INTRODUCTION

The biological sciences include topics that are viewed as controversial and even antithetical to the beliefs of some members of the public. Thus, research into new teaching methods, strategies, and tools for controversial topics could strengthen the educational experience as well as offer an assessment of teaching outcomes with respect to both material mastery and general attitudes toward science. When presenting science to general audiences, the primary goals often are to develop a fundamental appreciation of science and the scientific process in addition to specific content knowledge (32, 34, 35). This appreciation of science can be developed through engaging students of all ages—from elementary to elderly—in explicit and reflective discussion and hands-on experiences, i.e., research (1, 33).

Among the topics perceived as controversial in the biological sciences, perhaps the most commonly discussed is evolution (4, 31, 55). In recent decades, the educational setbacks and gains from teaching evolution in the United States provide a needed frame of reference and offer insights into instructional methods (22) for other “hot” topics such as climate change, genetically modified organisms (GMOs), and cloning, among others. Teaching climate change content in a biology classroom is complicated by many factors, some of which are present also when teaching evolution. Biology instructors and researchers regularly encounter the interconnected nature of the environment and organisms; contemporary discussions of climate change therefore should be enriched by fundamental concepts such as evolution and extinction.

Citizen science, the practice of nonscientists collecting information for investigations in an organized manner that yields data to test hypotheses, represents a key method to link science education and environmental education (5, 6, 7, 12, 15, 48, 54). Additionally, it may create a foundation for enhancing the engagement of citizens of all ages with the sciences by allowing them to participate actively rather than passively in science. The expansion of inquiry-based
education to encourage curiosity also has led to the rise of publishable research based on well-crafted testable hypotheses, with students participating in the faculty member’s research project (25). Citizen-science projects in evolution have shown success in allowing ordinary citizens to help test important hypotheses, a notable example being the large-scale Evolution MegaLab project, which spanned 15 countries and involved over 6,000 participants (56). Other notable citizen-science examples include eBird and Zooniverse (6, 18, 50, 59). Additional projects cover a variety of areas, from ecology to comparative genomics (27, 46, 48). Recently, developments in smartphone use platforms (36) and social networking patterns (16) have multiplied the ways popular technologies can be integrated into citizen-science research. Mobile devices and social media may be useful tools for encouraging participation. However, regardless of these advances and expanding projects, the results of such research are not often accepted as traditionally publishable data in the peer review process, but instead as education or outreach only (7). New interest from scientific and educational research perspectives must be utilized to validate the data generated and develop an appreciation for the scientific process.

**DISCUSSION**

American instructors in the earth and space sciences who cover “controversial” topics in science must be aware of the potential for controversy and respond respectfully to engage students, parents, the community, and their peers (26). Although environmental concerns receive significant public and media attention, the public has a poor understanding of the science in general, especially as these topics often require drawing upon information from multiple disciplines (52). Several key parallels exist between evolution and climate change, scientifically and in terms of public perception. Beyond discussing extinction or evolution, the topics share many similarities in how they are presented to students. Citing the teaching of evolution, Hermann (23) calls upon several key concepts (noted in italics), which we can extrapolate for these purposes to the teaching and learning of climate change:

1. **The issue represents a socioscientific controversy, not a scientific controversy.** That 97% of climate scientists are convinced about the human-caused warming trends while more than one-third of Americans reject the evidence of average global temperature increases (39, 40) is an ideological issue in a country that values ideology strongly. Herein, we acknowledge the nature of the debate being limited to “controversial” in the public eye, which classifies it as a socioscientific debate, not a scientific one (57). The major distinction between climate change and evolution is the nature of the sides—evolution is disagreeable with certain religious groups and climate change finds opposition primarily in the political arena.

2. **Conceptual frameworks for both span multiple scientific [and non-scientific] disciplines.** The teaching of evolution relies on the conceptual understanding of several sub-disciplines. On a larger scale, climate change and its implications require an even greater diversity of knowledge of many fields to understand the vast effects, even outside of the traditional science disciplines, with far-reaching implications into our everyday lives (42).

3. **There is debate, disagreement, and uncertainty between opposing sides.** Primarily, we encounter the “sides” of this debate in the media and political arenas. In both situations, the press plays a key role in influencing public opinion to perpetuate these debates. Although outside of our primary focus, legislature and politics often complicate the interactions of civics and education. For example, several states (Louisiana, South Dakota, and Tennessee) have legislature-mandated laws concerning the teaching of climate change, including aspects such as teaching it as a controversy (26). Creating a circular argument, governmental policy is driven ideally by constituent opinion and may be a direct reflection of citizen opinions.

4. **A clear path or decision does not exist for a “reasonable member of society,” with “reasonable” being defined in an ethical sense by Kupperman (29).** Controversial topics in the biological sciences generate many perspectives and receive commentary from a variety of perceived authoritative sources. It is difficult for a lay audience to create informed, educated viewpoints, especially when an overabundance of information is available or the perceptions challenge personal beliefs or value systems (45). Beyond the quantity of information, creating an organizational structure for analyzing information can be difficult for the lay audience.

In the literature, a number of instructional methods exist for engaging students in both general and controversial science topics. With evolution, the instructor’s approach can fit into one of four general categories: advocacy, affirmative neutrality, procedural neutrality, and avoidance (23). These include, respectively, arguing for a side, presenting several positions, allowing students to present sides from resources, and omitting the conversation (23). Regardless of the instructor’s choices relative to the topic, the educational approaches for evolution span a representative distribution of methods, including a selection from the nature of science (11, 24, 34, 35, 37, 42, 55), geological time (11, 30), as well as questioning, case studies, and law (20, 38). Relatively understated in the literature are studies evaluating the efficacy of newer active learning methods such as citizen science with respect to controversial topics. Among those
present, selected examples generally include teaching tools for inquiry or active learning, for students (8, 9, 17), or teacher training (14).

In the classroom, for example, science educators often have found success in teaching controversial topics (e.g., evolution) to traditionally non-receptive audiences by developing an understanding of the nature of science (47) and the value of the scientific process. As science teaching continues to move toward many established and/or validated active learning methods in the classroom (21), we must engage students in new ways on key issues, especially those of socioscientific controversy (2). Issues-based teaching favors a science curriculum that politicizes students and promotes empowerment through civic participation, decision-making, and action (43, 44, 57). One method of engaging people in controversial topics is to use various forms of communication, such as conversations, argumentation (19, 28), cognitive conflict (45), and citizen/expert panel simulations (3, 10).

To expand on interactive student experiences, citizen science projects have the ability to engage students and the larger community alike. Social and ethical issues offer students opportunities “to attach personal meaning to science concepts, theories and processes, and enable investigations that are closer to students’ daily existence” (58). This may enable educators to bring focus to important ideas by engaging students through emotional and intellectual stimulation, transforming otherwise distant topics into those central to their everyday lives (58). Although both evolution and climate change include some current citizen science projects, a continued expansion may be an educational opportunity for students of all ages, from the classroom to the community. These projects can expand on the use of inquiry in the classroom to create large-scale research projects. Additionally, students may gain a greater appreciation of science by being involved in areas of non-simulated research, as opposed to the traditional “cookbook” labs.

When considering the use of a citizen-science approach for climate awareness and education, a primary advantage is the past success demonstrated in citizen science. Several ongoing citizen science projects mentioned, including, for example, those of The Cornell Lab (13), have been shown to generate large amounts of scientifically valuable data while educating participants in the process of science and the specific areas of investigation (6). In North America alone, there may be more than 200 research projects (12), and several projects (notably eBird and Zooniverse) have led to scores of publications in many fields (7). Additionally, climate change project examples span a range from active participation in parks (41) to volunteering computer processing time (53). Although some of these projects have turned into published scholarly works, the field of citizen science as a whole is underdeveloped and seen as an educational opportunity (6). Additional opportunities exist to evaluate the educational aspects of these projects, as these remain understudied compared with other teaching techniques (51) such as those used in active learning or inquiry-based approaches.

Interestingly, studies focusing on the research and educational benefits of citizen-science projects for studying local and global impacts of climate change appear to be relatively underdeveloped in the literature. This represents an opportunity, especially for science education researchers. Beyond the possibilities of data generation and publications for the coordinating researchers and organizations, a key aspect of the citizen-science project is the education of nonscientists in how science works, as well as specific, project-related content (6, 51). Especially in those more controversial topics, public perception relies strongly on the overall perception of science. With citizen science, we can effect change through engagement to develop an appreciation for science in everyday life.

Using the principles of citizen science, students of all ages can be involved in research. Although ecology, evolution, and climate change are vastly interconnected, such studies have yet to show a strong presence in the science education literature. Searches of popular academic literature sites, for example Web of Science and ERIC Social Sciences database, with Boolean key words “citizen science AND education AND climate change” reveal approximately 50 or fewer total results, most of which relate to developing a productive or knowledgeable citizenry, instead of a citizen-science research project. The limited results show a large unexplored niche in educational research for the integration of citizen science in the curriculum and subsequent studies for efficacy or validation. In the case of climate change, this integration would be possible across many disciplines, especially with established topics of socioscientific controversy.

**CONCLUSION**

Many of the controversial topics in the biological sciences represent some of the most challenging concepts for communication and education in the sciences. The utilization of a variety of teaching tools to cover these subjects effectively and the continued investigation of new teaching methodologies for the education of students of all ages will be necessary to improve the appreciation for and understanding of subjects to which there is popular opposition. With citizen science in particular, there also exists an additional beneficial outcome: the ability to generate large-scale, publishable data for studies that may exceed traditional limitations. As both scientists and educational researchers, we can expand the opportunities for engaging nonscientists in research in the hope of strengthening the appreciation for and understanding of science in the general population, the “students” of any age. In turn, this positive experience may create excitement for scientific topics and empathy for the preservation of our only habitat.

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REFERENCES

1. Abell, S., M. Martini, and M. George. 2001. “That’s what scientists have to do”: preservice elementary teachers’ conceptions of the nature of science during a moon investigation. Int. J. Sci. Ed. 23:1095–1109.

2. Aikenhead, G. S. 1994. What is STS science teaching? p 47–59 In Solomon, J., and G. Aikenhead, (ed.), STS education: international perspectives in reform. Teachers College Press, New York, NY.

3. Albe, V., and M.-J. Gombert. 2012. Students’ communication, argumentation and knowledge in a citizens’ conference on global warming. Cult. Stud. Sci. Educ. 7:659–681.

4. Alters, B. J., and C. E. Nelson. 2002. Perspective: teaching evolution in higher education. Evolution 56:1891–1901.

5. Backstrand, K. 2003. Civic science for sustainability: reframing the role of experts, policy-makers and citizens in environmental governance. Global Environ. Polit. 3:24–41.

6. Bonney, R., et al. 2009. Citizen science: a developing tool for expanding science knowledge and scientific literacy. BioScience 59:977–984.

7. Bonney, R., et al. 2014. Next steps for citizen science. Science 343:1436–1437.

8. Brewer, M. S., and G. E. Gardner. 2013. Teaching evolution through the Hardy-Weinberg principle: a real-time, active-learning exercise using classroom response devices. Am. Biol. Teach. 75:476–479.

9. Bromham, L., and P. Oprandi. 2006. Evolution online: using a virtual learning environment to develop active learning in undergraduates. J. Biol. Evol. 41:21–25.

10. Byrne, J., M. Iedland, C. Malmberg, and M. Grace. 2014. Climate change and everyday life: repertoires children use to negotiate a socio-scientific issue. Int. J. Sci. Educ. 36:1491–1509.

11. Cherif, A., G. Adams, and J. Loehr. 2001. What on “Earth” is evolution? Am. Biol. Teach. 63:569–591.

12. Cohn, J. P. 2008. Citizen science: can volunteers do real research? BioScience 58:192–197.

13. Cornell Lab of Ornithology. 2015. Citizen science blog. [Online.] http://www.birds.cornell.edu/citsci/

14. Crawford, B. A., C. Zembal-Saul, D. Munford, and P. Friedrichsen. 2005. Confronting prospective teachers’ ideas of evolution and scientific inquiry using technology and inquiry-based tasks. J. Res. Sci. Teach. 42:613–637.

15. Dickinson, J. L., et al. 2012. The current state of citizen science as a tool for ecological research and public engagement. Front. Ecol. Environ. 10:291–297.

16. Dickinson, J. L., R. L. Crain, H. Kern Reeve, and J. P. Schuldt. 2013. Can evolutionary design of social networks make it easier to be ‘green’? Trends Ecol. Evol. 28:561–569.

17. Dremock, F. (ed.). 2002. Evolutionary biology instruction: what students gain from learning through inquiry. Princ. Pract. Math. Sci. Educ. 5:2–13.

18. eBird. 2015. Audubon and Cornell Lab of Ornithology. [Online.] ebird.org.

19. Erduran, S., and M. P. Jiménez-Aleixandre. 2007. Argumentation in science education: perspectives from classroom-based research. 1st ed. Springer, Netherlands. [Online.] http://www.springer.com/us/book/9781402066696.

20. Ferber, P. 2003. Teaching evolution & the nature of science. Am. Biol. Teach. 65:347–354.

21. Freeman, S., et al. 2014. Active learning increases student performance in science, engineering, and mathematics. Proc. Natl. Acad. Sci. U. S. A. 111:8410–8415.

22. Griffith, J. A., and S. K. Brem. 2004. Teaching evolutionary biology: pressures, stress, and coping. J. Res. Sci. Teaching. 41(8):791–809.

23. Herrmann, R. S. 2008. Evolution as a controversial issue: a review of instructional approaches. Sci. Educ. 17:1011–1032.

24. Hildebrand, D., K. Bilica, and J. Capps. 2008. Addressing controversies in science a pragmatic approach to evolution education. Sci. Educ. 17:1033–1052.

25. Jarvis, M. 2013. Science prize goes to undergraduate course that incorporates faculty research. AAAS, American Association for the Advancement of Science. [Online.] www.aas.org/news/science-prize-goes-undergrad-course-incorporates-faculty-research.

26. Johnson, R. 2013. Tackling climate change in the science classroom. Educ. Horiz. 91:12–15.

27. Kawrykow, A., et al. 2012. Phylo: a citizen science approach for improving multiple sequence alignment. PLoS One 7:e31362.

28. Kuhn, D. 2010. Teaching and learning science as argument. Sci. Ed. 94:810–824.

29. Kupperman, J. J. 1985. Why some topics are controversial. Educ. Leadership 42:73–76.

30. Kurpius, J., R. Guralnick, J. Johnson, A. Monk, J. Scotchmoor, and M. Stefanski. 2015. Understanding geologic time. [Online.] http://www.ucmp.berkeley.edu/education/explorations/tours/geotime/index.html.

31. Labov, J. B. (ed.), and Olson, S. (rapporteur). 2012. Thinking evolutionarily—evolution education across the life sciences, 1st ed. The National Academies Press, Washington, DC. [Online.] http://www.nap.edu/catalog/13403/thinking-evolutionarily-evolution-education-across-the-life-sciences-summary-of.

32. Lederman, N. G., P. D. Wade, and R. L. Bell. 1998. Assessing the nature of science: what is the nature of our assessments? Sci. Educ. 7:595–615.

33. Lederman, N. G., and J. S. Lederman. 2004. Revising instruction to teach nature of science. Sci. Teach. 71:36–39.

34. Lederman, N. G. 2006. Nature of science: past, present, and future, p 831–879. In Abell, S. K., and N. G. Lederman (ed.). Handbook of research on science education. Lawrence Erlbaum Associates, Mahwah, NJ.

35. Lederman, N. G., and J. S. Lederman. 2014. Research on teaching and learning of nature of science, p 600–620. In Lederman, N. G., and S. K. Abell, (ed.). Handbook of research on science education, Vol. II. Routledge, New York, NY.
36. Liu, C. H., J. Fan, P. Hui, J. Crowcroft, and G. Ding. 2013. QOI-aware energy-efficient participatory crowdsourcing. IEEE Sensors J. 13:3742–3753.
37. McLellan, C. V. 2006. The nature of science and the scientific method. The Geological Society of America. [Online.] www.geosociety.org/education/NatureScience.pdf.
38. Morishita, F. 1991. Teaching about controversial issues: resolving conflict between creationism and evolution through law-related education. Am. Biol. Teach. 53:91–93.
39. Motel, S. 2014. Polls show most Americans believe in climate change, but give it low priority. Pew Research Center. [Online.] http://www.pewresearch.org/fact-tank/2014/09/23/most-americans-believe-in-climate-change-but-give-it-low-priority/.
40. National Aeronautics and Space Administration. 2015. Climate change—how do we know? Scientific Consensus. Global Climate Change. Vital Signs of the Planet. [Online.] http://climate.nasa.gov/evidence/.
41. National Park Service. 2015. Climate change. Citizen Science. [Online.] www.nps.gov/subjects/climatechange/citizenscience.htm.
42. National Research Council. 2011. Forrest, S., and M. A. Feder, rapporteurs. Climate change education: goals, audiences, and strategies. A workshop summary. Board on Science Education, Division of Behavioral and Social Sciences and Education. The National Academies Press, Washington, DC. [Online.] www.nap.edu/catalog/13224/climate-change-education-goals-audiences-and-strategies-a-workshop-summary.
43. Pedretti, E. 1999. Decision-making and STS education: exploring scientific knowledge and social responsibility in schools and science centers through an issues-based approach. School Sci. Math. 99:174–181.
44. Pedretti, E. G., L. Benice, J. Hewitt, L. Romkey, and A. Jivraj. 2008. Promoting issues-based STSE perspectives in science teacher education: problems of identity and ideology. Sci. Educ. 17:941–960.
45. Posner, G. J., K. A. Strike, P.W. Hewson, and W. A. Gertzog. 1982. Accommodation of a scientific conception: toward a theory of conceptual change. Sci. Educ. 66:211–227.
46. Satterfield, D. A., J. C. Maerz, and S. Altizer. 2015. Loss of migratory behaviour increases infection risk for a butterfly host. Proc. R. Soc. B. 282:2014734.
47. Scharmann, L. C., M. U. Smith, M. C. James, and M. Jensen. 2005. Explicit reflective nature of science instruction: evolution, intelligent design, and umbrellaology. J. Sci. Teach. Educ. 16:27–41.
48. Silvertown, J. 2009. A new dawn for citizen science. Trends Ecol. Evol. 24:467–471.
49. Silvertown, J., et al. 2011. Citizen science reveals unexpected continental-scale evolutionary change in a model organism. PloS One 6:e18927.
50. Sullivan, B. L., et al. 2014. The eBird enterprise: an integrated approach to development and application of citizen science. Biol. Cons. 169:31–40.
51. Trumbull, D. J., R. Bonney, D. Bascom, and A. Cabral. 2000. Thinking scientifically during participation in a citizen-science project. Sci. Educ. 84:265–275.
52. Tsurusaki, B. K., and C. W. Anderson. 2010. Students’ understanding of connections between human engineered and natural environmental systems. Int. J. Environ. Sci. Educ. 5:407–433.
53. Union of Concerned Scientists. 2015. You + your computer = carbon detective. [Online.] www.ucsusa.org/global_warming/what_you_can_do/climate-change-citizen-science.html#VZoHrmC1JFK.
54. Wals, A. E. J., M. Brody, J. Dillon, and R. B. Stevenson. 2014. Convergence between science and environmental education. Science 344:583–584.
55. Working Group on Teaching Evolution, Board on Science Education, Division of Behavioral and Social Sciences and Education, National Academy of Sciences. 2008. Teaching about evolution and the Nature of Sciences. The National Academies Press, Washington, DC. [Online.] www.nap.edu/openbook.php?record_id=5787.
56. Worthington, J., P., et al. 2012. Evolution MegaLab: a case study in citizen science methods. Methods Ecol. Evol. 3:303–309.
57. Zeidler, D., T. Sadler, M. Simmons, and E. Howes. 2005. Beyond STS: a research-based framework for socioscientific issues education. Sci. Educ. 89:357–377.
58. Zeidler, D. L., and T. D. Sadler. 2008. Social and ethical issues in science education: a prelude to action. Sci. Educ. 17:799–803.
59. Zooniverse. People-powered research. zooniverse.org.