Evolution education is a complex landscape

Researchers in various contexts have long struggled with an apparent disconnect between an individual's level of understanding of biological evolution and their acceptance of it as an explanation for the history and diversity of life. Here, we discuss the main factors associated with acceptance of evolution and chart a path forward for evolution education research.

Ryan D. P. Dunk, M. Elizabeth Barnes, Michael J. Reiss, Brian Alters, Anila Asghar, B. Elijah Carter, Sehoya Cotner, Amanda L. Glaze, Patricia H. Hawley, Jamie L. Jensen, Louise S. Mead, Louis S. Nadelson, Craig E. Nelson, Briana Pobiner, Eugenie C. Scott, Andrew Shtulman, Gale M. Sinatra, Sherry A. Southerland, Emily M. Walter, Sara E. Brownell and Jason R. Wiles

Some recent work on evolution has left us perplexed, prompting us to reflect on what is known about the current research on evolution acceptance and where further work is needed. Unlike most other subjects, an individual's level of acceptance of evolution does not always depend on their level of understanding[1]. A person who understands little about the evidence for evolution might accept it as a matter of scientific consensus, while another person might reject evolution on religious or other non-scientific grounds despite having a good understanding of the concept.

As a result, ever since evolution became a dominant paradigm in biology, evolution educators have faced a distinctive challenge: how to cope with religious and other non-scientific factors that can impede student acceptance of evolution. For at least the past three decades, there has been an expanding interdisciplinary body of research regarding the acceptance of evolution among the public and among students in particular. We (the authors) have all studied reasons for— and solutions to—the lack of acceptance of evolution among various groups[2]. Here, we use our collective knowledge and experience to summarize what is known about acceptance of evolution, describe a path for further exploration, and offer recommendations for how evolution acceptance research can inform curricular choices and instructional practices in life-science education.

Although the disconnect between understanding and acceptance of evolution is not limited to the United States, the majority of research into this phenomenon has been done there for good reason— compared with 32 European countries and Japan, only Turkey has lower public acceptance of evolution than the United States[3]. Researchers have examined numerous factors associated with acceptance of evolution[4,5] and found two main factors, beyond understanding of evolution, that have a major association with evolution acceptance: understanding the nature of science (the means, aims, processes, and practice of science)[6,7] and religiosity (the salience of one's religious identity)[6–9].

Understanding of evolution is an important factor for acceptance. Earlier research in the field searched for a relationship between evolution acceptance and understanding but found contradictory results[1,10–13]. However, more recent studies employing multifactorial models have shown an independent significant association between evolution knowledge and acceptance when controlling for other variables[6–8,14], although the strength of this association varies between studies. Other recent work[15] suggests that in certain groups of UK secondary school students with relatively low levels of rejection of evolution, measures of knowledge alone may be sufficient to explain variation in evolution acceptance, although the authors did not directly measure or test for factors shown to be key in most other recent studies.

While an instructional approach focused almost exclusively on evolution knowledge may increase acceptance of evolution for students without religious barriers[15], such an approach may isolate and discourage students who have particular religious beliefs by reinforcing the stereotype that it is impossible to identify as both religious and a scientist[16]. Although no single strategy is likely to be sufficient to reach all learners, one technique that holds promise, particularly for religious students, is that of making evolution education 'culturally competent'[17] by taking into account the unique backgrounds and experiences of learners and working toward curricula that are compatibilist, not combative, in nature. This derives from a constructivist view of education, which holds that learners possess a wealth of attitudes and experiences that

influence their reception and interpretation of the information presented. In the context of evolution education, it is clear (and confirmed by research) that certain religious and sociocultural experiences tend to make students less receptive to the presentation of evolution. Culturally competent pedagogy uses appropriate strategies to reduce conflicts and obstacles induced by such experiences[18–20]. This approach should lead to an increase in both understanding and acceptance of evolution—indeed, in one study, identification with evolution acceptors was found to be the only factor significantly related to change in evolution acceptance[21].

Along with teaching in a culturally competent manner, the demonstrated connection between understanding the nature of science and acceptance of evolution[5–7,22,23] suggests that including clear and explicit instruction about the nature of science may have direct benefits in increasing evolution acceptance[24,25]. Student understanding of the nature of science is a good pedagogical target for a number of reasons. Beyond increasing evolution acceptance, learning and understanding more about the scientific enterprise could help students become better-informed citizens and more aware of the processes common to all scientific disciplines. In addition, the nature of science is already a common part of most life sciences curricula, and, hence, education interventions can be designed to align with teachers' existing pedagogical content knowledge.

To continue to progress in our understanding of evolution acceptance and associated factors, one area that needs to be addressed is consistency in measurement. Currently, there is no universally used tool for measuring evolution acceptance. The three most common measures, however, are all multi-item Likert scale tools— demonstrably better[26,27] than single-item measures of the type commonly used in

national surveys. Of the three measures of evolution acceptance, the Measure of Acceptance of the Theory of Evolution (MATE)[10,28] is the oldest and most widely used. The Inventory of Student Evolution Acceptance (I-SEA)[29] and Generalized Acceptance of Evolution Evaluation (GAENE)[30] tools were more recently developed to address concerns with the MATE and have gained some traction in the evolution education literature as robust measures. A recent study that employed more than one instrument found that the correlation between two measures may be quite strong[31]. However, on-going work in the measurement of evolution acceptance and associated factors is still of critical importance.

To avoid making overreaching recommendations across dissimilar contexts, researchers also need to explore in more detail the generalizability of results. Many existing studies have been performed in traditional university settings, which tend toward underrepresentation of certain groups of people, most notably racial and ethnic minorities. Do these same patterns hold in underrepresented minority groups, which already face barriers in science, technology, engineering and mathematics (STEM) education[32,33]? Does the general public have the same reasons for rejecting evolution as the students in the majority of studies (early evidence shows that they may[14])? Additionally, it is important to investigate whether the influence of various factors associated with evolution acceptance, such as understanding of the nature of science and religiosity, might change over time. Do these associations remain static in individuals, or does the relative impact of certain factors on an individual's acceptance of evolution change throughout their life and experiences[21,22]? And within and across populations, have these patterns been stable, or have changes occurred in the influence of these factors over the past 5, 10, or 30 years?

The ultimate goal of this area of research is to empower educators to increase their students' understanding of evolution. We also suggest that increasing acceptance of evolution should be a goal of instruction, insofar as possible, as long as it is not required of students. This will likely necessitate some diversification of strategies, as different groups will respond differently to different strategies; although it is appropriate to seek out educational strategies that are the most beneficial and minimize harmful complications, we acknowledge that there is no one-size-fits-all approach to evolution education. To this end, we hope to see an increase in the number of studies that use longitudinal data

sets and, where possible, comparison groups and other controls to isolate the effect of different interventions. If science educators succeed in increasing evolution acceptance, the benefits will accrue for not only students but also society as a whole, through better overall attitudes toward societal challenges that are tightly linked to evolution, such as antibiotic resistance, vaccine development, food security, and climate change.

We hope that this brief review will serve as a useful and clarifying primer on the state of evolution education research that highlights both the successes in the field and how much work still needs to be done. Much remains to be discovered, and the findings discussed here are certainly far from infallible. As in any field of study, novel research findings are important and useful, and they serve to drive the field forward. But we caution against sensationalist titles and conclusions that there is 'no missing link'[14] between evolution knowledge and acceptance (a majority of evolution education researchers would never have argued there was), or that 'teachers should teach the science and not focus on belief systems'[15] (an attitude which has been the driving force behind decades of curriculum changes that have failed to substantially move the bar on public acceptance of evolution[34]). Instead, we suggest that new research be understood through the lens of what we already know: acceptance of evolution is related to understanding of not only evolution, but also the nature of science and religious attitudes and identity. Strategies to increase evolution acceptance must necessarily include a consideration of all of these factors. To do less is to reject the preponderance of evidence arising from the science of teaching and learning— and to risk the scientific literacy of the rising generation. ❑

Ryan D. P. Dunk[1]*, M. Elizabeth Barnes[2], Michael J. Reiss[3], Brian Alters[4], Anila Asghar[5], B. Elijah Carter[6], Sehoya Cotner[7], Amanda L. Glaze[8], Patricia H. Hawley[9], Jamie L. Jensen[10], Louise S. Mead[11], Louis S. Nadelson[12], Craig E. Nelson[13], Briana Pobiner[14], Eugenie C. Scott[15], Andrew Shtulman[16], Gale M. Sinatra[17], Sherry A. Southerland[18], Emily M. Walter[19], Sara E. Brownell[2] and Jason R. Wiles[1,20]*

[1]Department of Biology, Syracuse University, Syracuse, NY, USA. [2]School of Life Sciences, Arizona State University, Tempe, AZ, USA. [3]UCL Institute of Education, University College London, London, UK. [4]Attallah College of Educational Studies & Schmid College of Science and Technology, Chapman University, Orange, CA, USA. [5]Department of Integrated Studies in Education, McGill University, Montréal, Québec,
Canada. [6]Department of Biology, Duke University, Durham, NC, USA. [7]Department of Biology Teaching and Learning, University of Minnesota, St. Paul, MN, USA. [8]Department of Middle Grades and Secondary Education, Georgia Southern University, Statesboro, GA, USA. [9]College of Education, Texas Tech University, Lubbock, TX, USA. [10]Department of Biology, Brigham Young University, Provo, UT, USA. [11]Department of Integrative Biology, Michigan State University & BEACON Center for the Study of Evolution in Action, East Lansing, MI, USA. [12]Department of Leadership Studies, University of Central Arkansas, Conway, AR, USA. [13]Department of Biology, Indiana University, Bloomington, IN, USA. [14]Department of Anthropology, Smithsonian National Museum of Natural History, Washington, D.C., USA. [15]National Center for Science Education, Oakland, CA, USA. [16]Department of Psychology & Department of Cognitive Science, Occidental College, Los Angeles, CA, USA. [17]Rossier School of Education, University of Southern California, Los Angeles, CA, USA. [18]College of Education, Florida State University, Tallahassee, FL, USA. [19]Department of Biology, California State University, Fresno, Fresno, CA, USA. [20]Department of Science Education, Harvard-Smithsonian Center for Astrophysics, Harvard University, Cambridge, Massachusetts, USA.
*e-mail: rddunk@syr.edu; jwiles01@syr.edu

References

1. Sinatra, G. M., Southerland, S. A., McConaughy, F. & Demastes, J. W. *J. Res. Sci. Teach.* **40**, 510–528 (2003).
2. Rosengren, K. S., Brem, S. K., Evans, E. M., & Sinatra, G. M. (eds) *Evolution Challenges: Integrating Research and Practice in Teaching and Learning About Evolution.* (Oxford University Press, Oxford, 2012).
3. Miller, J. D., Scott, E. C. & Okamoto, S. *Science* **313**, 765–766 (2006).
4. Wiles, J. R. & Alters, B. *Int. J. Sci. Educ.* **33**, 2559–2585 (2011).
5. Pobiner, B. *Am. J. Phys. Anthropol.* **159**, 232–274 (2016).
6. Dunk, R. D. P., Petto, A. J., Wiles, J. R. & Campbell, B. C. *Evol. Educ. Outreach* **10**, 4 (2017).
7. Glaze, A. L., Goldston, M. J. & Dantzler, J. *Int. J. Sci. Math. Educ.* **13**, 1189–1209 (2015).
8. Rissler, L. J., Duncan, S. I. & Caruso, N. M. *Evol. Educ. Outreach* **7**, 24 (2014).
9. Barnes, M. E., Evans, E. M., Hazel, A., Brownell, S. E. & Nesse, R. M. *Evol. Educ. Outreach* **10**, 7 (2017).
10. Rutledge, M. L. & Warden, M. A. *Am. Biol. Teach.* **62**, 23–31 (2000).
11. Trani, R. *Am. Biol. Teach.* **66**, 419–427 (2004).
12. Lawson, A. E. & Worsnop, W. A. *J. Res. Sci. Teach.* **29**, 143–166 (1992).
13. Ingram, E. L. & Nelson, C. E. *J. Res. Sci. Teach.* **43**, 7–24 (2006).
14. Weisberg, D. S., Landrum, A. R., Metz, S. E. & Weisberg, M. *Bioscience* **68**, 212–222 (2018).
15. Mead, R., Hejmadi, M. & Hurst, L. D. *Nat. Ecol. Evol.* **2**, 388–394 (2018).
16. Rios, K., Cheng, Z. H., Totton, R. R. & Shariff, A. F. *Soc. Psychol. Personal. Sci.* **6**, 959–967 (2015).
17. Barnes, M. E. & Brownell, S. E. *CBE Life Sci. Educ.* **16**, 1–10 (2017).
18. Barnes, M. E., Elser, J. & Brownell, S. E. *Am. Biol. Teach.* **79**, 104–111 (2017).
19. Hawley, P.H. & Sinatra, G.M. *J. Res. Sci. Teach.* (in the press) (2019).
20. Pobiner, B., Beardsley, P. M., Bertka, C. M. & Watson, W. A. *Evol. Educ. Outreach* **11**, 3 (2018).
21. Walker, J. D., Wassenberg, D., Franta, G. & Cotner, S. *J. Coll. Sci. Teach.* **47**, 46–56 (2017).
22. Carter, B. E. & Wiles, J. R. *Evol. Educ. Outreach* **7**, 6 (2014).

23. Lombrozo, T., Thanukos, A. & Weisberg, M. *Evol. Educ. Outreach* **1**, 290–298 (2008).
24. Alters, B.J. & Alters, S.M. *Defending Evolution in the Classroom: A Guide To The Creation/Evolution Controversy.* (Jones and Bartlett Publishers, Sudbury, MA, USA, 2001).
25. Pennock, R.T. On teaching evolution and the nature of science. in *Evolutionary Science and Society: Educating a New Generation (Proceedings of the BSCS, AIBS Symposium, November 2004, NABT Convention, Chicago, IL)* (eds. Cracraft, J. & Bybee, R. W.) 7–12 (BSCS, Colorado Springs, CO, USA, 2005).
26. McIver, J.P. & Carmines, E.G. *Unidimensional Scaling.* (SAGE Publications, Inc., Newbury Park, CA, USA, 1981).
27. Nunnally, J.C. & Bernstein, I.H. *Psychometric Theory.* (McGraw-Hill, New York, 1994).
28. Rutledge, M. L. & Sadler, K. C. *Am. Biol. Teach.* **69**, 332–335 (2007).
29. Nadelson, L. S. & Southerland, S. *Int. J. Sci. Educ.* **34**, 1637–1666 (2012).
30. Smith, M. U., Snyder, S. W. & Devereaux, R. S. *J. Res. Sci. Teach.* **53**, 1289–1315 (2016).
31. Metzger, K. J., Montplaisir, D., Haines, D. & Nickodem, K. *Evol. Educ. Outreach* **11**, 10 (2018).
32. Walls, L. J. *Res. Sci. Teach.* **53**, 1546–1570 (2016).
33. Mead, L. S., Clarke, J. B., Forcino, F. & Graves, J. L. *Evol. Educ. Outreach* **8**, 6 (2015).
34. Gallup. *Evolution, creationism, intelligent design* (Gallup, 2017); http://www.gallup.com/poll/21814/evolution-creationism-intelligent-design.aspx

Competing interests