance has declined by 3% (Directorate General Press and Communication 2005). However, the acceptance of human evolution is usually lower compared to the acceptance of the general or animal evolution when human evolution is excluded (Everhart & Hameed 2013; Unsworth & Voas 2018).

It is assumed that these differences in acceptance are, among other things, linked to the level of knowledge about evolution or personal religious faith (Dunk et al. 2017; Ha et al. 2012). However, it must be critically noted that further research indicates that a certain level of knowledge must be present in students for the connection between acceptance and knowledge to be significant. Especially younger and more inexperienced students in Germany partly revealed only a low positive correlation between knowledge about and acceptance of evolution (Beniermann 2019; Fenner 2013; Kuschmierz et al. 2020b; Lammert 2012; Southerland & Sinatra 2005).

Personal religious faith

Personal religious faith often referred to as religiosity, is "the degree to which religious faith and conviction have an impact on daily life" (Dunk et al. 2017, p. 2). European studies suggest a negative, mostly strong correlation between personal religious faith and acceptance of evolution and assume that personal religious faith is a predictor of acceptance of evolution (e.g., Großschedl et al. 2014; Kuschmierz et al. 2020b). Previous research shows that there is evidence that personal religious faith is negatively related to knowledge about evolutionary processes of natural selection but even more strongly related to acceptance of evolution. Furthermore, it was found that the religiosity of students is a significant predictor of their acceptance of evolution (Barnes et al., 2017a). These findings are consistent with the majority of studies, claiming that non-religious people or ones with low personal religious faith have higher evolution acceptance scores than (strongly) religious people (Betti et al. 2020; Unsworth & Voas 2018).

However, there is not necessarily a correlation, as personal religious faith does not always lead to lower acceptance of evolution. This argument is underlined by studies showing that religious people, both from the scientific community and the general population, accept evolution (Ecklund & Scheitle 2014; Everhart & Hameed 2013; Martin 2010).

Denominations and religious affiliations

According to the conceptual ecology model, a person's preconditions can affect information processing and, thus, knowledge building. As aforementioned, there is an indication that a person's personal religious faith can impact the knowledge about and acceptance of evolution. However, as denominations represent different interpretations of faith, including a person's views, values, and prioritization, the denomination might also be a relevant factor.

Barone et al. (2014) present evidence that a person's denomination is more predictive of acceptance of evolution than of knowledge about it. In this context, previous studies show that atheists have the highest acceptance scores while, for example, people of Christian or Muslim denominations tend to have lower scores (e.g., Betti et al. 2020; Unsworth & Voas 2018). Barnes et al. (2021a) showed in an American context that undergraduates with a Muslim denomination tended to have a lower acceptance of evolution than undergraduates of other denominations. These results were confirmed in studies examining German secondary school students, where students from a Muslim denomination had the lowest acceptance rate and even differed significantly from Protestants, who had the second-lowest acceptance rate (Fenner 2013; Lammert 2012). However, when comparing these results, it is important to note that the population proportions and faith interpretation vary depending on the studied region. For instance, the Christian communities in Germany and the United States differ, as Protestants in Germany are mainly Lutheran, Reformed, and United (Evangelical Church in Germany 2016). At the same time, Evangelicals are the largest Protestant group in the United States (Pew Research Center 2007) and are known for often interpreting the bible literally (Schneider 2020). Since both the strength of the personal religious faith and denomination shape the subjective perspective and how scientific knowledge about evolution is filtered (Clément 2015a, 2015b), both must be considered

in analyses to understand inconsistencies (Glaze & Goldston 2015).

The present study and research questions

Based on the theoretical background, we deliberately conducted this study in Germany. Germany provides a wide cultural diversity, as reflected by the approximately 26% of Germans with an immigrant background (Federal Ministry of the Interior Building and Community 2019). This cultural diversity allows us to consider different perspectives on evolution using different religious characteristics such as denominations. Furthermore, Germany is a secular state that protects religious freedom and allows students to participate in religious education with state-trained religious teachers as part of their schooling (though mainly for Catholic and Protestant students). In 2020, the majority of the German population was Christian (26.7% Catholics, 24.4% Protestants, 1.8% Orthodox), and around 5–6% were Muslims (divided into 74% Sunni, 8% Alevi, 4% Shiite, 14% others/unknown; Federal Ministry of the Interior and Home Affairs 2022; Federal Office for Migration and Refugees and German Islam Conference 2020). The remaining Germans were atheists or belonged to a different, marginally represented denomination of other religions (e.g., Judaism, Hinduism, or Buddhism). One must note that the terms religious affiliation and denomination are not always adequately delineated, so that Catholics and Protestants (denominations), and Muslims (religious affiliation) are referred to as denominations. However, it is important to distinguish between the terms religious affiliation (e.g., Christianity, Islam) and denomination (Christian denominations: e.g., Catholic, Protestant; Muslim denominations: e.g., Sunni, Shiite) as they describe different levels of the characteristics of religion. Thus, we will use the term *Muslim denominations* instead of *Muslim* to refer to a group of people who belong to one of its denominations. In general, denominations can be subdivided into further sub-denominations. However, for this study, a further subdivision is impractical because the sample sizes would be very small, impairing the statistical significance. Additionally, the subgroups of some denominations are relatively similar. To exemplify this, the Protestant Church in Germany amalgamates Lutheran, Reformed, and United denominations. This union of the Protestant Church in Germany includes a common synod, council, and church conference and thus represents common values and principles which are based on the Gospel (Evangelical Church in Germany 2021). Therefore, a distinction between the sub-denominations in Germany can be dispensed (this need not apply to other states, e.g., the ones of the United States).

We recognize that personal religious faith and denominations may be viewed as sensitive personal character traits which may result in a critical perspective on studies about them. We hereby clearly position ourselves that we appreciate cultural diversity and that we aim to promote educational equality for all students. We emphasize that we strongly oppose the creation of negative images of individuals or stereotyping groups, for instance, based on their denominations. However, for research purposes, it is crucial to identify whether a student's personal religious faith or denomination is a decisive factor for knowledge about and acceptance of evolution. Moreover, it helps to acquire a more profound understanding of potential barriers (e.g., due to conflicting religious views) that detract from educational equality. Also, it fosters researchers', educators', and the general readers' sensitivity to the topic.

Based on the findings of previous studies and the sociocultural factors in Germany, we aim to examine whether German upper secondary school students' personal religious faith and denomination are relevant to their knowledge about and acceptance of evolution. We expect to gain a more profound understanding of potential barriers (e.g., due to conflicting religious views) to knowledge and thereby strengthen educational equality. The study indirectly fosters readers' sensitivity to possible tensions between religious views and evolution. Considering the above, we set out to examine the following research questions:

1. Is there a correlation between the three variables of knowledge about evolution, use of key concepts, and use of misconceptions with the acceptance of evolution among students, and how do they correlate when separated by denominations?
2. Is there a difference in knowledge about evolution, use of key concepts and misconceptions, acceptance of evolution, and personal religious faith among students with different denominations?
3. Are personal religious faith and different denominations predictive of the knowledge about and acceptance of evolution?

Methods

Sample

For this study, we analyzed a data set of $N=172$ upper secondary school students, also used as part of a previous study by Aptyka et al. (2022). We deployed this subset because the participants provided additional information regarding their denominational group. The participants were 16.5 years of age ($SD=1.1$), and 63.7% reported being female. They attended secondary schools, divided

into grammar school (*Gymnasium*), comprehensive school, or vocational training, and were in grades 10–13 ($M = 11.0$, $SD = 0.9$). The International Standard Classification of Education (ISCED) classifies all surveyed school types at level ISCED3 (Eurydice 2021).

The participants reported being Protestant ($n = 32$), Catholic ($n = 84$), of a Muslim denomination ($n = 28$), or atheistic ($n = 28$). The four *denominational groups* reflect the largest groups in the socio-demographic profile of Germany (see the "The Present Study and Research Questions" section; Federal Ministry of the Interior and Home Affairs 2022; Federal Ministry of the Interior Building and Community 2019; Federal Office for Migration and Refugees and German Islam Conference 2020). There was no further differentiation of the Muslim denominations. Based on the socio-demographic profile of Germany, we anticipate that the majority of the Muslim participants belong to the Sunni denomination (Federal Office for Migration and Refugees and German Islam Conference 2020). It can be assumed that Catholic participants belong to the Roman Catholic Church since this represents the majority (Catholic Church in Germany 2020; Evangelical Church in Germany 2021; Federal Ministry of the Interior and Home Affairs 2022). The group of Protestants was not divided into further sub-denominations, as the Protestant Church in Germany already grouped them due to similar characteristics (for further explanations, see "The present study and research questions") section. We are aware that it is difficult to draw generic conclusion from statistical analyses based on such small samples and therefore like to emphasize that our research entails exploratory characteristics. Therefore, the implications gained for research and teaching must be considered critically (for more details, see "Limitations") section. Nevertheless, since we analyze a variety of variables (knowledge about and acceptance of evolution, personal religious faith and denomination) in this study, it provides valuable information for evaluating different variables (e.g., considering socio-economic status) for further research.

Research design and procedures

The survey was conducted in the students' regular environment to ensure ecological validity. First, students' general evolution-related knowledge, acceptance of evolution, personal religious faith, denomination, and socio-demographic data were collected. After an intervention on natural selection (for further information, see also Aptyka et al. 2022), students' conceptual knowledge was assessed by assigning them four tasks in which they had to explain the processes of natural selection in different scenarios. We varied the order of the four tasks to reduce the impact of fatigue effects, as it could diminish the last tasks (sequencing effects; Aptyka et al. 2022; Federer et al. 2015).

Measures

Knowledge about evolution (KAEVO 2.0)

The KAEVO 2.0 was initially designed to measure the knowledge about evolution of secondary school students in Germany. It was validated regarding content validity and internal structure, showing valid results in different samples (Aptyka et al. 2022; Beniermann 2019; Beniermann et al. 2021; Kuschmierz et al. 2020a). By answering true-false items and single-choice questions, students could score up to 24 points. In order to guarantee comparability of this instrument with other ones, Kuschmierz et al. (2020a) categorized the range of possible points as follows: very low knowledge (0–10 points), low knowledge (11–14 points), moderate knowledge (15–18 points), rather high knowledge (19–22 points), and high knowledge (23–24 points). Overall, the KAEVO 2.0 showed an internal consistency of Cronbach's $\alpha = 0.61$ ($M = 13.22$, $SD = 3.27$, range = 5.00–21.00).

Assessment of contextual reasoning about natural selection (ACORNS)

We used four items of the ACORNS instrument (Nehm et al. 2012; Opfer et al. 2012) to measure the students' contextual reasoning about natural selection. As the items were in English, we used the same translation as in earlier studies (Aptyka et al. 2022; Großschedl et al. 2018). The ACORNS is a constructed response instrument that examines the knowledge's free recall (Nehm & Ha 2011). Nehm et al. (2012) confirmed the convergent validity of the instrument.

Generally, the ACORNS items were designed as isomorphic items, meaning that they all have the same structure but vary in surface features of the content. In our case, the surface features of the four tasks were systematically varied regarding the taxon (animal vs. plant) and the polarity of trait change (trait gain vs. trait loss). Accordingly, the task definition read as follows: "How would biologists explain how a living (Taxon) species with [/lacking] (Trait) evolved from an ancestral (Taxon) species that lacked [/had] (Trait)?" (Nehm et al. 2012).

The open responses of the ACORNS items were coded using the scoring guide by Nehm et al. (2010), which allows for distinguishing between key concepts and misconceptions of natural selection. In detail, we investigated the following key concepts: *variation* (presence and cause of variation); *heritability* (heritability of variation); *individual fitness* (differential survival of individuals); *resource limitation* (limited resources); *competition* (competition); and *change of population* (generational changes in the distribution or frequency of variation; e.g.,

Nehm et al. 2010; Opfer et al. 2012). These concepts are also the most frequently used in the study of Großschedl et al. (2018). Additionally, we analyzed the use of the following four misconceptions: *need* (needs as drivers of evolutionary processes); *use/disuse* (the use or disuse of traits); *intentionality* (the intention to change a trait actively); and *adaptation* (the active adaptation to given circumstances or the environment; Federer et al. 2015; Nehm et al. 2012, 2013; Opfer et al. 2012). In total, students could use six key concepts and four misconceptions per item. Since we used four ACORNS items in this study, students could use a total of 24 key concepts ($M = 9.47$, $SD = 5.02$, range = 0–22.00) and 16 misconceptions ($M = 2.76$, $SD = 2.96$, range = 0–16.00). To ensure the reliability of the open response codings, a second trained person coded more than 30% of the data. We calculated the interrater reliability, which showed an almost perfect agreement (Cohen's $\kappa > 0.80$; Landis & Koch 1977; O'Connor & Joffe 2020).

Attitudes towards evolution (ATEVO 2.0)

We used the ATEVO 2.0 scale to collect data about a person's attitude toward evolution (Beniermann 2019). The initial validation of this instrument was carried out using statistical analyses such as principal component analysis, which were used to determine and confirm internal validity (Beniermann 2019). This instrument contains eight items on a 5-point Likert scale relating to the human mind and general attitudes toward evolution. Low values indicate a negative attitude towards evolution (rejection), while high values signify a positive attitude (acceptance; Beniermann 2019). The instrument revealed an internal consistency of Cronbach's $\alpha = 0.63$ ($M = 3.97$, $SD = 0.51$, range = 2.75–5.00).

Personal religious faith (PERF 2.0)

The PERF 2.0 scale enables the assessment of data about the strength of students' personal religious faith (Beniermann 2019). The validation process of this instrument was guided by the expertise of academics from related research disciplines such as theology, philosophy, and sociology. They reviewed and refined the instruments' wording to ensure content validity (Aptyka et al. 2022; Beniermann 2019). The PERF 2.0 encloses ten items on a 5-point Likert scale. High scores represented a high level of personal religious faith. The scale showed an excellent internal consistency of Cronbach's $\alpha = 0.96$ ($M = 2.64$, $SD = 1.27$, range = 1.00–5.00).

Data analysis

We used IBM SPSS Statistics (version 28.0) for the data analyses. Initially, we performed preliminary analyses (e.g., comparability of group sizes, extreme outliers, normal distribution, homogeneity of variances) to select the correct statistical analysis for the respective data characteristics. Descriptive statistics were used for sample specification. In addition, we analyzed the data using inferential statistical procedures (e.g., correlations, regression, and analyses of variances). Corresponding to the results of preliminary analyses, we used a non-parametric test (e.g., the Kruskal-Wallis test with the Dunn-Bonferroni post-hoc test) when the data did not meet the criteria for performing parametric tests. Moreover, we adjusted the test procedure for post-hoc analyses with the Bonferroni post-hoc test when the dependent variables of the compared groups showed homogeneity of variance. We applied the Games-Howell post-hoc test when variances were heterogeneous. Both post-hoc analyses promise the advantage of being robust against an unbalanced design (Field 2018). Multiple linear regressions were performed using dummy coded variables for the denominational groups (Protestant [vs. atheistic], Catholic [vs. atheistic], and Muslim denominations [vs. atheistic]). Partial responses were missing in the query for the four ACORNS items, whereby some participants were automatically excluded from the analyses. Consequently, a few values are missing at random (MAR). For all analyses, we set the significance level to 5%.

Results

The relationship between knowledge about and acceptance of evolution among students (of different denominations)

For our first research question, we conducted a Pearson product-moment correlation analysis and examined how strongly students' knowledge about and acceptance of evolution are related. The results show weak to moderate correlations between students' acceptance of evolution with knowledge about evolution with their acceptance of evolution ($r = .22$, $p = .003$) and the number of used key concepts ($r = .26$, $p < .001$; see Table 1). The number of used misconceptions and acceptance do not show a significant correlation. For Protestants, we found a relatively strong correlation between acceptance and key concept use ($r = .46$, $p = .008$). We did not find that the other denominational groups' acceptance was significantly related to knowledge about evolution, the use of key concepts, or misconceptions.

Differences between students with different denominations in their knowledge about evolution, use of key concepts and misconceptions, acceptance of evolution, and personal religious faith

To address our second research question, we examined whether students of different denominations differ in their knowledge about evolution, use of key concepts and

Table 1 Relationship between knowledge about, and acceptance of evolution separated by denominational groups

		Separation of the sample by denominational groups			
	Sample (*N* = 172)	**Protestant (*n* = 32)**	**Catholic (*n* = 84)**	**Muslim denominations (*n* = 28)**	**Atheistic (*n* = 28)**
Knowledge about evolution	.22**	.20	.10	.28	.21
Key concepts	.26**	.46**	.16	.17	.06
Misconception	–.01	–.12	–.12	.12	.17

** $p < .01$

misconceptions, acceptance of evolution, and personal religious faith.

Firstly, we conducted an analysis of variance to examine the knowledge about evolution for different denominational groups. Results reveal that students' knowledge about evolution differs between the denominational groups, $F(3, 168) = 3.62$, $p = .014$, $\eta_p^2 = .06$. Bonferroni's post-hoc tests of knowledge about evolution show significant differences between the denominational groups' Muslim denominations and atheistic, $p = .018$ ($M_{Diff} = -2.57$, 95%-CI[−4.85, −0.29], $d_{Cohen} = 0.92$). These results mean for our sample that students of Muslim denominations scored lower than the atheistic students on the KAEVO 2.0 and thus held less knowledge about evolution. We did not observe differences between students of the denominational groups Protestant and Catholic, $p > .99$ ($M_{Diff} = 0.35$, 95%-CI[−1.42, 2.13]), Protestant and Muslim denominations, $p = .054$ ($M_{Diff} = 2.19$, 95%-CI[−0.02, 4.40]), Protestant and atheistic, $p > .99$ ($M_{Diff} = 0.38$, 95%-CI[−2.59, 1.83]), Catholic and Muslim denominations, $p = .056$ ($M_{Diff} = 1.83$, 95%-CI[−0.03, 3.70]), Catholic and atheistic, $p > .99$ ($M_{Diff} = -0.74$, 95%-CI[−2.60, 1.13]).

Secondly, we used descriptive and inferential statistics to analyze which key concepts and misconceptions students (of different denominations) use when reasoning about natural selection. Descriptive statistics for the sample suggest that students used more key concepts than misconceptions when reasoning about natural selection. Students used the concept of resource limitation most often, followed by the concepts of variation, individual fitness, and heritability. In addition, it appears that students in both groups applied the misconception of adaptation most frequently and the misconception of intentionality least frequently (see Fig. 1).

Procedures of inferential statistics followed the descriptive statistics. We performed two ANOVAs, one with the sum of all used key concepts and one with the sum of all used misconceptions for the denominational groups. The results show that the students of different denominational groups varied in the number of used key concepts, $F(3, 168) = 2.72$, $p = .046$, $\eta_p^2 = .05$, but not of misconceptions, $F(3, 168) = 0.91$, $p = .439$. To identify the explicit concepts in which the students differed, we performed a multivariate analysis of variance (MANOVA; see Fig. 1). The results reveal that students of different denominational groups differed in the use of the key concepts of individual fitness, $F(3, 168) = 3.18$, $p = .025$, $\eta_p^2 = .05$, resource limitation, $F(3, 168) = 4.91$, $p = .003$, $\eta_p^2 = .08$, and competition, $F(3, 168) = 2.80$, $p = .042$, $\eta_p^2 = .05$. The students did not significantly differ in the use of the key concepts of variation, $F(3, 168) = 0.18$, $p = .912$, heritability, $F(3, 168) = 0.88$, $p = .453$, and change of population, $F(3, 168) = 1.49$, $p = .219$. Bonferroni's post-hoc tests regarding the key concept of individual fitness reveal a significant difference between the denominational groups Protestant and Muslim denominations, $p = .027$ ($M_{Diff} = 1.10$, 95%-CI[0.08, 2.12], $d_{Cohen} = 0.74$). The denominational groups of Protestant and Catholic, $p > .99$ ($M_{Diff} = 0.40$, 95%-CI[−0.42, 1.22]), Protestant and atheistic, $p > .99$ ($M_{Diff} = 0.14$, 95%-CI[−0.88, 1.16]), Catholic and Muslim denominations, $p = .185$ ($M_{Diff} = 0.70$, 95%-CI[−0.16, 1.56]), and Catholic and atheistic, $p > .99$ ($M_{Diff} = -0.26$, 95%-CI[−1.12, 0.60]) did not significantly differ. Bonferroni's post-hoc tests for the key concept of resource limitation show a significant difference between the denominational groups Protestant and Muslim denominations, $p = .007$ ($M_{Diff} = 1.12$, 95%-CI[0.22, 2.02], $d_{Cohen} = 0.87$), Catholic and Muslim denominations, $p = .005$ ($M_{Diff} = 0.96$, 95%-CI[0.20, 1.72], $d_{Cohen} = 0.72$), as well as Muslim denominations and atheistic, $p = .015$ ($M_{Diff} = -1.07$, 95%-CI[−2.00, −0.14]; $d_{Cohen} = 0.89$) but no differences for the denominational groups Protestant and Catholic, $p > .99$ ($M_{Diff} = 0.16$, 95%-CI[−0.57, 0.88]), Protestant and atheistic, $p > .99$ ($M_{Diff} = 0.05$, 95%-CI[−0.85, 0.95]), and Catholic and atheistic, $p > .99$ ($M_{Diff} = -0.11$, 95%-CI[−0.88, 0.65]). Games-Howell's post-hoc tests for the key concept of competition reveal a significant difference between the denominational groups Protestant and Muslim denominations, $p = .037$ ($M_{Diff} = 0.71$, 95%-CI[0.03, 1.38], $d_{Cohen} = 0.67$), Muslim denominations and atheistic, $p = .031$ ($M_{Diff} = -0.75$, 95%-CI[−1.45,

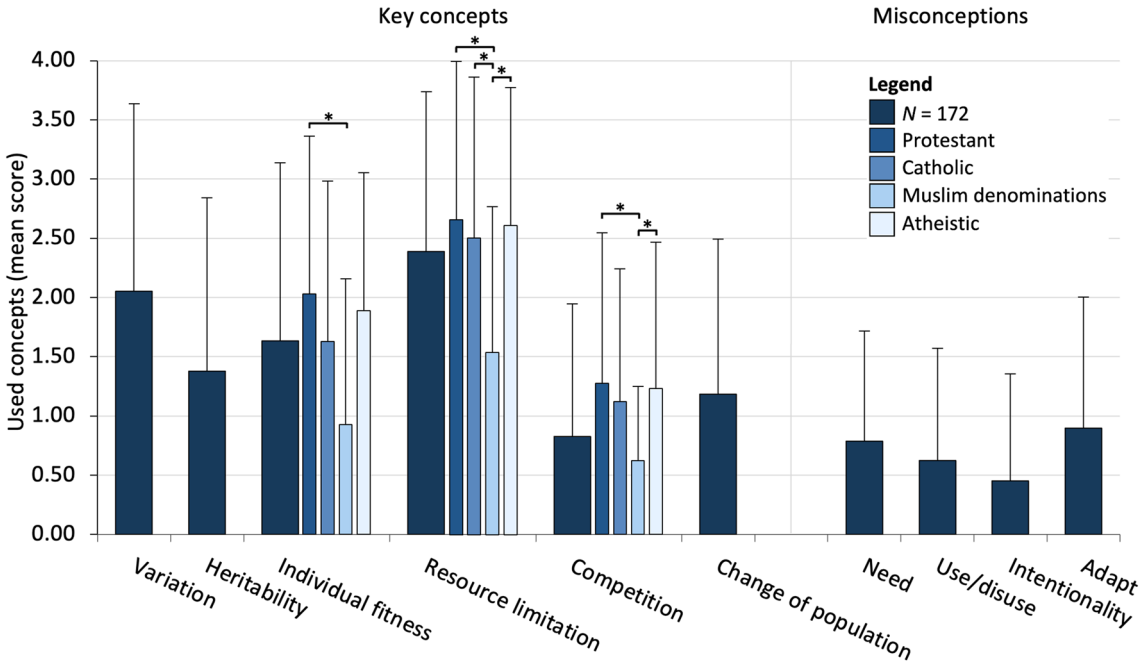

Fig. 1 Students' use of key concepts and misconceptions when reasoning about natural selection. The figure shows the key concepts (left) and misconceptions (right) that were used by students (with different denominations) when responding to four ACORNS items (*M* + *SD*). Denominational representation was chosen only when significant differences were present. * $p < .05$

−0.05], $d_{Cohen} = 0.77$). Students of the denominational groups Protestant and Catholic, $p = .728$ ($M_{Diff} = 0.26$, 95%-CI[−0.41, 0.94]), Protestant and atheistic, $p = .999$ ($M_{Diff} = -0.04$, 95%-CI[−0.90, 0.81]), Catholic and Muslim denominations, $p = .052$ ($M_{Diff} = 0.44$, 95%-CI[−0.00, 0.88]), and Catholic and atheistic, $p = .642$ ($M_{Diff} = -0.31$, 95%-CI[−1.01, 0.39]) show no significant differences.

Thirdly, we conducted an ANOVA to examine the dependent variable acceptance of evolution and the independent variable denominational groups. We found that students of different denominations show varying levels of acceptance of evolution, $F(3, 168) = 6.07$, $p < .001$, $\eta_p^2 = .10$. By applying a post-hoc Bonferroni test, we precisely observed differences between the denominational groups Protestant and Muslim denominations, $p = .011$ ($M_{Diff} = 0.52$, 95%-CI[0.18, 0.87], $d_{Cohen} = 0.78$) and Muslim denominations and atheistic, $p < .001$ ($M_{Diff} = -0.52$, 95%-CI[−0.87, −0.18], $d_{Cohen} = 1.05$) but not between Protestant and Catholic, $p > .99$ ($M_{Diff} = 0.14$, 95%-CI[−0.13, 0.41]), Protestant and atheistic, $p > .99$ ($M_{Diff} = -0.13$, 95%-CI[−0.46, 0.21]), Catholic and Muslim denominations, $p = .090$ ($M_{Diff} = 0.26$, 95%-CI[−0.02, 0.55]), and Catholic and atheistic, $p = .088$ ($M_{Diff} = -0.26$, 95%-CI[−0.55, 0.02]). Thus, students of the Muslim denominations in our samples are rather inclined to reject the evolution than Protestant and atheistic students.

Fourthly, we analyzed the dependent variable personal religious faith, with the independent variable denominational groups using a non-parametric Kruskal–Wallis test. We found that the students of different denominational groups differed in personal religious faith, $H(3) = 72.74$, $p < .001$. The following Dunn-Bonferroni post-hoc tests indicate that the denominational groups Protestant and Muslim denominations ($z = -5.15$, $p < .001$, $p_{adj} < .001$, $d_{Cohen} = 2.06$), Protestant and atheistic ($z = -3.56$, $p < .001$, $p_{adj} = .002$, $d_{Cohen} = 1.19$), Catholic and Muslim denominations ($z = -6.07$, $p < .001$, $p_{adj} < .001$, $d_{Cohen} = 1.93$), Catholic and atheistic ($z = -4.26$, $p < .001$, $p_{adj} < .001$, $d_{Cohen} = 1.13$), and Muslim denominations and atheistic ($z = -8.44$, $p < .001$, $p_{adj} < .001$, $d_{Cohen} = 5.45$) significantly differed in their level of personal religious faith. The only data not showing significant differences are between the groups Protestant and Catholic ($z = -0.04$, $p = .968$, $p_{adj} > .99$). Overall, we can conclude from the results that students of Muslim denominations have the lowest acceptance of evolution, and atheistic students have the highest (see Table 2). In addition, the descriptive results show that the acceptance scores are moderate to high in all groups (at least 3.7 on a 5-point Likert scale).

Prediction of the knowledge about and acceptance of evolution

Finally, we aimed to investigate how much of the variance in the knowledge about and acceptance of evolution

Table 2 Means and standard deviations for the knowledge, acceptance, concept use, and personal religious faith

	Sample ($N=172$)	Separation of the sample by denominational groups			
		Protestant ($n=32$)	Catholic ($n=84$)	Muslim denominations ($n=28$)	Atheistic ($n=28$)
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
KAEVO 2.0	13.22 (3.27)	13.69 (3.43)	13.33 (3.36)	11.50 (3.12)	14.07 (2.40)
ATEVO 2.0	3.99 (0.51)	4.10 (0.53)	3.96 (0.47)	3.70 (0.49)	4.22 (0.50)
PERF 2.0	2.64 (1.27)	2.50 (1.12)	2.52 (1.06)	4.38 (0.59)	1.45 (0.48)
ACORNS KC	9.47 (5.02)	10.69 (5.84)	9.70 (4.88)	7.18 (4.61)	9.64 (4.32)
ACORNS MIS	2.76 (2.96)	2.31 (2.83)	3.02 (2.94)	2.18 (2.79)	3.04 (3.32)

KAEVO 2.0 Knowledge about evolution 2.0; *ATEVO 2.0* Attitudes towards evolution 2.0; *PERF 2.0* Personal Religious Faith 2.0; *ACORNS KC* Assessment of contextual knowledge about natural selection (key concepts); *ACORNS MIS* Assessment of contextual knowledge about natural selection (misconceptions)

can be explained by the predictors of personal religious faith and denomination. We conducted a multiple linear regression for the criterion knowledge about evolution measured by the KAEVO 2.0, which shows a small goodness-of-fit (Cohen 1988), $R^2=.06$ ($R^2_{adj}=.04$). The model with the denominational groups Protestant (vs. atheistic), Catholic (vs. atheistic), Muslim denominations (vs. atheistic), and the personal religious faith significantly predicts the knowledge about evolution, $F(4, 167)=2.70$, $p<.032$. Nevertheless, only the group Muslim denominations (vs. atheistic) is a significant predictor ($B=-2.55$, $\beta=-0.29$, $S.E.=1.15$, $p=.028$), meaning that if a participant of our study was considered as an adherent of a Muslim denomination, the probability is higher that this individual has lower knowledge about evolution than individuals of other denominations. The denominational groups Protestant (vs. atheistic; $B=-0.38$, $\beta=-0.05$, $S.E.=0.88$, $p=.669$), Catholic (vs. atheistic; $B=-2.55$, $\beta=-0.11$, $S.E.=0.75$, $p=.335$), or the personal religious faith ($B=-0.01$, $\beta=-0.00$, $S.E.=0.26$, $p=.975$) do not directly relate to students' knowledge about evolution. After analyzing knowledge about evolution, we performed a multiple linear regression analysis with the denominational groups and personal religious faith as predictors of the acceptance of evolution. The overall model is significant, $F(6, 187)=5.22$, $p<.001$, and indicates a moderate goodness-of-fit (Cohen 1988), $R^2=.15$ ($R^2_{adj}=.12$). Only the personal religious faith ($B=-0.12$, $\beta=-0.29$, $S.E.=0.04$, $p=.003$) but not the denominational groups Protestant (vs. atheistic; $B=-0.00$, $\beta=-0.00$, $S.E.=0.13$, $p=.990$), Catholic (vs. atheistic; $B=-0.14$, $\beta=-0.14$, $S.E.=0.11$, $p=.222$), or Muslim denominations (vs. atheistic; $B=-0.18$, $\beta=-0.13$, $S.E.=0.17$, $p=.297$) enable a significant prediction of students' acceptance of evolution. In summary, religious students across all investigated denominations are less accepting of evolution.

Discussion

Low correlations between acceptance of evolution with knowledge about evolution and the use of key concepts, but no correlation with the use of misconceptions

In order to answer our first research question, we found weak to moderate correlations between knowledge about and acceptance of evolution in our sample. The correlation between knowledge about and acceptance of evolution coincides with previous findings. Low correlation among secondary school students compared to, for example, undergraduates may be explained by differences in the educational level, age of participants, or stages of faith (e.g., Beniermann 2019; Fowler & Dell 2006; Konnemann et al. 2012; Kuschmierz et al. 2020b). The identified correlation could also suggest that younger students do not perceive a conflict between scientific and religious views. The absence of conflict could be due to our sample's low level of knowledge. Low knowledge prevents students from understanding the overlaps or contradictions of scientific and religious views on evolution. Also, separating the subjects in school (i.e., biology or religion courses) and the missing interdisciplinary link can prevent the simultaneous confrontation of elaborated scientific and religious perspectives, obscuring potential conflicts. As knowledge becomes more differentiated, diverging perspectives on evolution might not be compatible anymore. Then, the decision to accept evolution, understand religious and biological views as Non-Overlapping Magisteria (NOMA; Gould 1999), or reject evolution seems almost inevitable (Sinatra et al. 2003).

Contrary to our expectations, only the number of used key concepts in our sample is significantly related to acceptance, but the number of used misconceptions is not. Students' use of misconceptions in reasoning about natural selection in the ACORNS instrument by the surveyed participants in our study correlated slightly

negatively with the acceptance of evolution, but unlike the results by Großschedl et al. (2018), our results were insignificant. These findings support the argument of previous studies that key concepts and misconceptions are not mutually exclusive and that students can have key concepts and misconceptions simultaneously (e.g., Aptyka et al. 2022; Evans 2001; Opfer et al. 2012).

Differences among students of different denominations in knowledge about, and acceptance of evolution, use of key concepts, and personal religious faith

We examined whether students of different denominations in our sample differed in their knowledge about evolution, use of key concepts and misconceptions, acceptance of evolution, and personal religious faith. The analyses revealed that students of Muslim denominations differed greatly from atheists in terms of general knowledge about evolution and from Protestants and atheists regarding acceptance of evolution. These explorative results are similar to those of Beniermann (2019) and Lammert (2012) on German students, who showed that Protestants and students of Muslim denominations differed strongly in their knowledge about evolution and moderately in their acceptance of evolution. Explanatory approaches suggest that the poor performance of certain denominations in knowledge surveys is attributable to prevalent negative stereotypes and prejudices about their scientific competence (Rios et al. 2015). In addition, there are attempts to explain low acceptance scores by a possible lack of importance of evolution to some denominations (Betti et al. 2020; Unsworth & Voas 2018). Also, the theory of evolution is often associated with atheism (Everhart & Hameed 2013). Overall, the students in our study showed low general knowledge (Kuschmierz et al. 2020a).

In our study, students most often used the key concept of resource limitation, followed by the three core concepts of variation, heritability, and individual fitness. The dominant use of these concepts could be associated with the intervention. Nevertheless, the results are similar to findings in America (Nehm & Ha 2011; Nehm et al. 2010; Opfer et al. 2012) and a comparable frequency of use of the key concepts of individual fitness, resource limitation, and variation by German university students (Großschedl et al. 2018). The key concept of resource limitation might have occurred relatively often in this specific sample as it is a less abstract and more accessible explanation for natural selection than other concepts, such as variation, which is rooted in molecular biology (Tibell & Harms 2017).

Regarding the differentiation of denominations, we found moderate to significant differences between the key concepts used by students of different denominations. It was noticeable that students of Muslim denominations used the fewest key concepts and differed significantly from at least one denominational group in their use of individual fitness, resource limitation, and competition. The differences were most pronounced on the key concept of resource limitation because students of Muslim denominations differed significantly from all other comparison groups. The reasons for the differences in the use of key concepts and misconceptions between students of different denominations are still poorly understood. Nevertheless, the results of our explorative approach are similar to those of Rachmatullah et al. (2018) regarding differences in the use of the key concept of resource limitation. They compared pre-service teachers from Indonesia (the world's largest Muslim majority) and America. They only found descriptive differences ($p = .055$) in the use of the key concept of resource limitation, with Indonesian participants using the concept less often than American participants. Because little research has been conducted on the denomination-specific use of key concepts and misconceptions, we recommend further research to assess these differences in more detail.

In this examined sample, misconceptions occurred less often than key concepts and did not dominate responses. These results oppose the ones of Lammert (2012). Purely descriptively, students in our sample used the misconception of adaptation most frequently. Our result is in accordance with earlier qualitative findings showing that German upper secondary school students explained the evolutionary change as an intentional, active change of an organism (Baalmann et al. 2004). However, our findings differ from those of German university students, who most frequently used the misconception of need (Großschedl et al. 2018). This contrast may indicate an argumentative shift from younger students using internal, active, and purposeful causes (Brennecke 2015) to older students using a more passive process with an external cause (e.g., environmental pressure) as arguments for evolutionary changes.

Furthermore, the misconception of adaptation often includes aspects of teleological reasoning (Kuschmierz et al. 2020b). Students might have resorted to teleological reasoning because they had to explain evolutionary change retrospectively and could have interpreted the wording of the ACORNS items as including a finalistic event with evoked start-finish-scenario.

Our explorative results again support the assumption that key concepts and misconceptions co-exist (Nehm & Ha 2011; Opfer et al. 2012). For example, the argument about evolutionary change based on the key concept of resource limitation was partly followed by the argument that an individual must actively adapt (misconception) to gain higher individual fitness and be the individual that

has the greatest chance of survival in the given environment (see also Großschedl et al. 2018).

Students of different denominations in our sample did not show differences in the use of misconceptions. One explanation for the missing differences in misconceptions between students of different denominations can be derived from cognitive psychological perspectives. Research in this area stated that teleological thinking, including misconceptions (e.g., need), is a pervasive feature of common human thinking, prevalent in all cultures and religions (Kelemen 2011).

Regarding personal religious faith, all denominational groups in this specific sample differed in personal religious faith except Catholics compared to Protestants. Students of Muslim denominations disclosed the highest and atheists the lowest scores in personal religious faith. These results are similar to those of Lammert (2012), showing differences between denominations and the effect of the denominations on personal religious faith for German students. Our results can be complemented by the findings of a recent survey conducted by the Federal Office for Migration and Refugees and the German Islam Conference in Germany (2020), showing that the majority of participants with a migration background stated to be strong to rather devout (approximately 82%; independent from their denomination). For the participants of Christian denominations without a migration background, the proportion of persons being strong to rather devout (approximately 55%) and being rather not or not at all devout (approximately 45%) was almost balanced (Federal Office for Migration and Refugees and German Islam Conference 2020). In relation to our results, this may suggest that personal religious faith reflects other variables that influence learning about evolution, such as cultural diversity represented by migration background. In addition, socio-economic status should also be considered since Barnes et al. (2017a) found a correlation between students' acceptance of evolution and the parental education level as well as the parents' attitudes toward evolution to be predictive of students' acceptance of evolution.

Denominations can predict knowledge about evolution, and personal religious faith can predict acceptance of evolution

Finally, we explored how much variance in the variables of knowledge about and acceptance of evolution can be explained by students' personal religious faith and denominations. In our sample, the group Muslim denominations was a significant predictor of a lack of knowledge about evolution to a small extent, whereas personal religious faith did not. Moreover, personal religious faith predicted the acceptance of evolution moderately, whereas a person's denomination was no significant predictor. In our study, personal religious faith was only a significant predictor of acceptance of evolution but not of knowledge about evolution, even though students of Muslim denominations had the highest personal religious faith. Similarly, Dunk et al. (2017) found that the effect of the denomination variable was reduced when other factors, such as religiosity, were included. The results of our study suggest reconsidering the role of personal religious faith and denomination when investigating knowledge about evolution. Exemplarily, demographic data show that most people of Muslim denominations in Germany have a migration background (Federal Office for Migration and Refugees and German Islam Conference 2020). Furthermore, the survey conducted by the Federal Office for Migration and Refugees and the German Islam Conference revealed that around 43% of the population in Germany aged 16 and older with a migration background and a religious affiliation do not have a school-leaving qualification or own a compulsory one. In contrast, this applies only to 15–20% of the persons without a religious affiliation (with or without a migration background) or people without a migration background belonging to Christian denominations (Federal Office for Migration and Refugees and German Islam Conference 2020). These results indicate educational inequality for individual groups. Combining facts about inequality with our results may indicate systemic educational or linguistic disadvantages, like lower economic status, of specific persons that should be considered as covariates in future studies.

Our results support previous findings that personal religious faith is associated with acceptance of evolution but less with knowledge about evolution (Barnes et al. 2017a). They provide complementary evidence that people with no or low personal religious faith are more accepting of evolution than strongly religious people (Betti et al. 2020; Lammert 2012; Unsworth & Voas 2018).

In research, hypothesis suggest that attitudes towards evolution are rooted in a nation's socio-cultural and historical contexts, and therefore differences in acceptance might be greater between countries than within one country (Clément 2015a). With regard to our sample, the differences in acceptance of evolution might be further explained by the identity-protective cognition of the culturally diverse students (Barnes et al. 2021b). The identity-protection cognition "refers to the tendency of culturally diverse individuals to selectively credit and dismiss evidence in patterns that reflect the beliefs that predominate in their group" (Kahan 2017, p. 1). Therefore, some of our sample's Muslims may reject evolution as part of their group identity.

Especially for people with insufficient knowledge about evolution in our sample, there are indications that not only increasing knowledge about evolution is vital to increase acceptance. Other studies imply that a learner's willingness to overcome controversial views on evolution might be more important in increasing acceptance of evolution than knowledge (Sinatra et al. 2003). Taking this idea into consideration, not only the direct effect of the personal religious faith or denomination but also the effect mediated by the perception of conflict between personal religious faiths and the science-based perspective on evolution could impact the acceptance or rejection of evolution. Barnes et al. (2021b) found that the perception of conflict between personal religious faith (especially regarding the belief in god) and evolution is predictive of acceptance of evolution. This relation was expressed in the higher perception of conflict was associated with lower acceptance. Moreover, previous research analyzing participants' perception of conflict shows the tendency that persons of non-Catholic Christian or Muslim denominations are most likely to perceive conflict among the examined denominational groups (Barnes et al. 2021b). Transferring these findings to our results, we cannot rule out the hypothesis that low acceptance scores in our sample originated from personal religious faith, the perception of conflict between faith, and religion. An explanation may be, as Barnes et al. (2017b) have suggested, that a combination of certain denominations and personal religious faith leads to the perception of conflict. A potential perception of a conflict could explain the results concerning the students of Muslim denominations. However, it must be noted that there are country-specific differences in personal religious faith and denominations. These differences could be attributed to, for example, the strength of belief, participation in religious practices, and the level of literal interpreting of the sacred scriptures (Clément 2015b; Schneider 2020). The perception of conflict may also help to understand differing relations between personal religious faith and acceptance of evolution for other denominations. As Catholics and Protestants in our study did not differ in the degree of personal religious faith but acceptance of evolution, it would be interesting to examine whether they also differed in their perception of conflict between the religious and scientific views and whether the perception of conflict could explain variance in the acceptance of evolution. Additionally, examining atheists' perceptions of conflict would be interesting, as previous research suggests that atheists associate evolution with an atheist perspective (Barnes et al. 2020a). Future studies should investigate the perception of conflict to make reliable statements about the relationship between denominations and personal religious faith with the acceptance of evolution.

Implications for research and education

This explorative study can be used to derive theoretical and practical implications for research in evolution education. It expands the understanding of denominational differences because we examined secondary school students of different denominations and their knowledge about evolution, use of key concepts and misconceptions, acceptance of evolution, and personal religious faith in one study.

Our results confirm a positive correlation between knowledge about and acceptance of evolution. We contributed to the research field of evolution education by exemplarily showing that the correlation between knowledge and acceptance is not as strong in our sample of secondary school students as it is for pre-service (Großschedl et al. 2018) or in-service teachers (Beniermann 2019). The results from our explorative approach provide a basis for comparison with other samples, suggesting that promoting acceptance is less important for younger individuals than for older ones (Kuschmierz et al. 2020b). Nevertheless, as we found a positive correlation between knowledge about and acceptance of evolution, facilitating acceptance could benefit all students in increasing knowledge (including the average secondary student). It is not the function of biology class to demand that students change their denomination or personal religious faith to increase acceptance (Ohly 2012). Instead, teachers should be aware that students could perceive conflicts. This perception of conflict could cause them to close themselves off from the topic of evolution, hindering the learning process (Waschke & Lammers 2012). One reason for this conflict may be the association of acceptance of evolution with atheism for which Barnes et al. (2020a) found that religious students who classify evolution as atheistic perceived higher conflict than those who classify it as agnostic Barnes et al. (2020a). The importance of the acceptance of evolution for teaching has been discussed for a long time without a clear solution being able to be established. Smith & Siegel (2016) see value in facilitating the acceptance of evolution as it combines the acquisition of knowledge with the ability to actively participate in society. Therefore, they proposed an approach with the fundamental goal of promoting the understanding of evolution. In subsequent steps, the acceptance of the students should also be promoted with this approach. The aim of this acceptance promotion is the insight evolution being considered an appropriate scientific explanation of biological phenomena. We consider this distinction between the promotion of the scientific perspective detached from the evaluation of religious perspectives to be valuable. Therefore, recommendations rather suggest that fostering acceptance needs to be adapted to the students individually. This critical view

can be justified by the fact that there are already studies showing that a forced imposition of an accepting attitude can have exactly the opposite effect and can lead to resignation (Elsdon-Baker 2015; Unsworth & Voas 2021). This should be explicitly avoided. Instead, approaches to promote acceptance of evolution in the sense of developing the willingness to learn about evolution could be to support students to reconcile their religious attitudes with the scientific view of evolution (e.g., agnostic evolution; Barnes et al. 2020b; Sinatra et al. 2003). In our sample, Protestants showed a relatively strong correlation between the use of key concepts when reasoning about natural selection and acceptance while showing an average level of personal religious faith. To validate these findings, a more extensive study with more participants representing all denominational subgroups would be valuable.

Upper secondary school students in our sample could apply key concepts in different evolutionary examples. Still, a significant number of misconceptions in students' understanding of evolution remained. To promote better scientific understanding among students, it would be helpful to contrast the differences between key concepts and misconceptions in the class and reflect on cognitive biases (e.g., Aptyka et al. 2022; Nehm et al. 2012). The frequent use of the misconception of adaptation could be due to ambiguous tests and learning situations. For future research, we suggest rephrasing the last part of the ACORNS item to a more neutral wording: "Explain this evolutionary process of change". The active form of the verb "to evolve" in the ACORNS item might have caused teleological, anthropomorphic, or intentionality misconceptions. Such reformulated items would focus on the evolutionary change process rather than a supposed active change of individuals from one species to another. As practical advice, we also recommend that educators refrain from using ambiguous wording in oral and written language (e.g., information texts or task instructions) to avoid that adaptation being understood as actively controlled by an individual instead of a passive process (Baalmann et al. 2004). Therefore, it is essential to familiarize pre-service teachers with linguistic subtleties during their studies. Pre-service teachers should learn to use language purposefully to prevent or at least minimize misunderstandings and to develop a deeper understanding of complex processes of evolution.

Moreover, the results imply that students of different denominations differ in using specific concepts. These results suggest that the variable denomination is gaining importance in evolution education research. In terms of practical education, these findings imply that it might be essential to adopt learning content, especially the thematized concepts, to different individuals to provide equal support to students with denomination-specific difficulties. The varying use of key concepts by students from different denominations raises the intriguing questions of why certain concepts occur, what prior experiences they are based on, and to what extent these concepts correspond to or contradict statements in religious scriptures.

We included the denomination as an additional variable when investigating the relationship between personal religious faith and knowledge about evolution. This approach elicited that personal religious faith is not a direct predictor of knowledge. Still, particular denominations (Muslim denominations vs. atheistic) explained a small amount of the variance in the knowledge about evolution. Thus, we recommend that future studies addressing variables on religious characteristics should include the denomination to minimize the potential for biased interpretations. In addition, we confirmed that the personal religious faith of a secondary school student, rather than their denomination, predicts variance in acceptance of evolution (e.g., Kuschmierz et al. 2020b).

Our study indicates that students may differ in prior knowledge and acceptance of evolution and personal religious faith, especially when students differ in denominations. Biology teachers should consider the spectrum of individual factors related to religious characteristics to adequately respond to all students and increase everyone's learning quality. Diversity awareness is crucial for educators to reflectively classify differences in students' knowledge (e.g., Barnes et al. 2017b, 2020a; Truong et al. 2018).

It is also important to note that there is currently a considerable debate about whether the relationship between personal religious faith and acceptance of evolution may be moderated by an individual's perception of conflict between religious and scientific views (e.g., Barnes et al. 2020a, b, 2021a, b). Since the role of perception of conflict was not examined in this study, further quantitative studies are needed to complement our chosen variables with a perception of conflict and qualitative studies that analyze the emergence of this conflict.

Although there is room for optimization in the future, our findings can guide approaches for practice for sensitization of potentially perceived conflict. Pre-service teachers could benefit from a stronger focus on cultural competencies during their university education, but also in-service teachers should be offered specialized training. For example, a clear distinction between religious and scientific views and guidance on becoming aware of and reflecting on one's conflict could be crucial for teacher preparation (e.g., Anderson 2007; Barnes et al. 2021b). It could enable educators to observe tensions between religious and scientific views and assist them in dealing with these professionally and reflectively (Dunk et al. 2019;

Truong et al. 2018). These multi-perspective approaches could help reduce conflicts, prevent religious students from closing their minds to evolutionary contexts, and facilitate effective learning (Waschke & Lammers 2012). However, a certain balance of discourse must be maintained when including different perspectives in biology lessons. The instruction must focus on the biological perspective and scientific knowledge about evolution, but at the same time, educators should not force their students to change their personal religious faith or denomination (Ohly 2012).

Limitations

The limitations of the study should be considered when interpreting the results. The sizes of some denominational groups are small (around 30 persons), limiting the generalizability of these results and the exclusion of false negative errors (see the section "Discussion"). Due to the relatively small sample size in the subsamples, our study should be seen as an exploratory study in the research field. Moreover, the group sizes of the denominational groups differed significantly. The different-sized groups result from a random sample of the population in Germany. Since denominations are not evenly distributed in Germany, this is also reflected in our study. We cannot exclude that the unbalanced design may somehow biased the results. Nevertheless, we took this risk to maintain other advantages of randomized sampling (e.g., higher external validity; Döring et al. 2016). Additionally, the chosen procedures, such as the ANOVA, are robust to an unbalanced design, especially when variances are homogeneous. Furthermore, the post-hoc tests used were selected according to their suitability for unbalanced designs so that effects due to unequal group sizes could be mitigated (Field 2018).

In addition, it must be noted that the nonsignificant correlations for each denomination should be assessed with caution. We do not insist on discarding the null effects. However, since the results show significant correlations, we point out that we cannot exclude false negative errors due to the small sample sizes of the groups divided into denominations.

Overall, we recommend that studies on denominations use a cross-sectional study design, assess data of a larger sample, and use our effect to calculate the optimal sample size in an a priori calculation (Döring et al. 2016). When deciding on the suggested sample survey, two choices should be considered. First, researchers could select a sample representing the cross-section of secondary school students, as we did, with the associated unequal distribution of denominations. Second, researchers could use non-randomized sampling and recruit the same number of respondents for each denomination. One of the advantages of our approach is maintaining the external validity; an advantage of non-randomized sampling is that it is easier to technically retain the equality of group sizes. Additionally, we recommend collecting information on students' migration status in future studies. We incorporated data from the Federal Office for Migration and Refugees and German Islam Conference (2020) to contextualize and discuss our findings. Yet, it would have been more insightful if this information was directly available for each student in the sample.

It should also be noted that our results are not necessarily generalizable to other European countries, as both the predominant denominations in the various European countries and the importance of religiosity for the population differ (Becuwe & Baneth 2021; Pickel 2013).

Conclusions

This study sought to exploratively investigate the relationship between secondary school students' knowledge about and acceptance of evolution and underlying processes such as natural selection. It aimed to gain deeper insights into possible obstacles (personal religious faith, denomination) affecting this relation. Our results confirm correlations between knowledge about and acceptance of evolution. Furthermore, we identified differences in the sample regarding knowledge about evolution, use of key concepts when reasoning about natural selection, acceptance of evolution, and personal religious faith among students of different denominations, but not regarding students' use of misconceptions. Students' extensive use of misconceptions with anthropomorphic and teleological components may also indicate a need for more deliberate and well-reflected communication (e.g., the wording in tasks or educators' language use) about natural selection. Regression analyses imply that denominations could predict knowledge about evolution, and personal religious faith could predict acceptance of evolution. These results suggest that future studies that include religious characteristics variables should assess a person's denomination. Additionally, students' perceptions of conflict between religious and scientific views should be assessed to ascertain the origins of these conflicts. Overall, this study strengthens the idea that students' religious characteristics are relevant for evolution class. This may imply that educators must be aware of these variables, deal with conflicts sensitively, and guide students to find an individual reconciliation method. Future studies should qualitatively investigate the denomination-specific differences in using key concepts and misconceptions. Qualitative research could improve knowledge about the relationship between different evolutionary key concepts, unscientific misconceptions, and

religious views. It could inform about possible learning obstacles for students of different denominations.

The findings of our study provide in-depth insights into students' knowledge about evolution and suggest possible internal conflicts that may hinder the acceptance of evolution.

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Author contributions
All authors contributed equally to the development of the research goals and aims. JG conceived the research design and conducted the data collection. RG and HA were responsible of writing, performing statistical analyses, and creating the figures. All authors critically reviewed previous versions of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The dataset supporting the conclusions of this article is not publicly available because it was collected on secondary school students. However, the dataset is available upon reasonable request from the corresponding author JG.

Declarations

Ethics approval and consent to participate
This study was conducted following school legislation, ethical principles, and procedures for the protection of research participants (Ministry of the Interior of the State of North Rhine-Westphalia 2022; National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research 1979). The use of a personal code ensured anonymous merging of the materials. No rewards or payments were made to participants.

Competing interests
The authors declare no competing interests.

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References

Anderson RD. Teaching the theory of evolution in social, intellectual, and pedagogical context. Sci Educ. 2007;91(4):664–77. https://doi.org/10.1002/sce.20204.

Anderson LW, Krathwohl DR, Airasian PW, Cruikshank KA, Maver RE, Pintrich PR, Raths J, Wittrock MC. A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Longman; 2001.

Aptyka H, Fiedler D, Großschedl J. Effects of situated learning and clarification of misconceptions on contextual reasoning about natural selection. Evol Educ Outreach. 2022. https://doi.org/10.1186/s12052-022-00163-5.

Baalmann W, Frerichs V, Weitzel H, Gropengiesser H, Kattmann U. Schülervorstellungen zu Prozessen der Anpassung—Ergebnisse einer Interviewstudie im Rahmen der Didaktischen Rekonstruktion [Students' conceptions of processes of adaptation - Results of an interview study in the context of didactic reconstruction]. Zeitschrift Für Didaktik Der Naturwissenschaften. 2004;10:7–28.

Barnes ME, Evans EM, Hazel A, Brownell SE, Nesse RM. Teleological reasoning, not acceptance of evolution, impacts students' ability to learn natural selection. Evol Educ Outreach. 2017a. https://doi.org/10.1186/s12052-017-0070-6.

Barnes ME, Truong JM, Brownell SE. Experiences of Judeo-Christian students in undergraduate biology. Cell Biol Educ. 2017b. https://doi.org/10.1187/cbe.16-04-0153.

Barnes ME, Dunlop HM, Sinatra GM, Hendrix TM, Zheng Y, Brownell SE. "Accepting evolution means you can't believe in god": atheistic perceptions of evolution among college biology students. CBE Life Sci Educ. 2020a. https://doi.org/10.1187/cbe.19-05-0106.

Barnes ME, Werner R, Brownell SE. Differential impacts of religious cultural competence on students' perceived conflict with evolution at an Evangelical university. Am Biol Teach. 2020b;82:93–101. https://doi.org/10.1525/abt.2020.82.2.93.

Barnes ME, Roberts JA, Maas SA, Brownell SE. Muslim undergraduate biology students' evolution acceptance in the United States. PLoS One. 2021a;16(8):e0255588. https://doi.org/10.1371/journal.pone.0255588.

Barnes ME, Supriya K, Zheng Y, Roberts JA, Brownell SE. A new measure of students' perceived conflict between evolution and religion (PCoRE) Is a stronger predictor of evolution acceptance than understanding or religiosity. CBE Life Sci Educ. 2021b. https://doi.org/10.1187/cbe.21-02-0024.

Barone LM, Petto AJ, Campbell BC. Predictors of evolution acceptance in a museum population. Evol Educ Outreach. 2014. https://doi.org/10.1186/s12052-014-0023-2.

Becuwe N, Baneth O. Special Eurobarometer 508 on Values and Identities of EU citizens. 2021; https://publications.jrc.ec.europa.eu/repository/bitstream/JRC126943/JRC126943_01.pdf

Beniermann A. Evolution—von Akzeptanz und Zweifeln. Empirische Studien über Einstellungen zu Evolution und Bewusstsein [Evolution—about acceptance and doubts. Empirical studies on attitudes towards evolution and consciousness]. 1st ed. Wiesbaden: Springer Spektrum; 2019. https://doi.org/10.1007/978-3-658-24105-6.

Beniermann A, Kuschmierz P, Pinxten R, Aivelo T, Bohlin G, Brennecke J, Cebesoy Ü, Cvetković D, Đorđević M, Dvořáková R, Futo M, Geamana N, Korfiatis K, Lendvai A, Mogias A, Paolucci S, Petersson M, Pietrzak B, Porozovs J, Graf D. Evolution Education Questionnaire on acceptance and knowledge (EEQ)—Standardised and ready-to-use protocols to measure acceptance of evolution and knowledge about evolution in an international context (COST: European cooperation in science & technology, Ed). 2021;10.5281/zenodo.4554742

Betti L, Shaw P, Behrends V. Acceptance of biological evolution by first-year life sciences university students. Sci Educ. 2020;29(2):395–409. https://doi.org/10.1007/s11191-020-00110-0.

Bishop BA, Anderson CW. Student conceptions of natural selection and its role in evolution. J Res Sci Teach. 1990;27(5):415–27. https://doi.org/10.1002/tea.3660270503.

Bloom BS, Engelhart MD, Furst EJ, Hill WH, Krathwohl DR. (1956). Taxonomy of educational objectives. The classification of educational goals. Handbook I: Cognitive comain. (BS Bloom, Engelhart, MD., Furst EJ, Hill, WH, Krathwohl DR, Ed. 1st ed.). David McKay Company, Inc.

Bloom P, Weisberg D. Childhood origins of adult resistance to science. Science. 2007;316:996–7. https://doi.org/10.1126/science.1133398.

Brasseur A. The dangers of creationism in education. (11375). Luxembourg: Committee on Culture, Science and Education. 2007. https://assembly.coe.int/Documents/WorkingDocs/2007/EDOC11375.pdf.

Brennecke JS. Schülervorstellungen zur evolutionären Anpassung: qualitative Studien als Grundlage für ein fachdidaktisches Entwicklungskonzept in einem botanischen Garten [Universitätsbibliothek]. Gießen. 2015. http://geb.uni-giessen.de/geb/volltexte/2015/11320

Catholic Church in Germany. Zahlen und Fakten 2021/22 [Numbers and facts 2019/20]. 2020. https://www.dbk.de/fileadmin/redaktion/Zahlen%20und%20Fakten/Kirchliche%20Statistik/Allgemein_-_Zahlen_und_Fakten/AH332_BRO_ZuF_2021-2022_WEB.pdf

Clément P. Creationism, science and religion: a survey of teachers' conceptions in 30 countries. Procedia Soc Behav Sci. 2015a;167:279–87. https://doi.org/10.1016/j.sbspro.2014.12.675.

Clément P. Muslim teachers' conceptions of evolution in several countries. Public Underst Sci. 2015b;24(4):400–21. https://doi.org/10.1177/0963662513494549.

Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Cambridge: Academic Press; 1988.

Council of Europe. *The dangers of creationism in education*. (Doc. 11375). Committee on Culture, Science and Education. 2007. https://assembly.coe.int/Documents/WorkingDocs/2007/EDOC11375.pdf

Deniz H, Donnelly LA, Yilmaz I. Exploring the factors related to acceptance of evolutionary theory among Turkish preservice biology teachers: toward a more informative conceptual ecology for biological evolution. J Res Sci Teach. 2008;45(4):420–43. https://doi.org/10.1002/tea.20223.

Department for Education (England). The national curriculum in England—Key stages 3 and 4 framework document. 2014. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/840002/Secondary_national_curriculum_corrected_PDF.pdf

Directorate General Press and Communication. Europeans, Science and Technology (Special Eurobarometer, Issue). 2005.

Döring N, Bortz J, Poeschl-Guenther S. *Forschungsmethoden und Evaluation in den Sozial-und Humanwissenschaften* [research methods and evaluation in the social and human sciences]. Springer; 2016.

Dunk RDP, Petto AJ, Wiles JR, Campbell BC. A multifactorial analysis of acceptance of evolution. Evol Educ Outreach. 2017. https://doi.org/10.1186/s12052-017-0068-0.

Dunk RDP, Barnes ME, Reiss MJ, Alters B, Asghar A, Carter BE, Cotner S, Glaze AL, Hawley PH, Jensen JL, Mead LS, Nadelson LS, Nelson CE, Pobiner B, Scott EC, Shtulman A, Sinatra GM, Southerland SA, Walter EM, Wiles JR. Evolution education is a complex landscape. Nat Ecol Evol. 2019;3(3):327–9. https://doi.org/10.1038/s41559-019-0802-9.

Ecklund EH, Scheitle CP. Religion among academic scientists: distinctions, disciplines, and demographics. Soc Probl. 2014;54(2):289–307. https://doi.org/10.1525/sp.2007.54.2.289.

Elsdon-Baker F. Creating creationists: the influence of 'issues framing' on our understanding of public perceptions of clash narratives between evolutionary science and belief. Public Underst Sci. 2015;24(4):422–39. https://doi.org/10.1177/0963662514563015.

European Commission, D.-G. f. C. *European citizens' knowledge and attitudes towards science and technology* (Special Eurobarometer 516—April–May 2021, Issue. 2021.

Eurydice. National specificities of the education system. 2021. https://eacea.ec.europa.eu/national-policies/eurydice/content/germany_en.

Evangelical Church in Germany. Evangelical Church in Germany. Evangelical Church in Germany. 2016. https://www.ekd.de/ekd_en/ds_doc/facts_and_figures_2016.pdf.

Evangelical Church in Germany. *Gezählt 2021. Zahlen und Fakten zum kirchlichen Leben* [Counted 2021. Numbers and facts on church life]. 2021. https://www.ekd.de/ekd_de/ds_doc/Gezaehlt_zahlen_und_fakten_2021.pdf.

Evans EM. Cognitive and contextual factors in the emergence of diverse belief systems: creation versus evolution. Cogn Psychol. 2001;42(3):217–66. https://doi.org/10.1006/cogp.2001.0749.

Everhart D, Hameed S. Muslims and evolution: a study of Pakistani physicians in the United States. Evol Educ Outreach. 2013. https://doi.org/10.1186/1936-6434-6-2.

Federal Ministry of the Interior Building and Community. 2019 Migration Report Key Results. 2019. https://www.bamf.de/SharedDocs/Anlagen/EN/Forschung/Migrationsberichte/migrationsbericht-2019-zentrale-ergebnisse.pdf?__blob=publicationFile&v=4

Federal Office for Migration and Refugees & German Islam Conference. Executive summary of the study "Muslim Life in Germany 2020". 2020. https://www.bamf.de/SharedDocs/Anlagen/EN/Forschung/Forschungsberichte/Kurzberichte/fb38-muslimisches-leben-kurzfassung.pdf?__blob=publicationFile&v=14.

Federal Ministry of the Interior and Home Affairs. Christliche Kirchen [Christian Churches]. 2022. https://www.bmi.bund.de/DE/themen/heimat-integration/gesellschaftlicher-zusammenhalt/staat-und-religion/christliche-kirchen/christliche-kirchen-node.html. Accessed 08 09 2022.

Federer MR, Nehm RH, Opfer JE, Pearl D. Using a constructed-response instrument to explore the effects of item position and item features on the assessment of students' written scientific explanations. Res Sci Educ. 2015;45(4):527–53. https://doi.org/10.1007/s11165-014-9435-9.

Fenner A. Schülervorstellungen zur Evolutionstheorie : Konzeption und Evaluation von Unterricht zur Anpassung durch Selektion [Student conceptions of evolutionary theory: designing and evaluating lessons on adaptation by selection] Universitätsbibliothek]. Gießen. 2013. http://geb.uni-giessen.de/geb/volltexte/2013/9250.

Field A. Discovering statistics using IBM SPSS statistics. 5th ed. California: Sage; 2018.

Fowler JW, Dell ML. Stages of faith from infancy through adolescence reflections on three decades of faith development theory. In: Roehlkepartain EC, King PE, Wagener L, Benson PL, editors. The handbook of spiritual development in childhood and adolescence. California: Sage Publications, Inc; 2006. p. 34–5. https://doi.org/10.4135/9781412976657.n3.

German National Academy of Sciences Leopoldina. Teaching evolutionary biology at schools and universities. Halle (Saale): Deutsche Akademie der Naturforscher Leopoldina e.V. Nationale Akademie der Wissenschaften. 2017. https://www.leopoldina.org/uploads/tx_leopublication/2017_Stellungnahme_Evolution_ENG.pdf

Glaze AL, Goldston MJ. U.S. Science teaching and learning of evolution: a critical review of the literature 2000–2014. Sci Educ. 2015;99(3):500–18. https://doi.org/10.1002/sce.21158.

Gould SJ. Rocks of ages. Science and religion in the fullness of life. Libr Contemp Thought. 1999;400:830.

Großschedl J, Konnemann C, Basel N. Pre-service biology teachers' acceptance of evolutionary theory and their preference for its teaching. Evol Educ Outreach. 2014;7(1):18. https://doi.org/10.1186/s12052-014-0018-z.

Großschedl J, Seredszus F, Harms U. Angehende biologielehrkräfte: evolutionsbezogenes wissen und akzeptanz der evolutionstheorie [pre-service biology teachers: evolution-related knowledge and acceptance of evolutionary theory]. Zeitschrift Für Didaktik Der Naturwissenschaften. 2018;24(1):51–70. https://doi.org/10.1007/s40573-018-0072-0.

Ha M, Haury DL, Nehm RH. Feeling of certainty: uncovering a missing link between knowledge and acceptance of evolution. J Res Sci Teach. 2012;49(1):95–121. https://doi.org/10.1002/tea.20449.

Heddy BC, Sinatra GM. Transforming misconceptions: Using transformative experience to promote positive affect and conceptual change in students learning about biological evolution. Sci Educ. 2013;97(5):723–44. https://doi.org/10.1002/sce.21072.

Kahan D. Misconceptions, misinformation, and the logic of identity-protective cognition. SSRN Electron J. 2017. https://doi.org/10.2139/ssrn.2973067.

Kelemen D. Teleological minds: How natural intuitions about agency and purpose influence learning about evolution. In: Rosengren K, Brem SK, Evans EM, Sinatra GM, editors. Evolution challenges: integrating research and practice in teaching and learning about evolution. 1st ed. Oxford: Oxford University Press; 2011.

Konnemann C, Asshoff R, Hammann M. Einstellungen zur evolutionstheorie: theoretische und messtheoretische klärungen [attitudes toward evolutionary theory: theoretical and measurement-theoretical clarifications]. Zeitschrift Für Didaktik Der Naturwissenschaften. 2012;18:55–79.

Kuschmierz P, Beniermann A, Graf D. Development and evaluation of the knowledge about evolution 2.0 instrument (KAEVO 2.0). Int J Sci Educ. 2020a;42(15):2601–29. https://doi.org/10.1080/09500693.2020.1822561.

Kuschmierz P, Meneganzin A, Pinxten R, Pievani T, Cvetković D, Mavrikaki E, Graf D, Beniermann A. Towards common ground in measuring acceptance of evolution and knowledge about evolution across Europe: a systematic review of the state of research. Evol Educ Outreach. 2020b;13(1):18. https://doi.org/10.1186/s12052-020-00132-w.

Kuschmierz P, Beniermann A, Bergmann A, Pinxten R, Aivelo T, Berniak-Woźny J, Bohlin G, Bugallo-Rodriguez A, Cardia P, Cavadas BF, Pinto B, Cebesoy UB, Cvetković DD, Demarsy E, Đorđević MS, Drobniak SM, Dubchak L, Dvořáková RM, Fančovičová J, Graf D. European first-year university students accept evolution but lack substantial knowledge about it: a standardized European cross-country assessment. Evol Educ Outreach. 2021;14(1):17. https://doi.org/10.1186/s12052-021-00158-8.

Lammert N. Akzeptanz, Vorstellungen und Wissen von Schülerinnen und Schülern der Sekundarstufe I zu evolution und Wissenschaft [lower secondary school students' acceptance, perceptions, and knowledge of evolution and science]. Technische Universität Dortmund. 2012. https://doi.org/10.17877/DE290R-4832.

Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–74. https://doi.org/10.2307/2529310.

Martin JW. Compatibility of major U.S. christian denominations with evolution. Evolu Educ Outreach. 2010;3(3):420–31. https://doi.org/10.1007/s12052-010-0221-5.

Miller J, Scott E, Okamoto S. Public acceptance of evolution. Science. 2006;313:765–6. https://doi.org/10.1126/science.1126746.

Miller JD, Scott EC, Ackerman MS, Laspra B, Branch G, Polino C, Huffaker JS. Public acceptance of evolution in the United States, 1985–2020. Public

Underst Sci. 2022;31(2):223–38. https://doi.org/10.1177/09636625211035919.
Ministry for School and Education of North Rhine-Westphalia. Kernlehrplan für die Sekundarstufe II Gymnasium/Gesamtschule in Nordrhein-Westfalen: Biologie. [Core curriculum for secondary level II gymnasium/comprehensive school in North Rhine-Westphalia: Biology] Düsseldorf. 2013. https://www.schulentwicklung.nrw.de/lehrplaene/upload/klp_SII/bi/GOSt_Biologie_Endfassung.pdf
Ministry of the Interior of the State of North Rhine-Westphalia. Schulgesetz für das Land Nordrhein-Westfalen (Schulgesetz NRW—SchulG). [School law for the state of North Rhine-Westphalia] North Rhine-Westphalia. 2022. https://bass.schul-welt.de/pdf/6043.pdf?20220912183404.
National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research. The Belmont Report: ethical principles and guidelines for the protection of human subjects of research. 1979. https://www.hhs.gov/ohrp/regulations-and-policy/belmont-report/read-the-belmont-report/index.html.
Nehm RH, Ha M. Item feature effects in evolution assessment. J Res Sci Teach. 2011;48(3):237–56. https://doi.org/10.1002/tea.20400.
Nehm RH, Reilly L. Biology majors' knowledge and misconceptions of natural selection. Bioscience. 2007;57(3):263–72. https://doi.org/10.1641/b570311.
Nehm RH, Beggrow EP, Opfer JE, Ha M. Reasoning about natural selection: diagnosing contextual competency using the ACORNS instrument. Am Biol Teach. 2012;74(2):92–8. https://doi.org/10.1525/abt.2012.74.2.6.
Nehm RH, Ha M, Rector M, Opfer JE, Perrin L, Ridgway J, Mollohan K. Scoring guide for the open response instrument (ORI) and evolutionary gain and loss test (EGALT). 2010. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.471.7384&rep=rep1&type=pdf
Nehm RH, Ha M, Großschedl J, Harms U, Roshayanti F. (2013, April 6–April 9). American, German, Korean, and Indonesian pre-service teachers' evolutionary acceptance, knowledge, and reasoning patterns. Paper in the proceedings of the National Association for Research in Science Teaching (NARST) conference, Rio Grande, Puerto Rico.
O'Connor C, Joffe H. Intercoder reliability in qualitative research: debates and practical guidelines. Int J Qual Methods. 2020;19:1609406919899220. https://doi.org/10.1177/1609406919899220.
Ohly K-P. Evolutionstheorie und schöpfungslehre im biologieunterricht [theory of evolution and creation in biology classes]. In: Dreesmann DC, Graf D, Witte K, editors. Evolutionsbiologie: moderne themen für den unterricht. Heidelberg: Spektrum Akademischer Verlag; 2012. p. 485–503. https://doi.org/10.1007/978-3-8274-2786-1_17.
Opfer JE, Nehm RH, Ha M. Cognitive foundations for science assessment design: knowing what students know about evolution. J Res Sci Teach. 2012;49(6):744–77. https://doi.org/10.1002/tea.21028.
Park HJ. Components of conceptual ecologies. Res Sci Educ. 2007;37(2):217–37. https://doi.org/10.1007/s11165-006-9023-8.
Pew Research Center. Religious Landscape Study. 2007. https://www.pewresearch.org/religion/religious-landscape-study/. Accessed 02 04 2022.
Pickel G. *Religionsmonitor verstehen was verbindet. Religiosität im internationalen Vergleich* [Religion Monitor Understanding what connects. Religiosity in International Comparison]. 2013. https://www.bertelsmann-stiftung.de/fileadmin/files/BSt/Publikationen/GrauePublikationen/GP_Religionsmonitor_verstehen_was_verbindet_Religioesitaet_im_internationalen_Vergleich.pdf
Posner GJ, Strike KA. A revisionist theory of conceptual change. Philosophy of science, cognitive psychology, and educational theory and practice. 1992;147
Rachmatullah A, Nehm RH, Roshayanti F, Ha M. Evolution education in Indonesia: pre-service biology teachers' knowledge, reasoning models, and acceptance of evolution. In: Deniz H, Borgerding LA, editors. Evolution education around the globe. Cham: Springer International Publishing AG; 2018. p. 335–55. https://doi.org/10.1007/978-3-319-90939-4_18.
Rios K, Cheng ZH, Totton RR, Shariff AF. Negative stereotypes cause Christians to underperform in and disidentify with science. Soc Psychol Pers Sci. 2015;6(8):959–67. https://doi.org/10.1177/1948550615598378.
Schneider V. Wirkungen des Protestantismus auf Einstellungen und Wertorientierungen. USA und Deutschland im Vergleich [effects of protestantism on attitudes and value orientations. USA and Germany in comparison]. 1st ed. Wiesbaden: Springer VS; 2020. https://doi.org/10.1007/978-3-658-30654-0.
Sinatra GM, Southerland SA, McConaughy F, Demastes JW. Intentions and beliefs in students' understanding and acceptance of biological evolution. J Res Sci Teach. 2003;40(5):510–28. https://doi.org/10.1002/tea.10087.
Sinatra GM, Brem SK, Evans EM. Changing minds? Implications of conceptual change for teaching and learning about biological evolution. Evol Educ Outreach. 2008;1(2):189–95. https://doi.org/10.1007/s12052-008-0037-8.
Smith MU. Current status of research in teaching and learning evolution: II pedagogical issues. Sci Educ. 2010;19(6):539–71. https://doi.org/10.1007/s11191-009-9216-4.
Smith MU, Siegel H. On the relationship between belief and acceptance of evolution as goals of evolution education. Sci Educ. 2016;25(5):473–96. https://doi.org/10.1007/s11191-016-9836-4.
Southerland SA, Sinatra GM. The shifting roles of acceptance and dispositions in understanding biological evolution. In: Cobern WW, Tobin K, Brown-Acquay H, Espinet M, Irzik G, Jegede O, Herrera LR, Rollnick M, Sjøberg S, Tuan H-l, Alsop S, editors. Beyond Cartesian dualism: encountering affect in the teaching and learning of science. Berlin: Springer; 2005.
Strike KA, Posner GJ. Conceptual change and science teaching. Eur J Sci Educ. 1982;4(3):231–40. https://doi.org/10.1080/0140528820040302.
Tibell LAE, Harms U. Biological principles and threshold concepts for understanding natural selection. Sci Educ. 2017;26(7):953–73. https://doi.org/10.1007/s11191-017-9935-x.
Truong JM, Barnes ME, Brownell SE. Can six minutes of culturally competent evolution education reduce students' level of perceived conflict between evolution and religion? Am Biol Teach. 2018;80(2):106–15. https://doi.org/10.1525/abt.2018.80.2.106.
Unsworth A, Voas D. Attitudes to evolution among christians, muslims and the non-religious in Britain: differential effects of religious and educational factors. Public Underst Sci. 2018;27(1):76–93. https://doi.org/10.1177/0963662517735430.
Unsworth A, Voas D. The Dawkins effect? Celebrity scientists, (non)religious publics and changed attitudes to evolution. Public Underst Sci. 2021;30(4):434–54. https://doi.org/10.1177/0963662521989513.
Waschke T, Lammers C. Evolutionstheorie im biologieunterricht—(k)ein thema wie jedes andere? [evolutionary theory in biology classes—(not) a topic like any other?]. In: Dreesmann DC, Graf D, Witte K, editors. Evolutionsbiologie: moderne themen für den unterricht. Heidelberg: Spektrum Akademischer Verlag; 2012. p. 505–34. https://doi.org/10.1007/978-3-8274-2786-1_18.

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