Evolution: Education and Outreach

RESEARCH

Open Access

Exploring teacher self-efficacy in human evolution instruction following a dynamic hands-on professional development workshop

Molly C. Selba[1], Michael J. Ziegler[2], Amanda L. Townley[3] and Pavlo D. Antonenko[4*]

Abstract

Background Human evolution is a topic that is largely excluded from K-12 classrooms for a variety of reasons, including the inability, unwillingness, or lack of preparedness of educators to teach a topic that has been seen as controversial. This study explored how engagement in professional development infused with 3D printing and ways of knowing discussion influenced science teachers' self-efficacy for teaching human evolution. The professional development opportunity was designed to empower teachers and provide them with the tools necessary to incorporate human evolution into their curriculum. During this workshop, participants learned about paleontology and human origins, spoke with professional paleoanthropologists, discussed implementation strategies with evolution educators, and developed lesson plans centered around human evolution. To explore the role of this professional development on teachers' self-efficacy and perceptions of the teaching of evolution, we used a previously validated survey that was employed in the pre-test and post-test format and semi-structured focus group interviews.

Results The results of this study indicate that the workshop positively impacted teacher perceptions of the teaching of evolution with significant improvements on two of the three tested factors and the third factor almost reaching significance.

Conclusions Our data demonstrate that a three-day workshop can successfully impact teachers' perception dof the teaching of evolution and, in turn, increase the implementation of human evolution in K-12 classrooms. By specifically structuring the workshop content in a way that addressed many of the previously indicated obstacles in teaching evolution, we were able to positively impact educators and provide them with the information and tools necessary to add human evolution into their curricula.

Keywords Evolution education, Pedagogy, Human evolution

Introduction

Perceived obstacles in the teaching of evolution in the K-12 classroom are well-documented (Alters and Nelson 2002; Geher et al. 2019; Kruger et al. 2012; Lerner 2000, Nelson 2008; Rohrbacher 2013; Scharmann 2005; Ziadie and Andrews 2018), however, assessing and addressing barriers against the implementation of human evolution as a specific approach has been largely unstudied. Previously addressed obstacles in the teaching of evolution include a lack of scientific literacy and distrust of the scientific community (Geher et al. 2019), a dearth

*Correspondence:
Pavlo D. Antonenko
p.antonenko@ufl.edu
[1] University of Maryland Eastern Shore, 11868 College Backbone Rd, Princess Anne, MD 21853, USA
[2] Max Planck Institute of Geoanthropology, Kahlaische Str. 10, 07745 Jena, Germany
[3] National Center for Science Education, 230 Grand Avenue, Suite 101, Oakland, CA 94610, USA
[4] University of Florida, 201 Criser Hall, PO Box 114000, Gainesville, FL 32611, USA

© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

of educator knowledge about the ever-changing field of human origins (Pobiner 2016), a deficiency of easily-implemented teaching materials (Selba 2019), a lack of access to the actual fossils on which our understanding of evolution is based (Ziadie and Andrews 2018), as well as the perceived controversial nature of the teaching of evolution (Hermann 2008). Even within the implementation of human evolution curriculum, there is controversy regarding the real or perceived interdisciplinarity and scope of the material (Hanisch and Eirdosh 2020). The Next Generation Science Standards (NGSS) for example, reference key concepts of selection, common ancestry, and evidence for evolution writ large, but do not specifically address human evolution or encourage the inclusion of such in classroom teaching (NGSS 2013). Furthermore, although they are a set of national-level standards, they are not mandated and have been adopted by only 22 states, with states holding the authority to determine their own standards for teaching science. As a result, evolution has only recently been added to the statewide teaching standards in many states (for example, the word 'evolution' was not included in the teaching standards for Florida until 2008) (Fowler and Meisels 2010). Combining these factors leaves teachers interested in teaching evolution without the resources and support to do so. It can also discourage disinterested or skeptical teachers from incorporating it into their curriculum in the first place.

This study aimed to better understand how to help educators increase the inclusion of human evolution into existing K-12 science curricula with accuracy and confidence. This study was designed to address the following research question:

- How does human evolution teacher professional development integrating 3D printing and discussions of "ways of knowing" (i.e., the ways in which humans acquire knowledge and process experiences to make sense of the world) impact teacher perceptions and self-efficacy for teaching human evolution?

Review of literature

Research on the teaching and learning of evolution has expanded widely in the twenty-first century. However, national polls indicate that public perceptions of evolution have remained primarily unchanged over three decades, and further efforts are still required (Evolution, Creationism, Intelligent Design, 2019). Not only does the minimal change in public perceptions represent a challenge for evolution, it is a critical blow to scientific literacy as a whole, suggesting the by-and-large evidence-only approach to teaching scientific concepts seen by the public as "controversial" fail to reach goals to build a scientifically literate society (Rankey 2003; Robbins and Roy 2007; Schilders et al. 2009; Smith and Seigel 2016). In response to the polls, researchers have focused on the foundations of knowledge, understanding, belief, and acceptance of evolution (Matthews 2001; Rutledge and Sadler 2011) to understand the interactions that drive public thinking (Miller et al. 2006). Similar focus looked toward university and K-12 classroom experiences, standards, and teaching approaches to foster change on a broader scale (Glaze and Goldston 2019; Ha et al. 2012; Hermann et al. 2020). Guided by our growing understanding of how students learn, how teachers engage their autonomy, effective practices in science, and actively mitigating conflict, now it is possible to put theory into practice, utilizing understandings of what does and does not work in new ways to build practical approaches that translate and transfer with fidelity into the classroom.

Evolution teaching, learning, and perceptions are complicated

Foundational explorations in evolution education center around differentiation and interactions among knowledge/understanding and acceptance of evolution (Kim and Nehm 2011; Matthews 2001; Nehm and Reilly 2007; Nehm and Schonfeld 2007). A common theme in research is whether knowledge or acceptance of evolution should be the goal of education, with differences noted between goals for K-12 education and post-secondary education (Barnes and Brownell 2016; Glaze 2017; Meadows 2009; Smith and Seigel 2016). While the literature finds little agreement on whether and to what extent knowledge impacts acceptance, it is clear that there is a disconnect between the two that does not follow the logical pattern shown in other topics (Bertka et al. 2019; Sinatra et al. 2003). As a result, subsequent studies often begin with at least a cursory exploration of evolution content knowledge or acceptance levels of students and teachers to establish baselines or explore groups compared to others. It has been concluded that increasing content alone is not enough to instigate conceptual change that leads to greater acceptance of evolution (Bertka et al. 2019; Barnes et al. 2017; Glaze and Goldston 2015; Glaze et al. 2015; Hermann 2012). Whether the goal is to ensure acceptance or increase understanding, students should learn about evolution from a scientific perspective in their science classes (Bertka et al. 2019).

Understanding and accepting evolution requires acknowledging barriers

We are combating challenges arising from content knowledge disparities, worldviews, and culture when teaching evolution and negative perceptions (Bertka et al. 2019). In addition to content barriers, cultural objections

play a role in the teaching and learning of evolution in the classroom, including but not limited to religious beliefs and historical contexts surrounding race (Bertka et al. 2019; Brem et al. 2003; Goldston and Kyzer 2009; Meadows et al. 2000). Failing to acknowledge worldview elements in a considerate and not suppressive way creates an environment of exclusion and discomfort, preventing conceptual change (Barnes et al. 2017; Bertka et al. 2019; Hermann 2012). Additionally, there can be conceptual challenges such as misconceptions, the semantics of the language of science, and a need for more modeling to cope with conflict (see reviews in Glaze and Goldston 2015; Glaze et al. 2015; Pobiner 2016). Conflict exists long before formal experience with the concepts in schools and persists long after those experiences where nothing is done to address concerns and support the navigation of the conflict (Bertka et al. 2019; Glaze and Goldston 2015; Glaze et al. 2015; Griffith and Brem 2004; Long 2012), therefore, approaches meant to increase knowledge or acceptance, and thereby teachers' autonomous choices in the instruction of evolution, must address diverse elements from content and conflict mitigation to coping skills and pedagogical strategies that are desperately needed (Bertka et al. 2019).

Teacher autonomy impacts what and how evolution is taught in the classroom

While there are national Next Generation Science Standards (2013) for science education in the United States, each state can adopt or craft its standards. In the Southeastern United States, where this study occurred, none of the states (TX, LA, MS, AL, GA, FL, SC, TN) adopted the national standards, although several elected to craft similar standards to the NGSS. As a result, states maintain autonomy in selecting topics covered in a given school year in science classes. At the same time, there is still a great deal of local control and very little oversight to ensure all standards are taught outside of standardized testing in most states. One by-product of the need for national standards and assurance of coverage is that there is a great deal of autonomy on a classroom-by-classroom basis. Teachers are often responsible for selecting their curriculum either entirely or on a supplementary level and have an ultimate say in what and whether they teach evolution (Rutledge and Mitchell 2002).

Evolution instruction notably impacts teacher persona and approach in the classroom. In a study of established classroom teachers, Goldston and Kyzer (2009) observed marked changes in how teachers spoke to their students, modeled thinking, and responded to questions when teaching evolution, all involving being less confident and engaged than those same teachers were when teaching other topics. Not only do many teachers demonstrate a limited understanding of the basic concepts of evolution (goal of education, with differences noted between goals), but even in the presence of advanced certifications and experience, they often struggle with processes and practices of science, grouped as the Nature of Science (NOS) (Bartos and Lederman 2014). Limited understandings of fundamentals and NOS are critical failings, as this is where most of the misconceptions surrounding evolution and other sciences are grounded (e.g., law vs. theory, social constructs of science, even what science is and is not) (McComas 1997).

Science teachers' self-efficacy for teaching evolution

Teachers' self-efficacy beliefs also influence instructional practices for evolution instruction for teaching evolution. Self-efficacy beliefs impact "how teachers think, feel and teach" (Gibbs 2003, p. 1). Self-efficacy mediates various cognitive, affective, and volitional factors that define how we plan, organize, implement, and reflect on our activities (Bandura 1997). High self-efficacy beliefs support intrinsic motivation and increased engagement. On the other hand, low self-efficacy results in feelings of incompetence diminished potential for higher-order cognition, and, consequently, decreased task performance (Bandura 1993).

Self-efficacy for teaching evolution specifically is known to be impacted by a host of factors, including religious views (Alters and Nelson 2002; Asghar et al. 2007), misconceptions about evolution (Gregory 2009; Meir et al. 2007), inadequate level of acceptance of evolution (e.g., Kim and Nehm 2011; Peker et al. 2010), and lack of understanding of nature of science (Dagher and Bou-Jaoude 2005; Kim and Nehm 2011; Rutledge and Warden 2000). The ongoing perceptions in society that there is an evolution versus creationism "controversy" further hinders a teacher's ability to develop knowledge and self-efficacy for teaching evolution (Hawley and Sinatra 2019). Teachers must balance their sense of duty to their profession, the demands and concerns of their community, their response to the greater political climate, and their beliefs. Secondary science textbooks, a primary instructional resource for most teachers, caution new teachers to refrain from allowing students to debate the issue and to distinguish between a theory and a fact when teaching evolution (e.g., Chiappetta and Koballa 2002).

Teachers are encouraged to "plan ahead to determine how to deal with objections from students and parents who oppose instruction, including evolution. [Make] provisions to give students alternative work in science, if they wish to leave the classroom during instruction on evolution" (Chiappetta and Koballa 2002, p. 144). However, more support is needed for teachers on how to communicate with students and parents regarding teaching

evolution. In addition, teachers often struggle with the issue of disclosure versus neutrality, that is, whether to share their personal views and opinions with students or to adopt the role of an impartial facilitator during the deliberation of evolution (Hermann 2008; Miller-Lane et al. 2006). It is no wonder why many teachers have low self-efficacy beliefs for teaching human evolution and feel anxious and stressed about the need to protect themselves from the potential consequences of conflict over teaching evolution.

Several studies have demonstrated that biology teachers need more confidence in their knowledge of evolution (Glaze and Goldston 2015; Glaze et al. 2015; Griffith and Brem 2004). A path analysis study examining the relative effects of teacher self-efficacy, understanding and acceptance of evolution, and views on the nature of science revealed that higher levels of both understanding and acceptance of the theory and naive views on NOS were found to be associated with stronger self-efficacy beliefs for teaching evolution effectively (Akyol et al. 2012). Another relevant study examined the sources of pressure, resulting stresses, and coping strategies Arizona biology teachers devised for teaching evolution (Griffith and Brem 2004). Based on the results of focus groups, interviews, and surveys, teachers were clustered into three groups: "Conflicted," who struggled with their beliefs and the possible impact of their teaching, "Selective," who carefully avoided complex topics and situations, and "Scientists," who saw no place for controversial social issues in their science classroom. Teachers from each group felt that they could be more effective in teaching evolution if they possessed: (a) the most up-to-date information about evolution (interdisciplinary content knowledge), (b) a safe space in which to reflect on the possible social and personal implications with their peers, and (c) access to more rigorous and rich lesson plans for teaching evolution that include not only science but personal stories regarding how the lessons arose, and what problems and opportunities they created. The authors emphasized that workshops on the most recent information about evolution and how to teach it may enhance science teachers' confidence in teaching evolution.

Professional development impacts teacher perceptions and actions in the classroom

Teachers' attitudes directly impact their choices of what and how they teach in their classrooms (Rutledge and Mitchell 2002). Therefore, to impact curriculum and pedagogical selections, interventions are needed that positively impact teacher attitudes and confidence surrounding topics perceived as contentious. Effective professional development is a fundamental supporting tool in science education (Loucks-Horsley 2003) that has become more necessary since implementing the Next Generation Science Standards (2013). Although there are limited studies on evolution-specific professional learning opportunities for K-12 teachers, the research suggests that lasting, large-scale effects on teaching practices and confidence are possible through effective professional learning for teachers (Ha et al. 2015; Schrein et al. 2009). In their study on evolution education interventions, Ha et al. (2015) identified only seven existing studies, most of which still needed to be replicated, all of which varied widely in focus and approach. Despite the variety, each of the studies demonstrated self-reported or measured impacts on teacher confidence (Firenze 1997), knowledge (Crawford et al. 2005; Firenze 1997; Nehm and Schonfeld 2007), enthusiasm (Firenze 1997), acceptance (Nadelson and Sinatra 2023; Southerland and Nadelson 2012), or willingness to teach evolution (Nehm and Schonfeld 2007), although there was no consistency or homogeneity across the studies in those outcomes. What studies do agree on is that professional development can positively influence what and how teachers teach in their classrooms while providing ongoing content and pedagogical support for effective instruction, feelings of self-efficacy, and culturally relevant practices (Ha et al. 2015; Pobiner 2016).

Effective professional development for evolution requires a multi-dimensional approach

Teachers and students face internal and external pressure regarding the teaching and learning of evolution (Dotger et al. 2010; Glaze and Goldston 2015; Glaze et al. 2015; Pobiner 2016; Smith 2010a, b). One tool recommended by a wide range of studies in evolution education is ongoing professional learning that focuses on confidence, cultural considerations, and content knowledge (Berkman and Plutzer 2015; Glaze and Goldston 2015; Glaze et al. 2015; Hermann 2011; Pobiner 2016; Rutledge and Mitchell 2002). According to Bertka et al. (2019), classrooms must be structured in a way that approaches content and allows teachers and students to acknowledge controversy while including pedagogy to navigate the conflict between elements of worldview and evolution. The call for classroom experiences, teacher preparation, and professional development that meets those needs is strong (Crawford et al. 2005; Meadows 2009; Reiss 2009; Barnes et al. 2017; Wiles 2014; Yasri and Mancy 2016). However, evolution education researchers are only beginning to make headway in applying these approaches to work with students and teachers (Barnes et al. 2017; Bertka et al. 2019). In a study by Berkman and Plutzer (2012), more than half of surveyed teachers actively taught evolution using techniques they knew needed to be more robust in addressing evolution with their students. Similarly, other

studies have shown that teachers often approach evolution with misconceptions, inaccurate content, alternatives to evolution, or avoiding teaching evolution for various reasons (Glaze and Goldston 2015; Glaze et al. 2015; Pobiner 2016).

Teachers face difficulty looking beyond their perceptions of conflict, confidence in content, pedagogical knowledge, incompatibility of beliefs, and concerns. However, these concerns must be identified and addressed to create meaningful learning experiences (Sanders and Ngxola 2009). With challenges coming from so many angles–teacher discomfort, low confidence in content, feelings of non-support, lack of pedagogy to address cultural/worldview conflict, and more—professional development that embraces multiple elements is crucial.

Human evolution presents a unique approach to personalizing evolution education in classrooms

While research on evolution education is steadily increasing, the connection between humans and science is most often needed, specifically our evolutionary history as a species. Admittedly, human evolution represents one of the most substantial hurdles for many when it comes to evolution. As recently as 2019, 40% of polled individuals believe that God created humans in their present form, and 33% believe that Humans evolved with God guiding their evolution (Evolution, Creationism, Intelligent Design, 2019). Studies show that responses from confidence in teaching to acceptance of evolution can demonstrate a downward trend based on whether they discuss human evolution or evolution among non-human organisms (Pobiner 2016). While human evolution can represent a barrier to acceptance, it also represents a missed opportunity to frame evolutionary study in a manner that is both personal and connects us to science on a deeper level.

In this study, professional development targeted a variety of teacher concerns and areas of need, building from existing studies on teaching human evolution in K-12 settings. Included in the approach were content features on teaching human evolution in K-12 settings (Pobiner et al. 2018), using cladistics in support of evolutionary relationships and tree-thinking (Catley 2006; Walter et al. 2013), and addressing misconceptions and the nature of science (Schilders et al. 2009; Martin-Hansen 2010). Open discourse space was created, and specific attention was paid to exploring and discussing cultural barriers, including religiosity, to focus on elements of conflict and context (Bertka et al. 2019; Barnes et al. 2017; Oliveira et al. 2011) as well as approaches to mitigating and acknowledging conflict without teaching the controversy (Bertka et al. 2019). Finally, the use of 3D models produced using 3D printing technology, viewed as a new tool for scientific discovery when materials are hard to come by or unavailable for a specific setting, was employed to provide specific supports from which teachers could approach human evolution through mediums that strongly mimic the practices and processes of scientists making discoveries in the field (Bayer and Luberda 2016; Drake and Pawlina 2014).

The Human Evolution Summer Teacher Workshop (HESTW)

Evolution is considered a unifying concept in science. It is a required component of the middle school curriculum in the Next Generation Science Standards (NGSS Lead States 2013). Unfortunately, teachers often fail to effectively or accurately teach human evolution due to barriers such as a lack of curricular support, lack of content knowledge, not understanding the nature of science, or a lack of confidence in teaching what they perceive to be a controversial subject (Glaze and Goldston 2015; Glaze et al. 2015). To prepare science teachers to integrate human evolution into their instruction more effectively, the authors of this study designed and implemented a Human Evolution Professional Development Institute hosted at a large research university in the Southeastern United States. The institute was designed to address these specific issues and obstacles as part of the workshop design. Nineteen K-12 educators from the Southeastern United States were chosen to attend the workshop. The first of the three days was dedicated to providing the educators with a thorough background on paleontology and paleoanthropology, both through a discussion of significant discoveries made in both fields and a conversation about the primary research in both fields, past and present. The participants then had the opportunity to ask questions of paleoanthropologists, paleontologists, and anthropologists in person and virtually over Skype. By the end of the first day, participants were provided with the information that would inform the teaching of evolution, specifically human evolution, in their classrooms.

Additionally, during the first and second days of the workshop, participants were introduced to 3D printing as a potential strategy for teaching a concept as morphologically-heavy as human evolution. The educators were provided with a better understanding of what free digital resources are available (Morphosource, AfricanFossils, the Human Evolution Teaching Materials Project, and more) and their potential applications. They received guidance on structuring lesson plans (aligned to state-specific science standards) around open-source data. They could experience firsthand the power of using 3D prints in the classroom.

During this time, the educators were given a tour of a maker space, provided with the use of 3D printers to make test prints and given access to over 45 full-size hominin crania. They participated in a demonstration lesson that utilized 3D-printed hominin mandibles. The participants used all this information to develop their lesson plans, which will be used by those educators in their classrooms in the coming school year but will also be made available to the public. By using open-source 3D files as part of their lesson plans, teachers not only incorporated materials that were very up-to-date (with the most recent of the 3D files being made available by the Max Planck Institute in the Spring of that year), but they were also able to present their students with the tangible evidence of human evolution. Sharing evidence allows students to conclude the theory of evolution is supported by observing the fossilized evidence of adaptation and natural selection instead of only being asked to believe evolutionary theory as presented in their textbook.

During days two and three of the workshop, the issues inherent to evolution education were addressed in various ways. Direct instruction addressing the public evolution-religion "controversy" in the public arena and a panel on the obstacles in the teaching of evolution allowed the workshop participants to ask many questions and derive real-world solutions to the problems that might arise when they go to implement their newly-developed lesson plans. The process focused both on theory and practical implementation. Educators were introduced to the concept of religion and science as two different ways of knowing (Gould 1997; Hermann 2012) that can both be a part of a student's worldview without existing in opposition to one another—viewing evolutionary theory and religion as two equally valid "ways of knowing" provided educators with a way to teach evolution that does not risk dismantling any student's way of seeing the world.

By directly addressing many previously-identified obstacles in teaching evolution, we hoped to directly impact the teacher's perceptions of the teaching of evolution and provide educators with the tools needed to successfully implement human evolution into their existing science curricula. With this workshop being the first of several evolution-focused teacher workshops in the United States, we conducted this study to better address educator needs and successfully provide the resources and support required to overcome many obstacles in teaching human evolution.

Methodology

This mixed-method study employed a combination of a quantitative pre-test and post-test as well as qualitative focus-group interviews of a selection of the workshop participants.

Sampling

The sample utilized in this study is a self-selected convenience sample. The HESTW Professional Development opportunity was marketed via Twitter, Facebook, and The University of Florida Thompson Earth Systems Institute website, and teachers interested in attending the event were asked to submit applications for consideration. From the total group of applicants (81), a cohort of 19 teachers was selected and all were able to attend. The teachers were chosen based on their application responses, with a goal of having a cohort that was as geographically diverse as possible, with diversity across demographics including gender, race/ethnicity, years of teaching experience, and school type. The teachers whose applications were selected for participation were extended an invitation and provided with informed consent documents and a request to participate in the study.

Participants

Participants were nineteen K-12 science educators from the Southeastern United States, representing Florida, Georgia, Alabama, Louisiana, and Mississippi. These teachers ranged in age from 25 to 57 with an average age of 38.5 years (median = 38, mode = 32), and were primarily white and female (17/19 white, 2/19 black/African American with no other race/ethnicity represented; 16/19 female, 3/19 male, with no other gender identified). Of the nineteen participants, nine taught solely in secondary education (9–12th grades), six taught solely in middle grades (4th–8th), and four taught across levels. One of the latter four also taught teacher educators in an accredited program. Eighteen of the teachers were public school teachers, with one teaching in a private Catholic school. Among the public schools was the representation of one magnet school, one rural Title 1 school, three developmental research schools, and one primarily minority school. The educators also reported a range of prior experiences with the implementation of human evolution into their curriculum, with some teachers having no previous experience and others previously implementing some elements of human evolution into their science curricula.

Instrumentation

Teachers' Perceptions of Teaching Evolution Scale (TPTES)

The survey instrument consisted of 18 questions adapted from the *Teachers' Perceptions of Teaching Evolution Scale* (TPTES) by Tekkaya et al. (2012) and one free-response question added to allow participants to share additional thoughts, concerns, or perceptions they felt inclined to share. In this measure, the first 18 questions were Likert scale questions with answers ranging including 'strongly disagree,' 'disagree,' 'agree,' and 'strongly

agree.' Those questions addressed three domains: teachers' perceptions of the necessity of addressing evolution in their classrooms (seven items), teachers' perceptions of the factors that impede addressing evolution in their classrooms (six items), and personal science teaching efficacy beliefs regarding evolution (five items). The Teachers' Perceptions of Teaching Evolution Scale was examined by domain and shown to have a Cronbach's alpha of 0.84, 0.63, and 0.68 aligned to the domains noted above (Tekkaya et al. 2012). The authors note that two of these values are in the low range, however, consideration of having fewer than ten questions likely impacts the measure, therefore, they performed a mean inter-item correlation which resulted in scores of 0.22 for "perceptions of the factors that impede addressing evolution" and 0.31 for "personal science teaching efficacy beliefs regarding evolution" (Tekkaya et al. 2012). Since the acceptable range of that analysis is between 0.2 and 0.4, the authors suggest the measure is reliable (Pallant 2011). This measure can be found in its entirety as deployed in this study in Appendix A.

Human evolution summer teacher workshop focus group interview protocol

The questions for the qualitative exploration were derived from discussions around the body of research on evolution education amongst the research team. The team consists of two education professors with more than three decades of experience in teacher education, evolution education, measurement design, technology, and curriculum, and two doctoral students in anthropology with extensive human evolution content knowledge plus several years of teaching experience at the university level. While open-ended interviews lack construct validity, it is posited that interviews are reliable and valid when they are credible, authentic, critical, and uphold integrity (Whittemore et al. 2001). Based on a critical dissection of potential questions, the selected questions were deemed relevant to the issue of teaching evolution; provided space for the participants to voice free-flowing, thoughtful responses; and questions aligned to critical areas of exploration in the literature. Both co-investigators utilized the questions in the focus group sessions following the workshop to provide structure and focus to critical issues from the existing body of knowledge and increase the credibility of the interview process. The protocol for the focus group interviews is provided in Appendix B.

Procedures

A week before the workshop, participants completed a pre-test of the *Teachers' Perceptions of Teaching Evolution Scale* adapted from Tekkaya et al. (2012). The results of this pre-test were used to place a selection of the participants into two focus groups (each consisting of six participants) to achieve the most diversity in previous knowledge of human evolution, previous experience implementing evolution, and diversity in age and sex. Upon the workshop's conclusion, the nineteen participants were asked to complete the same survey again as a post-test. The participants were then divided into two focus groups and interviewed by different co-investigators using the HESTW interview protocol. Each of the semi-structured interviews lasted approximately one hour.

Data analysis

For analysis of quantitative data, a series of repeated measures ANOVA tests were conducted to explore the changes in teachers' perceptions of teaching evolution between the pre-test and post-test of the *Teachers' Perceptions of Teaching Evolution Scale*. Data met independent, normality, and sphericity assumptions, indicating reliable analysis.

Qualitative coding techniques were then used to analyze HESTW participants' personal experiences with human evolution before and after participating in the workshop. Before coding, twelve HESTW participants were split into two groups of six educators based on this diverse experience with human evolution in the classroom and K-12 teaching grade level and school type (i.e., private, public, title one) and systematically interviewed. All interview responses were transcribed verbatim from audio recordings and made accessible to researchers with the names of HESTW interviewees replaced to establish anonymity and reduce potential biases. Data were analyzed in three rounds of coding as an iterative process to reveal strong themes amongst the responses. All transcribed data were stored and examined on the online qualitative data analysis and scientific research software ATLAS.ti Cloud.

To qualitatively analyze these results, two researchers coded both sets of response data independently to aggregate a datum of codes using both descriptive and in vivo processing (Saldaña 2009). An initial coding round created 782 code tags with 374 associated comments added to support the generation of distinguishable code and help reduce ambiguity. During a second coding round, the saturation of coded data was scrutinized, and emerging commonalities in both sets of coded data were identified. Detailed notes were recorded in the memo manager of ATLAS.ti Cloud by both researchers for comparison of updated codes, categories, and emergent themes. From that point, all researchers met to discuss their independently coded data and reveal thematic trends by reconciling, verifying, and distilling code until a consensus was reached.

Findings

Quantitative study

A repeated measures ANOVA with Measure 1 "teachers' perceptions of the necessity of addressing evolution in their classrooms" as the dependent variable revealed that teacher's perceptions regarding the necessity of addressing evolution in their classrooms significantly improved from pre to post-test ($F_{1,18}=9.94$, $p<006$, $\eta^2=0.36$). Specifically, teachers' perceptions regarding the necessity of addressing evolution in their classrooms improved from $M_{pre}=32.37$, $SD_{pre}=1.98$ to $M_{post}=33.84$, $SD_{post}=1.68$. A partial eta squared value indicates a large effect size.

A repeated measures ANOVA with Measure 2 "teachers' perceptions of the factors that impede addressing evolution in their classrooms" as the dependent variable demonstrated that teachers' perceptions regarding the factors that impede addressing evolution in their classrooms did not significantly change from pre to post-test, but the differences approached significance ($F_{1,18}=3.91$, $p=06$, $\eta^2=0.18$). Specifically, teachers' perceptions regarding the factors that impede addressing evolution in their classrooms changed from $M_{pre}=24.84$, $SD_{pre}=3.23$ to $M_{post}=26.26$, $SD_{post}=2.13$.

A repeated measures ANOVA with Measure 3 "personal science teaching efficacy beliefs regarding evolution" as the dependent variable revealed that teacher's perceptions regarding personal science teaching efficacy beliefs regarding evolution significantly improved from pre to post-test ($F_{1,18}=16.01$, $p<001$, $\eta^2=0.47$). Specifically, teachers' perceptions regarding personal science teaching efficacy beliefs regarding evolution improved from $M_{pre}=18.21$, $SD_{pre}=2.90$ to $M_{post}=20.68$, $SD_{post}=1.49$. A partial eta squared value indicates a large effect size.

Qualitative study

When analyzing the focus group interviews, the teacher responses could be broken down into three main categories: student-centered responses, teacher-centered responses, and content-centered responses. These are the three areas of primary concern when considering implementing human evolution education in the science classroom.

The teachers in our workshop had responses that focused primarily on what previous knowledge students would come to class with and a desire for students to leave their classes being scientifically literate. Student-centered responses included considerations about student interactions in the classroom, specific concerns about what background knowledge they would bring into conversations about evolution, and the best ways to engage with them with potentially polarizing topics. The teachers acknowledged that their students might come in with varying amounts of background knowledge on the topic of evolution (or more specifically, human evolution), both since it is a topic that is often brought into the realm of popular culture and also because there are not consistent standards addressing evolution in school across the United States. Regardless of what background information the students came in with, one unifying concept echoed by many teachers was a desire for their students to leave school as scientifically literate members of society. One teacher remarked:

> *Our ultimate goal is to have them be citizens that are educated enough to vote one way or another on certain items, and we want them to be able to have that literacy to walk in and make the conscious choice that is educated and not just what they see on TV [or] that is thrown at them by way of the media. We want them to have their thought process. Be literate enough to determine what that might be.*

Another concept that several teachers echoed was the desire to have the classroom be a 'safe space,' especially when discussing potentially charged topics such as evolution and human origins. This was deemed essential to having an open and honest dialogue and addressing topics that might polarize some communities. One teacher emphasized, "If they want to share, and they want to have a class discussion, then I would always facilitate it, but never shut it down, like, ever. If they are not going to have it in that safe space that I created in my classroom, where are they going to have it, you know?".

The next category of responses was teacher-centered responses. Teacher-centered responses included reflections about the demands associated with a career in education, the relationship between teachers and their administrators, obstacles in teaching human evolution, issues surrounding accessibility, and teacher autonomy in the classroom. The teachers in this professional development workshop acknowledged that evolution needs to be taught consistently in K-12 science classrooms. Although evolution is part of the NGSS standards (e.g., HS-LS4-1 through HS-LS4-5), only 20 states have adopted NGSS standards (NGSS 2013), and none of those states are in the Southeastern United States. Evolution may be included in the standards utilized by those other states. However, this does lead to major inconsistencies in how evolution is incorporated into the science curriculum.

Furthermore, teachers from the focus group also mentioned that administrator support was one major consideration in incorporating human evolution into the existing science curriculum. Teachers reflected that the degree to which they are given autonomy to create and structure their lesson plans, pursue professional development workshops in more niche topics such as human

evolution, and incorporate non-traditional learning materials like 3D prints into their lesson plans impacts their ability to teach topics that may not necessarily be covered in depth by their state standards. To many teachers, administrator support is a looming factor in incorporating human evolution lesson plans into existing science curricula.

Many teachers reflected as well on their comfort level in teaching evolution. It was a common trend in the focus group interviews to hear a teacher mention that they had previously felt uncomfortable addressing a subject area like evolution. One teacher remarked, "It is not a topic that we see at professional development workshops… I think that lack of knowledge prevents us from wanting… to get out of your comfort zone—not wanting to have your kids ask questions that you will not know the answer to, so—I usually went the other route."

Teachers who already taught evolution mentioned that they stuck to classic examples of adaptation and change over time, such as Darwin's finches and salt-and-pepper moths, and purposely avoided incorporating examples from human evolution to avoid the risk of making students or their parents uncomfortable. Additionally, many teachers reported feeling they needed more mastery of the topic of human evolution, and for that reason, they decided to rely on more common examples of evolutionary theory.

It is not just their discomfort with the material that the teachers identified as one of the significant limitations surrounding the implementation of teaching human evolution in K-12 classrooms. Other significant limitations mentioned in the focus-group interviews included limited materials, outdated resources, limited support from schools and administrators to support learning about human evolution, as well as the need for more professional development opportunities that included information on human evolution. One teacher remarked, "Materials are the problem. I did not have the materials."

Another major disconnect noted by the teachers was the lack of accessibility between teachers who teach science and scientists actively doing scientific research. Especially in a field like paleoanthropology, where every discovery changes our understanding of our human origin story, teachers want more direct access to the scientists to be able to adapt their curriculum in real-time as these changes are made. One teacher noted, "I liked being able to interact with people in the ivory tower, doing real science. The fact that we have been able to talk with you guys, see what you are doing, and consult with your expertise really grounds everything". Additionally, when so much of human origins is reliant on the analysis of fossil materials, teachers in this professional development workshop voiced their desire to have these fossil discoveries made accessible to them, either through open-source 3D files or publications that are not stuck behind a paywall.

The final category represented the content-centered responses. Content-centered responses included frustration at the common misconceptions about our human origin story and a discussion of the many benefits of including human evolution in the science curriculum. Many teachers acknowledged the misconceptions students commonly have surrounding evolution/human evolution. One teacher remarked, "I will always address the misconception that chimps turned into monkeys."

Many teachers noted that correcting these misconceptions is integral to K-12 science education. Additionally, many teachers remarked that after getting to experience some lesson plans that addressed human evolution, they found the curricula to be interactive, fun, personal, and inclusive. The fact that human evolution is our collective origin story made many teachers perceive lessons that included this material to be particularly inclusive and unifying in an increasingly divisive time. One teacher remarked, "When things are so polarized, this brings us together as one species." It was agreed, however, that there were many different ways in which this specific content could be presented and that this would allow teachers to approach the topic with variations in the style and manner in which it is addressed. These variations included using various media such as 3D prints, 3D pdfs, podcasts, videos, journal articles, interviews with scientists, and museum visits.

Summary

As demonstrated by both the qualitative and quantitative data, the Human Evolution Summer Teacher Workshop had a significant impact on the teachers in attendance. Of the three target factors included in the pre-test/post-test measure, two measures (Measures 1 and 3) show significant improvements by the end of the teacher workshop: teachers' perceptions of the necessity of addressing evolution in their classrooms (seven items) and personal science teaching efficacy beliefs regarding evolution (five items). The remaining measure [Measure 2- teachers' perceptions of the factors that impede addressing evolution in their classrooms (six items)] approached significance.

A significant improvement in Measure 1 indicates that teachers left the workshop feeling like human evolution was a more important topic to cover in their curriculum than was previously considered. They were more willing to incorporate materials on evolution in their curricula and attend evolution-centered professional development after the HESTW PD. They reported stronger beliefs that the inadequacy of students' backgrounds regarding

evolution needs to be addressed and that the incorporation of evolution into science/biology classes will increase students' interest in science. They also identified that teaching evolution was worth their time and effort.

There was also a significant improvement in Measure 3: teachers' perceptions of the factors that impede addressing evolution in their classrooms. This measure assessed educator confidence in teaching topics pertaining to evolution. By the end of the workshop, teachers felt more confident in their ability to teach evolution and more knowledgeable about various teaching strategies to deal with evolution in science/biology classes. They also felt as though they have the knowledge necessary to effectively teach about human evolution to their students. This came from feeling as though they sufficiently understand what evolution is and have confidence in developing teaching and learning materials about evolution by the end of the workshop. Interestingly, the variability in the responses decreased and means significantly improved from the pre-test to the post-test.

Although Measure 2 only approached significance, it still yielded some interesting results. This measure assessed teachers' perceptions of the factors that impede addressing evolution in their classrooms. It asked teachers to consider whether or not students are mature enough to be interested in and understand evolution and whether or not classes dealing with evolution are most likely to be aimed at high-achieving students only. It also asked them to gauge perceived student interest and consider if it could confuse them about their own values. Although teachers' views on these matters did not change significantly from the pretest to the post-test, one interesting pattern did emerge. For this measure, the standard deviations are very high for the pre-test and much lower for the post-test. This indicated that there was much more variability in teachers' responses on the pre-test than on the post-test. Although the teacher responses did not change significantly from the pre-test to the post-test, their responses were more consistent within the entire group after the conclusion of the workshop.

The focus group interviews allowed us to hear more in-depth feedback from the teachers regarding their experience at the workshop. When discussing evolution education, teachers expressed their concerns and opinions in three main categories: student-centered responses, teacher-centered responses, and content-centered responses. In order for a teacher to feel confident incorporating evolution into their curriculum, they need to feel comfortable with their own background knowledge and abilities in teaching the subject material, be able to meet the needs of their students (not just from an educational standpoint but also in terms of their wellbeing, spiritual life, home life, etc.), and have sufficient support in creating their lesson materials. It is clear through their responses that evolution education that does not address all three of these needs will fall short. Providing educators with an evolution curriculum without offering them support (as well as a way to support their students) is ineffective.

One unexpected observation made by many participating educators is their belief that the teaching of human evolution specifically has the capacity to bring students together in an increasingly divided world. The idea that our human origin story is inherently more personal than other anecdotes more traditionally used to teach evolution makes it an attractive element to add to the existing science curriculum. When combined with the storytelling nature of many of the paleoanthropological discovery stories and the occasional opportunity to connect directly with the scientists and researchers responsible for these fantastic finds, the teachers agreed that human evolution can be an extremely exciting and engaging subject area for students of all ages.

Discussion

The findings of this study suggest that there is much that can be done to impact teacher confidence, efficacy, and approaches to teaching evolution. In regards to changing perceptions from before and after participating in the HESTW program, we found that similar to Rutledge and Mitchell (2002) that engaging more with the concepts does positively impact teacher perceptions of the importance of teaching evolution, suggesting more willingness to include this material in classrooms. Efficacy was also a factor that was impacted by the experience, demonstrating that professional learning positively impacts teachers' perceptions of their ability to accurately and confidently teach evolution (Alters and Nelson 2002; Asghar et al. 2007).

While improvements occured in teacher thinking regarding their efficacy and the need for evolution to be taught, the factors teachers perceived as impeding their teaching remained relatively consistent and closely mirrored those identified in other evolution education studies. In this study, common themes emerged from the teachers surrounding their expectations of the varying backgrounds, knowledge, and beliefs their students would bring to the classroom (Bertka et al. 2019). Despite concerns about the variability of knowledge and expectations of their students, teacher perceptions in this study aligned closely with those by both Bertka et al. (2019) and Barnes et al. (2017) in that they also perceived open dialogue and acknowledging those variations are key to teaching evolution in general, and especially human evolution (Hermann 2008; Miller-Lane et al. 2006). Teachers in this study expressed feeling external pressures

surrounding their teaching of evolution much like those found in other studies. Those perceptions included the importance of being given autonomy by their administrators to make choices about their classrooms (Rutledge and Mitchell 2002) and reflection on how negative pressures from administration (Glaze and Goldston 2015; Glaze et al. 2015; Pobiner 2016) and lack of support for teaching evolution in the state standards, as none of the states in the Southeastern United States adopted the NGSS standards (2013).

Content knowledge is certainly of importance despite not always having a direct impact on acceptance of evolution (Glaze and Goldston 2019) and plays a critical role in building confidence for teachers to approach evolution in their classrooms (Glaze and Goldston 2015; Glaze et al. 2015; Griffith and Brem 2004). At the same time, research shows that content knowledge alone is not enough (Bertka et al. 2019) and teachers are in dire need of a range of supports to enable them to teach human evolution in the classroom (Barnes et al. 2017; Glaze and Goldston 2015; Glaze et al. 2015). Teachers in this study focused on critical areas of need that have been expressed in other seminal studies on evolution teaching and learning including frustration with the breadth of misconceptions about evolution and human evolution (McComas 1997; Gregory 2009) and a desire to have more than just traditional examples to address concepts in the classroom (Glaze and Goldston 2015; Glaze et al. 2015, 2019). Along that line, while there are tons of resources that are available, teachers felt they had minimal support to actually implement what they do have or were left to supplement outdated resources provided in their school settings, confirming Chiappetta and Koballa's (2002) concern that textbooks, although seen as an authority in the classroom setting, are not as robust and up-to-date as they need to be to adequately teach topics such as evolution.

Teachers in the HESTW program left with the view that teaching evolution through human evolution lenses is a more inclusive and personal view for students (Berkman and Plutzer 2012) and that addressing misconceptions about human evolution is critically important (Schilders et al. 2009; Martin-Hansen 2010). Furthermore, they felt connected to the scientists that engaged in the program in such a way that they specifically noted the need for deeper connection between what is happening in science and the teaching of that science in the classroom. The connection between field science and classroom learning ties directly to the nature of science (NOS) which also circles back to addressing misconceptions and engaging students in scientific thinking and process skills (Glaze and Goldston 2015; Glaze et al. 2015; Bartos and Lederman 2014; Bayer and Luberda 2016; NGSS 2013). Finally, teachers are strongly aware of the importance of professional development in their growth and efficacy as educators (Loucks-Horsley 2003) and benefit strongly from modeling, whether that be processes of science, acknowledging controversy, or engaging with new information (Bertka et al. 2019; Ha et al. 2015; Schrein et al. 2009; Pobiner 2016).

Conclusion

The teaching and learning of evolution continues to be a strong focus of science education research due to the robust nature of evolution as the unifying theory in biology and the perceptions of controversy that persist in the public. Professional learning targeted to meet teachers where they are while also building confidence, content knowledge, and pedagogy for their unique teaching contexts is one approach impacting whether and how evolution is taught in K-12 classrooms. Integrating elements of human evolutionary studies engages students in their placement in the tree of life. Additionally, human evolution is a topic about which many have questions that often need to be addressed due to the absence of human focus from most evolution-based teaching standards and cultural considerations that enter from outside the classroom. The Human Evolution Teaching Materials Project and subsequent Human Evolution Summer Teacher Workshop combined various approaches to address content understanding, the nature of science, ways of knowing, and hands-on learning to support and empower teachers to teach evolution in their classrooms with accuracy and confidence.

Researchers must continue exploring ways to approach teacher preparation relative to evolution for various reasons. First, teachers have the autonomy and authority in their classrooms to select what and how to teach within reason. Those teachers who are comfortable with their ability to mitigate conflict their students might perceive are more likely to teach evolution. Second, teacher content training is critical to ensure that when evolution is taught, the information is accurate. Many programs do not specifically have courses on evolution even though it is so ingrained in life sciences; targeting this content area ensures that those connections are made throughout life science education at the K-12 levels. Third, evolution is a topic that defies traditional relationships between knowing and accepting, as research exploring correlations between knowledge and acceptance demonstrates that a person can have high knowledge with low acceptance or low knowledge with high acceptance, as well as all the interactions between. As such, teachers must be trained in the specific pedagogical approaches that not only represent the nature and practice of science, but that support them–and, by extension, their students–in navigating social, cultural, and other elements that give rise

to confusion and conflict. Finally, integrating human evolution brings the conversation to a more personal level for students in looking at how we fit as a species in the larger picture of biodiversity. By studying human evolution specifically, students can learn that humans are not the exception to the rules of evolution, but instead are governed by them in the same way: the way that applies to all animals.

Limitations

There were several limitations of this study, including the small number of teachers involved in the professional development and the inability to represent the teacher population regarding gender, diversity, and background. Additionally, the teachers involved in this professional development workshop each applied to attend. Hence, it was inherently a group of teachers that self-selected to be involved and thus would not be representative of the range of perspectives and levels of acceptance found across classroom teachers around the nation. Had this professional development involved a larger and more representative group of teachers (especially those who did not have a pre-existing desire to incorporate human evolution into their existing science curriculum), the results of the pre/post-survey and focus group interviews may have vastly been different.

Implications for science teacher education & professional learning

Science teacher education has a broad range of topics to address to ensure that pre-service teachers have effective content and pedagogical skills, making it difficult to adequately address subject-specific strategies during pre-certification training. The broad range of topics covered by science teachers also lends itself well to the incorporation of human origins in the curriculum, since the study of human evolution is inherently multidisciplinary. However, our study demonstrates that professional development provides the ability to target teachers who specifically address evolution in their classrooms while creating a community for shared learning. The focus of professional development on specific content areas where teachers need support and the ability to discuss shared experiences and concerns mean a greater opportunity to positively impact teaching practice and student outcomes.

Suggestions for further study

History demonstrates that there are no one-size-fits-all approaches to the successful teaching of evolution due to the nature of the topic and the wide range of divisive angles that arise when the topic is mentioned. We know that more than just sharing evidence is needed to enact conceptual change and understand where that perception of conflict is present. We also recognize that at times, controversy can be inherent to the scientific process, such as among various naturalistic causal models of gene-culture coevolution. Therefore, ongoing research is needed to develop and assess the impact of approaches that target the needs of teachers as they learn to navigate a diverse array of student belief systems and cultural practices, as well as the historical conflicts that surround evolution in different parts of the United States and around the world. To do so, we must continue to strive to understand the nature of the issue in different places and among different groups of people. We must also do so with unified measures that allow more substantial generalizations and comparisons among and across these groups than what we have been able to do in the past. As we establish those baseline understandings, a wide range of approaches that integrate the needs of these groups must be developed and studied.

The field of evolution education research now hosts an array of data supporting the use of approaches such as culturally responsive strategies, targeting the nature of science, and modeling the ways of knowing to encourage us to keep exploring. We must build on those foundations to determine whether such approaches support teachers across place-based and other boundaries and whether those changes, once implemented in the classroom, positively impact student outcomes. The authors hope to see the application of this and similar projects to a more diverse representation of teachers, including those outside of the region, those teaching a variety of levels of students (both grade and rigor), those teaching across the many disciplines and subject areas that inform modern human evolutionary sciences, and those who do not immediately have interest in teaching evolution, much less human evolution. Each of these areas represents gaps where there is still much to learn to positively change the teaching and learning of evolution and public perceptions of evolution and science.

Appendix A

Human evolution summer teacher workshop focus group interview protocol

1. Why is evolution important to address in the K-12 science curriculum?
2. What is the role of human evolution in the K-12 science curriculum? Do you address human evolution in your own teaching?

3. What are some challenges associated with teaching evolution in K-12?
4. What was the most relevant or interesting aspect of this workshop to you?
5. To what extent do you discuss your students' personal views on evolution with your students?
6. Does your school require parental consent to discuss evolution in the science classroom? Are there any formal or informal mechanisms for this?
7. What do you think students will gain, if anything, from the inclusion of human evolution into K-12 science curriculum?
8. What, if any, supports does your school/district provide to support the implementation of evolution (or more specifically human evolution) in your science curriculum?

Appendix B

Participant data and analysis

De-identified participant data from the HESTW project can be explored at this link https://docs.google.com/spreadsheets/d/1CTqRS_urwE_ReMXJEtV3gQn94GlbI5GR/edit?usp=sharing&ouid=105952734616987473749&rtpof=true&sd=true.

Acknowledgements
Thank you to the teachers who attended this workshop for all of their hard work and their continued commitment to the implementation of human evolution education in their science curricula.

Author contributions
M. Selba and M. Ziegler planned and orchestrated the teacher professional development workshop and conducted the focus group interviews. P. Antonenko developed the research design including the pre/post surveys and analysis of the statistics. A. Townley grounded the research in the literature and helped to contextualize the results of the study within current pedagogical research.

Funding
Funding for this teacher professional development workshop was provided by The University of Florida Thompson Earth Systems Institute.

Availability of data and materials
Survey data from this study is not publicly available, however, the lesson materials that were developed by teachers during this professional development workshop are open-source and are hosted on the website for the Human Evolution Teaching Materials Project (www.hetmp.com).

Declarations

Competing interests
Not applicable.

Received: 13 August 2023 Accepted: 11 March 2024
Published online: 27 May 2024

References

Akyol G, Tekkaya C, Sungur S, Traynor A. Modeling the interrelationships among pre-service science teachers' understanding and acceptance of evolution, their views on nature of science and self-efficacy beliefs regarding teaching evolution. J Sci Teacher Educ. 2012;23(8):937–57. https://doi.org/10.1007/s10972-012-9296-x.

Alters BJ, Nelson CE. Perspective: teaching evolution in higher education. Evolution. 2002;56(10):1891–901. https://doi.org/10.1111/j.0014-3820.2002.tb00115.x.

Asghar A, Wiles JR, Alters B. Discovering international perspectives on biological evolution across religions and cultures: Insights gained through developing methodological tools for research in diverse contexts. Int J Divers Organ Communities Nations. 2007;6(4):81–8. https://doi.org/10.18848/1447-9532/cgp/v06i04/39200.

Bandura A. Perceived self-efficacy in cognitive development and functioning. Educ Psychol. 1993;28(2):117–48. https://doi.org/10.1207/s15326985ep2802_3.

Bandura A. Self efficacy: the exercise of control. New York: W H Freeman & Co Student Success; 1997. p. 333.

Barnes ME, Brownell SE. Practices and perspectives of college instructors on addressing religious beliefs when teaching evolution. CBE Life Sci Educ. 2016;15(2):ar18. https://doi.org/10.1187/cbe.15-11-0243.

Barnes ME, Brownell SE. A call to use cultural competence when teaching evolution to religious college students: introducing Religious Cultural Competence in Evolution Education (ReCCEE). CBE Life Sci Educ. 2017;16(4):es4. https://doi.org/10.1187/cbe.17-04-0062.

Bartos SA, Lederman NG. Teachers' knowledge structures for nature of science and scientific inquiry: conceptions and classroom practice: knowledge structures for NOS and SI. J Res Sci Teach. 2014;51(9):1150–84. https://doi.org/10.1002/tea.21168.

Bayer CN, Luberda M. Measure, then show: Grasping human evolution through an inquiry-based, data-driven hominin skulls lab. PLoS ONE. 2016;11(8): e0160054. https://doi.org/10.1371/journal.pone.0160054.

Berkman M, Plutzer E. An evolving controversy: the struggle to teach science in science classes. Am Educ. 2012;36(2):12.

Berkman MB, Plutzer E. Enablers of doubt: how future teachers learn to negotiate the evolution wars in their classrooms. Ann Am Acad Pol Soc Sci. 2015;658(1):253–70. https://doi.org/10.1177/0002716214557783.

Bertka CM, Pobiner B, Beardsley P, Watson WA. Acknowledging students' concerns about evolution: a proactive teaching strategy. Evolution. 2019. https://doi.org/10.1186/s12052-019-0095-0.

Brem SK, Ranney M, Schindel J. Perceived consequences of evolution: college students perceive negative personal and social impact in evolutionary theory. Sci Educ. 2003;87(2):181–206. https://doi.org/10.1002/sce.10105.

Catley KM. Darwin's missing link—a novel paradigm for evolution education. Sci Educ. 2006;90(5):767–83. https://doi.org/10.1002/sce.20152.

Chiappetta EL, Koballa TR. Science instruction in the middle and secondary schools. Merrill/Prentice Hall; 2002.

Crawford BA, Zembal-Saul C, Munford D, Friedrichsen P. Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. J Res Sci Teach. 2005;42(6):613–37. https://doi.org/10.1002/tea.20070.

Dagher ZR, Boujaoude S. Students' perceptions of the nature of evolutionary theory. Sci Educ. 2005;89(3):378–91. https://doi.org/10.1002/sce.20054.

Dotger S, Dotger BH, Tillotson J. Examining how preservice science teachers navigate simulated parent-teacher conversations on evolution and intelligent design: evolution and Parent conferencing. Sci Educ. 2010;94(3):552–70. https://doi.org/10.1002/sce.20375.

Drake RL, Pawlina W. Multimodal education in anatomy: the perfect opportunity. Anat Sci Educ. 2014;7(1):1–2. https://doi.org/10.1002/ase.1426.

Firenze R. Have the creationists already won? Or the teaching of faux-biology. Rep Natl Cent Sci Educ. 1997;17(2):10–4.

Fowler SR, Meisels GG. Florida teachers' attitudes about teaching evolution. Am Biol Teach. 2010;72(2):96–9. https://doi.org/10.1525/abt.2010.72.2.8.

Geher G, Sokol-Chang R, Waldo J, Wilson DS, Mativetsky H. Evolutionary Studies in higher education: interdisciplinarity and student success embodied. In: Geher G, Sokol-Chang R, Waldo J, Wilson DS, Mativetsky H, editors. Darwin's roadmap to the curriculum. Oxford: Oxford University Press; 2019. p. 13–28.

Gibbs C. Explaining effective teaching: self-efficacy and thought control of action. J Educ Enq. 2003;4(2). https://ojs.unisa.edu.au/index.php/EDEQ/article/view/520. Accessed 26 July 2023.
Glaze AL. Bridging the gaps between science and public opinion: Pre-Service science teachers as catalysts for change. In: Lynn C, Glaze A, Reed L, Evans W, editors. Evolution education in the American South: culture, politics, and resources in and around Alabama. Palgrave McMillian Publishers; 2017. p. 103–19.
Glaze AL, Goldston MJ. Evolution and science teaching and learning in the United States: a critical review of literature 2000–2013. Science Education. 2015;99(3):500–18. https://doi.org/10.1002/sce.21158.
Glaze AL, Goldston MJ. Acceptance, understanding, and experience: Exploring obstacles to evolution education among Advanced Placement teachers. Am Biol Teach. 2019;81(2):71–6. https://doi.org/10.1525/abt.2019.81.2.71.
Glaze AL, Goldston MJ, Dantzler J. Evolution in the Southeastern United States: factors influencing acceptance and rejection in pre-service science teachers. Int J Sci Math Educ. 2015;13(6):1189–209. https://doi.org/10.1007/s10763-014-9541-1.
Goldston MJD, Kyzer P. Teaching evolution: narratives with a view from three southern biology teachers in the USA. J Res Sci Teach. 2009;46(7):762–90. https://doi.org/10.1002/tea.20289.
Gould SJ. Nonoverlapping magisteria. Nat Hist. 1997;106:16–22.
Gregory TR, Ellis CAJ. Conceptions of evolution among science graduate students. Bioscience. 2009;59(9):792–9. https://doi.org/10.1525/bio.2009.59.9.11.
Griffith JA, Brem SK. Teaching evolutionary biology: pressures, stress, and coping. J Res Sci Teach. 2004;41(8):791–809. https://doi.org/10.1002/tea.20027.
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.
Ha M, Baldwin BC, Nehm RH. The long-term impacts of short-term professional development: science teachers and evolution. Evolution. 2015. https://doi.org/10.1186/s12052-015-0040-9.
Hanisch S, Eirdosh D. Educational potential of teaching evolution as an interdisciplinary science. Evol: Educ Outreach. 2020;13(1):1–26.
Hawley PH, Sinatra GM. Declawing the dinosaurs in the science classroom: reducing Christian teachers' anxiety and increasing their efficacy for teaching evolution. J Res Sci Teach. 2019;56(4):375–401. https://doi.org/10.1002/tea.21479.
Hermann RS. Evolution as a controversial issue: a review of instructional approaches. Sci & Educ. 2008;17(8–9):1011–32. https://doi.org/10.1007/s11191-007-9074-x.
Hermann RS. Breaking the cycle of continued evolution education controversy: on the need to strengthen elementary level teaching of evolution. Evolution. 2011;4(2):267–74. https://doi.org/10.1007/s12052-011-0325-6.
Hermann RS. Cognitive apartheid: on the manner in which high school students understand evolution without believing in evolution. Evolution. 2012;5(4):619–28. https://doi.org/10.1007/s12052-012-0446-6.
Hermann RS, Shane JW, Meadows L, Binns IC. Understanding of evolution law among K-12 public school teachers. Am Biol Teach. 2020;82(2):86–92. https://doi.org/10.1525/abt.2020.82.2.86.
Kim SY, Nehm RH. A cross-cultural comparison of Korean and American science teachers' views of evolution and the nature of science. Int J Sci Educ. 2011;33(2):197–227. https://doi.org/10.1080/09500690903563819.
Kruger DJ, Fisher ML, Platek S, Salmon C. Survey of evolutionary scholars and students: perceptions of progress and challenges. Evostudies.org. https://evostudies.org/wp-content/uploads/2010/10/KrugerVol4Iss2.pdf. Accessed 26 July 2023.
Lerner LS. Good science, bad science: teaching evolution in the states. 2000. http://files.eric.ed.gov/fulltext/ED447099.pdf. Accessed 26 July 2023.
Long DE. The politics of teaching evolution, science education standards, and Being a creationist. J Res Sci Teach. 2012;49(1):122–39. https://doi.org/10.1002/tea.20445.
Loucks-Horsley S. Curriculm development and adaptation. In: Loucks-Horsley S, editor. Designing professional development for teachers of science and mathematics. 2003; p. 79–85. https://files.eric.ed.gov/fulltext/ED430810.pdf.
Martin-Hansen L. Reexamining inquiry pedagogy in the science classroom. Electron J Res Sci Math Educ. 2010;14(2). https://ejrsme.icrsme.com/article/view/7966/5692.
Matthews D. Effect of a curriculum containing creation stories on attitudes about evolution. Am Biol Teach. 2001;63(6):404–9. https://doi.org/10.2307/4451146.
McComas WF. The discovery & nature of evolution by natural selection: misconceptions & lessons from the history of science. Am Biol Teach. 1997;59(8):492–500. https://doi.org/10.2307/4450364.
Meadows L. The missing link: an inquiry approach for teaching all students about evolution. Portsmouth: Heinemann Educational Books; 2009.
Meadows L, Doster E, Jackson DF. Managing the conflict between evolution & religion. Am Biol Teach. 2000;62(2):102–7. https://doi.org/10.1662/0002-7685(2000)062[0102:mtcber]2.0.co;2.
Meir E, Perry J, Herron JC, Kingsolver J. College students' misconceptions about evolutionary trees. Am Biol Teach. 2007;69(7):e71-6.
Miller JD, Scott EC, Okamoto S. Public acceptance of evolution. Science. 2006;313(5788):765–6. https://doi.org/10.1126/science.1126746.
Miller-Lane J, Denton E, May A. Social studies teachers' views on committed impartiality and discussion. Soc Stud Res Pract. 2006;1(1):30–44. https://doi.org/10.1108/ssrp-01-2006-b0003.
Mundry S, Loucks-Horsley S. Eric.ed.gov. https://files.eric.ed.gov/fulltext/ED430810.pdf. Accessed 26 July 2023
Nadelson LS, Sinatra GM. Shifting acceptance of evolution: promising evidence of the influence of the understanding evolution website. Nrmera.org. https://www.nrmera.org/wp-content/uploads/2016/02/Researcher v23.1Nodelson.pdf. Accessed 26 July 2023.
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, Schonfeld IS. Does increasing biology teacher knowledge of evolution and the nature of science lead to greater preference for the teaching of evolution in schools? J Sci Teacher Educ. 2007;18(5):699–723. https://doi.org/10.1007/s10972-007-9062-7.
Nelson CE. Teaching evolution (and all of biology) more effectively: strategies for engagement, critical reasoning, and confronting misconceptions. Integr Comp Biol. 2008;48(2):213–25. https://doi.org/10.1093/icb/icn027.
NGSS. Next generation science standards: for states, by states. Washington: National Academies Press; 2013.
Oliveira AW, Cook K, Buck GA. Framing evolution discussion intellectually. J Res Sci Teach. 2011;48(3):257–80. https://doi.org/10.1002/tea.20396.
Pallant J. SPSS survival manual: a step by step guide to data analysis using IBM SPSS. Milton Park: Routledge; 2020.
Peker D, Comert GG, Kence A. Three decades of anti-evolution campaign and its results: Turkish undergraduates' acceptance and understanding of the biological evolution theory. Sci Educ. 2010;19(6–8):739–55.
Pobiner B, Beardsley PM, Bertka CM, Watson WA. Using human case studies to teach evolution in high school A.P. biology classrooms. Evolution. 2018. https://doi.org/10.1186/s12052-018-0077-7.
Pobiner B. Accepting, understanding, teaching, and learning (human) evolution: obstacles and opportunities. Am J Phys Anthropol. 2016;159:232–74. https://doi.org/10.1002/ajpa.22910.
Rankey EC. The use of critical thinking skills for teaching evolution in an introductory historical geology course. J Geosci Educ. 2003;51(3):304–8. https://doi.org/10.5408/1089-9995-51.3.304.
Reiss MJ. The relationship between evolutionary biology and religion. Evolution. 2009;63(7):1934–41. https://doi.org/10.1111/j.1558-5646.2009.00714.x.
Robbins JR, Roy P. The natural selection: identifying & correcting non-science student preconceptions through an inquiry-based, critical approach to evolution. Am Biol Teach. 2007;69(8):460–6. https://doi.org/10.1662/0002-7685(2007)69[460:tnsicn]2.0.co;2.
Rohrbacher C. Evolving: using science fiction to engage students in evolutionary theory. EvoS J: J Evol Stud Consort. 2013. https://doi.org/10.59077/GFFT1771.
Rutledge ML, Mitchell MA. High school biology teachers' knowledge structure, acceptance & teaching of evolution. Am Biol Teach. 2002;64(1):21–8. https://doi.org/10.1662/0002-7685(2002)064[0021:hsbtks]2.0.co;2.
Rutledge ML, Sadler KC. University students' acceptance of biological theories—is evolution really different? J Coll Sci Teach. 2011;41(2):38–43.
Rutledge ML, Warden MA. Evolutionary theory, the nature of science & high school biology teachers: critical relationships. Am Biol Teach. 2000;62(1):23–31. https://doi.org/10.1662/0002-7685(2000)062[0023:ettnos]2.0.co;2.

Saldaña J. The coding manual for qualitative researchers. Sage Publications Ltd.; 2009.
Sanders M, Ngxola N. Addressing teachers' concerns about teaching evolution. J Biol Educ. 2009;43(3):121–8. https://doi.org/10.1080/00219266.2009.9656166.
Scharmann LC. A proactive strategy for teaching evolution. Am Biol Teach. 2005;67(1):12–6. https://doi.org/10.2307/4451775.
Schilders M, Sloep P, Peled E, Boersma K. Worldviews and evolution in the biology classroom. J Biol Educ. 2009;43(3):115–20. https://doi.org/10.1080/00219266.2009.9656165.
Selba MC. The human evolution teaching materials project: a case for the incorporation of 3D prints into K-12 science curricula. EvoS J: J Evol Stud Consort. 2019;10(1):43–81.
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.
Smith MU. Current status of research in teaching and learning evolution: II. Pedagogical issues. Sci Educ. 2010;19(6–8):539–71.
Smith MU. Current status of research in teaching and learning evolution: I philosophical/epistemological issues. Sci Educ. 2010;19(6–8):523–38.
Smith MU, Siegel H. On the relationship between belief and acceptance of evolution as goals of evolution education: twelve years later. Sci Educ. 2016;25(5–6):473–96.
Southerland SA, Nadelson L, Sowell S, Saka Y, Kahveci M, Granger EM. Measuring one aspect of teachers' affective states: development of the science teachers' pedagogical discontentment scale. Sch Sci Math. 2012;112(8):483–94. https://doi.org/10.1111/j.1949-8594.2012.00168.x.
Tekkaya C, Akyol G, Sungur S. Relationships among teachers' knowledge and beliefs regarding the teaching of evolution: a case for turkey. Evolution. 2012;5(3):477–93. https://doi.org/10.1007/s12052-012-0433-y.
Evolution, creationism, intelligent design. Washington, D.C. : The Gallup Organization; 2019. https://news.gallup.com/poll/21814/evolution-creationism-intelligent-design.aspx.
Walter EM, Halverson KM, Boyce CJ. Investigating the relationship between college students' acceptance of evolution and tree thinking understanding. Evolution. 2013. https://doi.org/10.1186/1936-6434-6-26.
Whittemore R, Chase SK, Mandle CL. Validity in qualitative research. Qual Health Res. 2001;11(4):522–37. https://doi.org/10.1177/104973201129119299.
Wiles JR. Gifted students' perceptions of their acceptance of evolution, changes in acceptance, and factors involved therein. Evolution. 2014. https://doi.org/10.1186/s12052-014-0004-5.
Yasri P, Mancy R. Student positions on the relationship between evolution and creation: what kinds of changes occur and for what reasons? J Res Sci Teach. 2016;53(3):384–99. https://doi.org/10.1002/tea.21302.
Ziadie MA, Andrews TC. Moving evolution education forward: a systematic analysis of literature to identify gaps in collective knowledge for teaching. CBE Life Sci Educ. 2018;17(1):ar11. https://doi.org/10.1187/cbe.17-08-0190.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Molly C. Selba was a PhD student at the University of Florida when she planned and executed this teacher professional development workshop. She is now an assistant professor at the University of Maryland Eastern Shore.

Michael J. Ziegler was an MS student at the University of Florida when he helped with the planning and execution of this workshop. He is now a PhD student at the Max Planck Institute.